# *Phytophthora* species infesting soil in a California forest affected by sudden oak death

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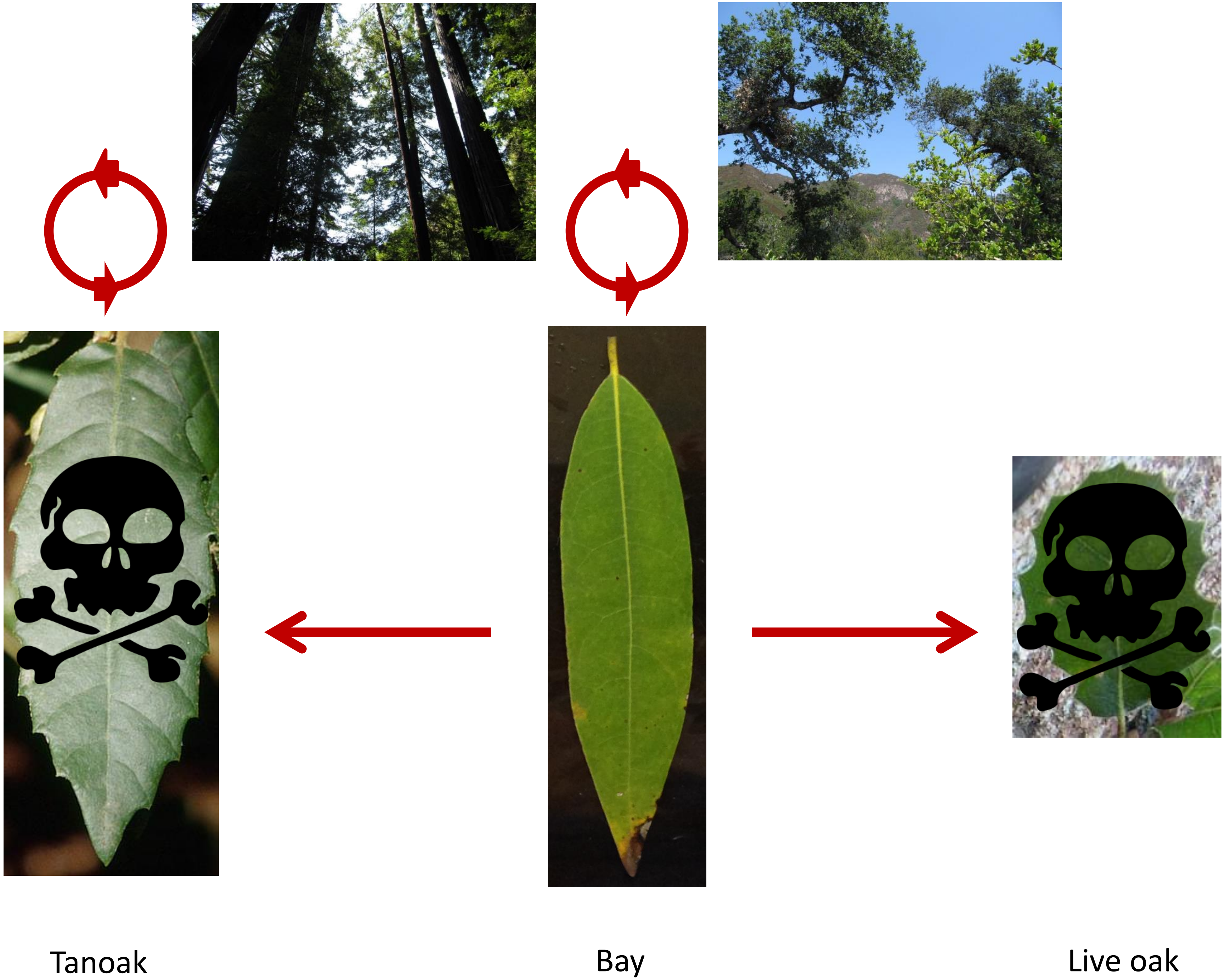
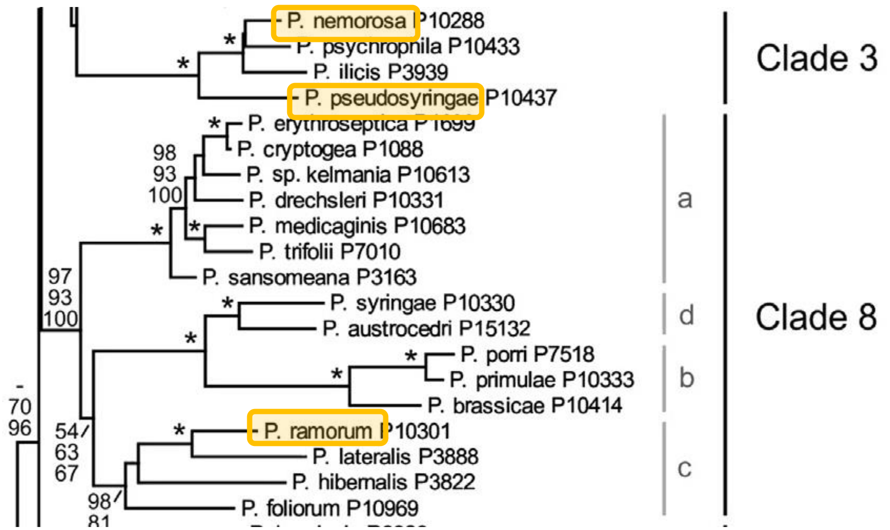
# Sudden oak death (SOD)

- Caused by exotic oomycete *Phytophthora ramorum*
  - introduced to California via ornamental nursery trade
- Massive mortality of tanoak (*Notholithocarpus densiflorus*) and oaks (esp. *Quercus agrifolia*)
- California bay laurel (*Umbellularia californica*) supports high inoculum levels but is not negatively affected


Tanoak
Bay
Live oak

# Other species of *Phytophthora*

- Two other species co-occur with *P. ramorum*
- *P. pseudosyringae* and *P. nemorosa* cause identical symptoms on SOD hosts, but rarely tree mortality
- Unclear whether they are native to California



# Big Sur SOD Plot network


- Plot network was established about a decade ago to study long-term effects of SOD
- 40 plots in redwood forest, 50 plots in mixed evergreen forests
- In 2008, two forest fires burned many of the plots

# Effects of fire on *Phytophthora*

- Post-fire sampling revealed that *P. ramorum* persisted where infected bay trees survived
- *P. pseudosyringae* and *P. nemorosa* dominated post-fire resprouts, even in plots where they had never previously been detected
- Why did the fire have different effects on different species of *Phytophthora*?

# Oospores in the soil?

- Oospores are the most  resistant structures formed by *Phytophthora*
- *P. ramorum* is heterothallic, with only one mating present in CA forests
  - This means it can’t complete its sexual cycle and form oospores
- *P. pseudosyringae & P. nemorosa* are homothallic, forming oospores readily without mating

# Hypothesis & objectives

- If *P. pseudosyringae* & *P. nemorosa* survived the fire as oospores in the soil, they should be detectable in the soil of unburned plots
- Objective: Use Rhodo-dendron leaves to "bait" *Phytophthora* out of soil
- Plots were to be visited during summer field seasons of 2013 & 2014
  - This meant sampling during an ongoing drought
- Plant tissue was also sampled from within plots

- The 40 plots containing coast redwood were sampled in 2013
- The 50 "mixed evergreen" plots were sampled in 2014

# 2013 results

| *Phytophthora* species | Successful isolations 2013 (Redwood) | |
|---|---|---|
| | Plant Tissue | Soil Baiting n=360 |
| *P. ramorum* | 492 | 7 |
| *P. pseudosyringae* | 2 | 6 |
| *P. nemorosa* | 13 | 1 |
| *P.* "sequoiasoil" | | 10 |
| *P. syringae* | | 1 |
| *P. chlamydospora* | | 1 |

- Due to the ongoing SOD epidemic, isolation of *P. ramorum* from foliage was extremely common
- *P. pseudosyringae* was more common in soil than in plant tissue
- Three plots yielded multiple species (up to 4)
- A previously undescribed species related to *P. cactorum* was most commonly baited
  - This species was given the placeholder taxon “sequoiasoil”

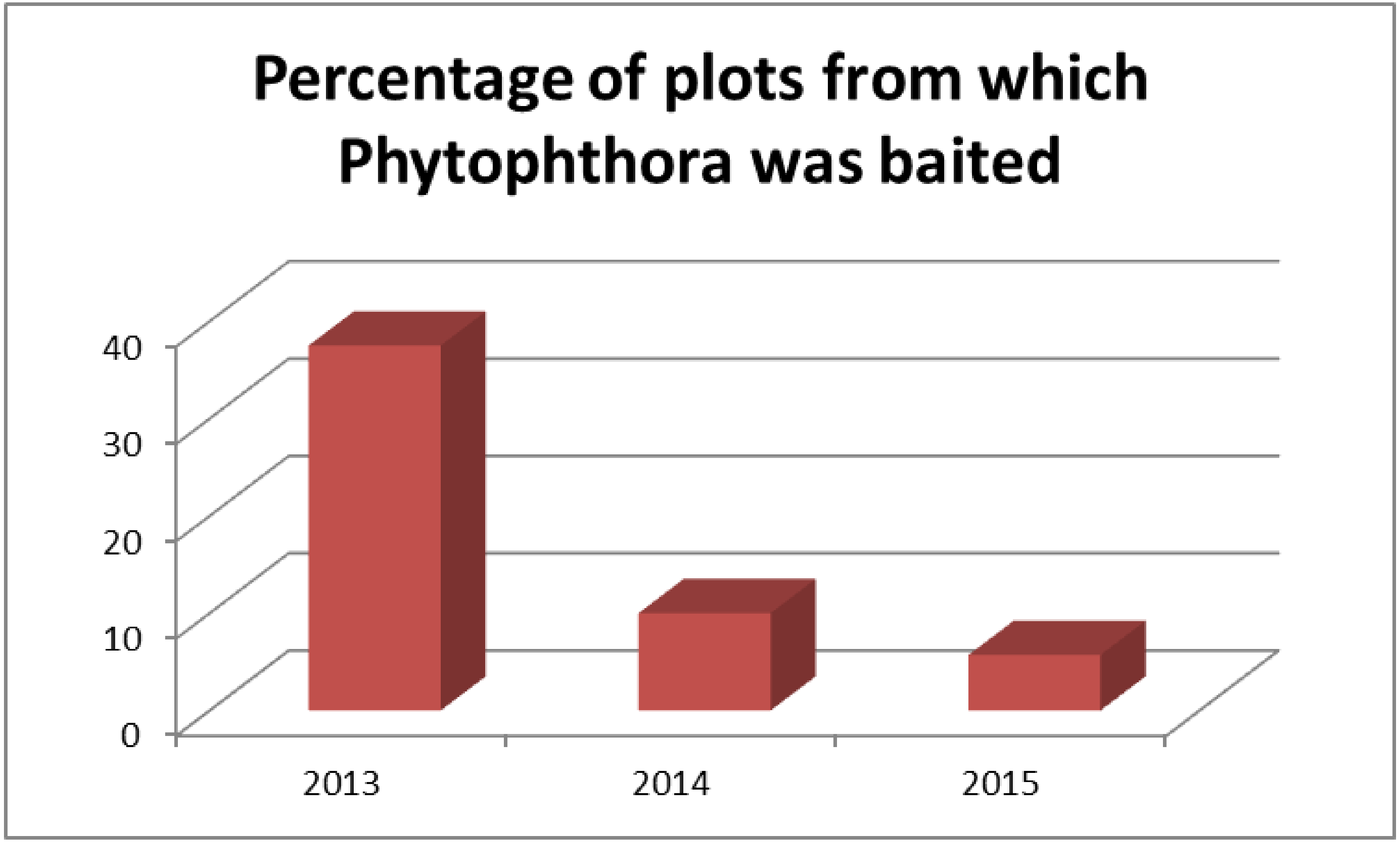
# 2014 results

| *Phytophthora* species | Successful isolations | | | |
|---|---|---|---|---|
| | 2013 (Redwood) | | 2014 (Mixed evergreen) | |
| | Plant Tissue | Soil Baiting n=360 | Plant Tissue | Soil Baiting n=300 |
| *P. ramorum* | 492 | 7 | 198 | |
| *P. pseudosyringae* | 2 | 6 | 3 | 4 |
| *P. nemorosa* | 13 | 1 | 1 | |
| *P.* "sequoiasoil" | | 10 | | |
| *P. syringae* | | 1 | 1 | 2 |
| *P. chlamydospora* | | 1 | | |

- The drought increased to maximum severity in 2014
- *P. ramorum* was not recovered from soil
- Viable propagules of *P. pseudosyringae* were present in Big Sur forest soil during an extreme drought
  - These are likely the same propagules that allowed it to survive the 2008 fire
- Difficult to separate the effect of drought from the effect of forest type

| *Phytophthora* species | Successful isolations | | | | | |
|---|---|---|---|---|---|---|
| | 2013 (Redwood) | | 2014 (Mixed evergreen) | | 2015 | Total |
| | Plant Tissue | Soil Baiting n=360 | Plant Tissue | Soil Baiting n=300 | Soil Baiting n=210 | |
| *P. ramorum* | 492 | 7 | 198 | | 2 | 699 |
| *P. pseudosyringae* | 2 | 6 | 3 | 4 | | 15 |
| *P. nemorosa* | 13 | 1 | 1 | | | 15 |
| *P. "sequoiasoil"* | | 10 | | | | 10 |
| *P. syringae* | | 1 | 1 | 2 | | 4 |
| *P. chlamydospora* | | 1 | | | | 1 |

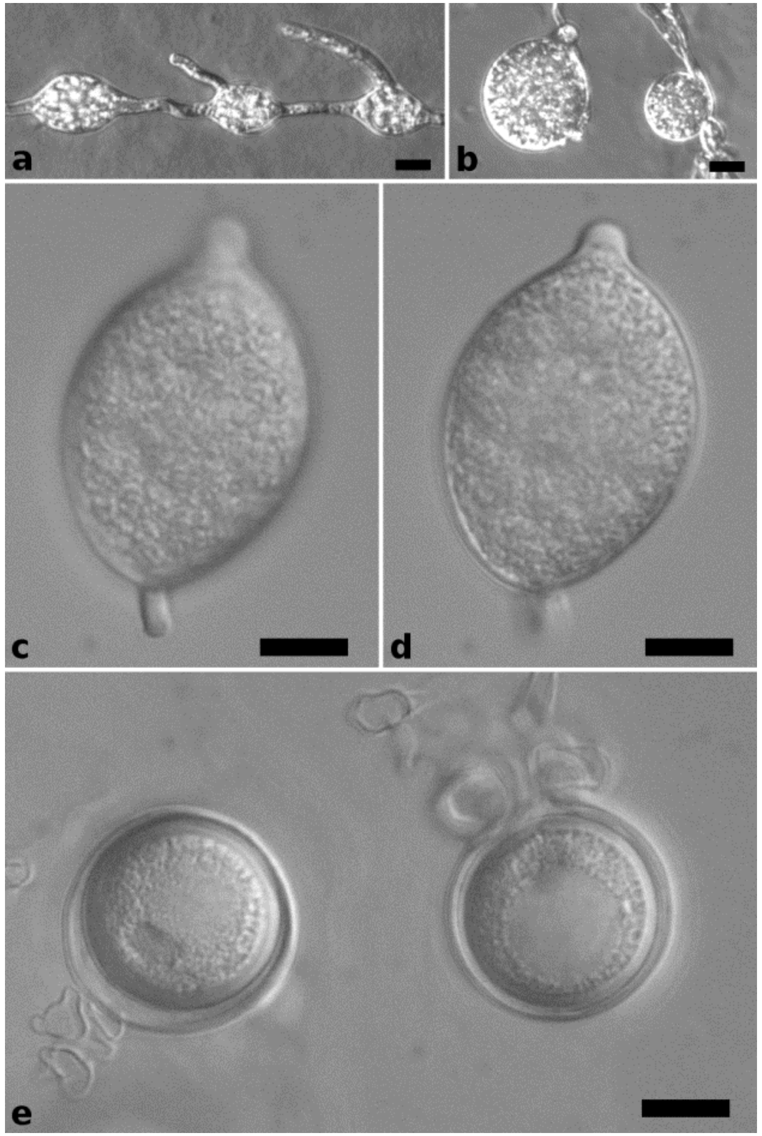
- The drought continued into 2015
- Soil was baited from all 20 previously positive plots plus 15 previously negative plots

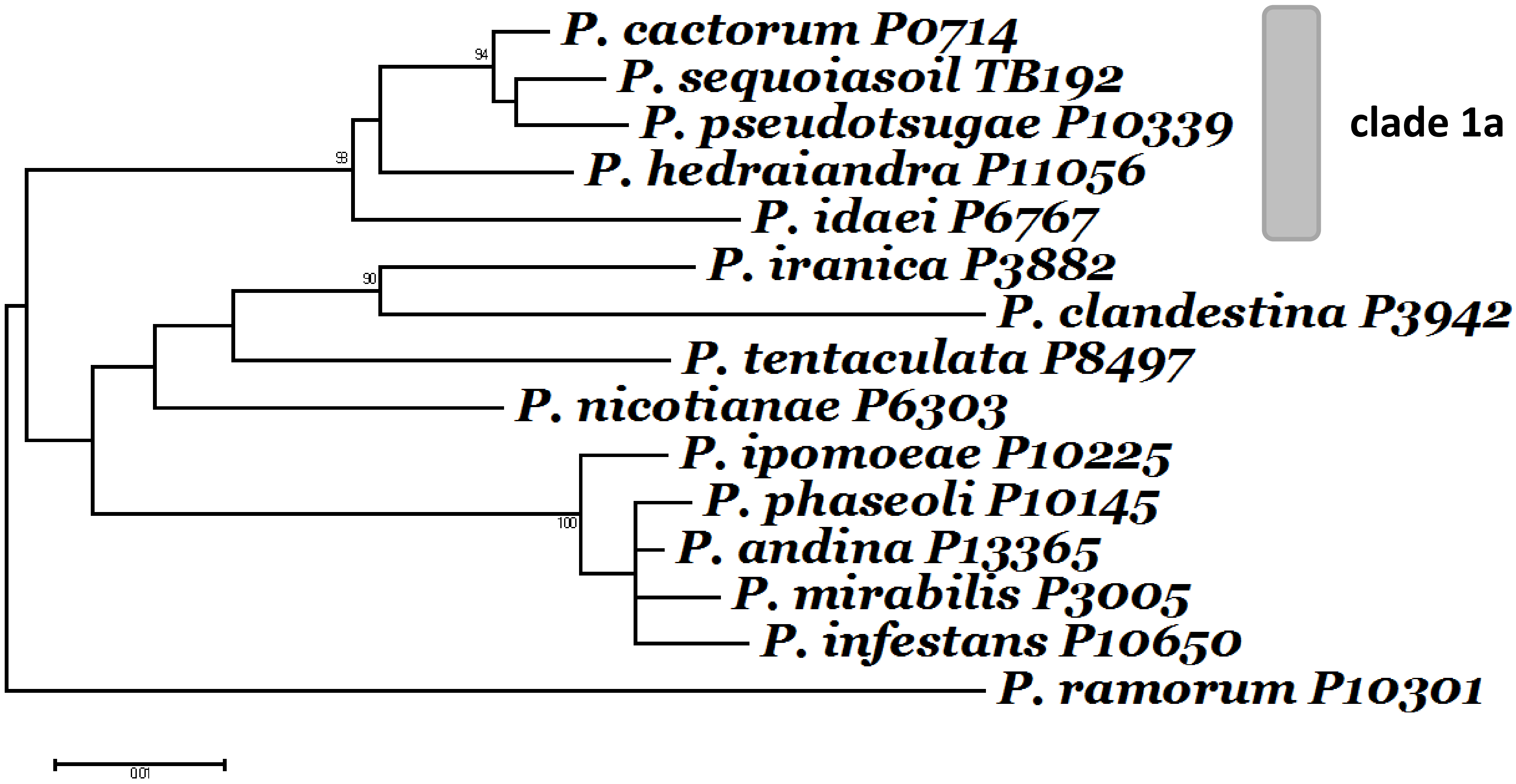



*Phytophthora* baited from 15/40 = 38% of plots in 2013, 5/50 = 10% of plots in 2014, 2/35 = 6% of plots in 2015

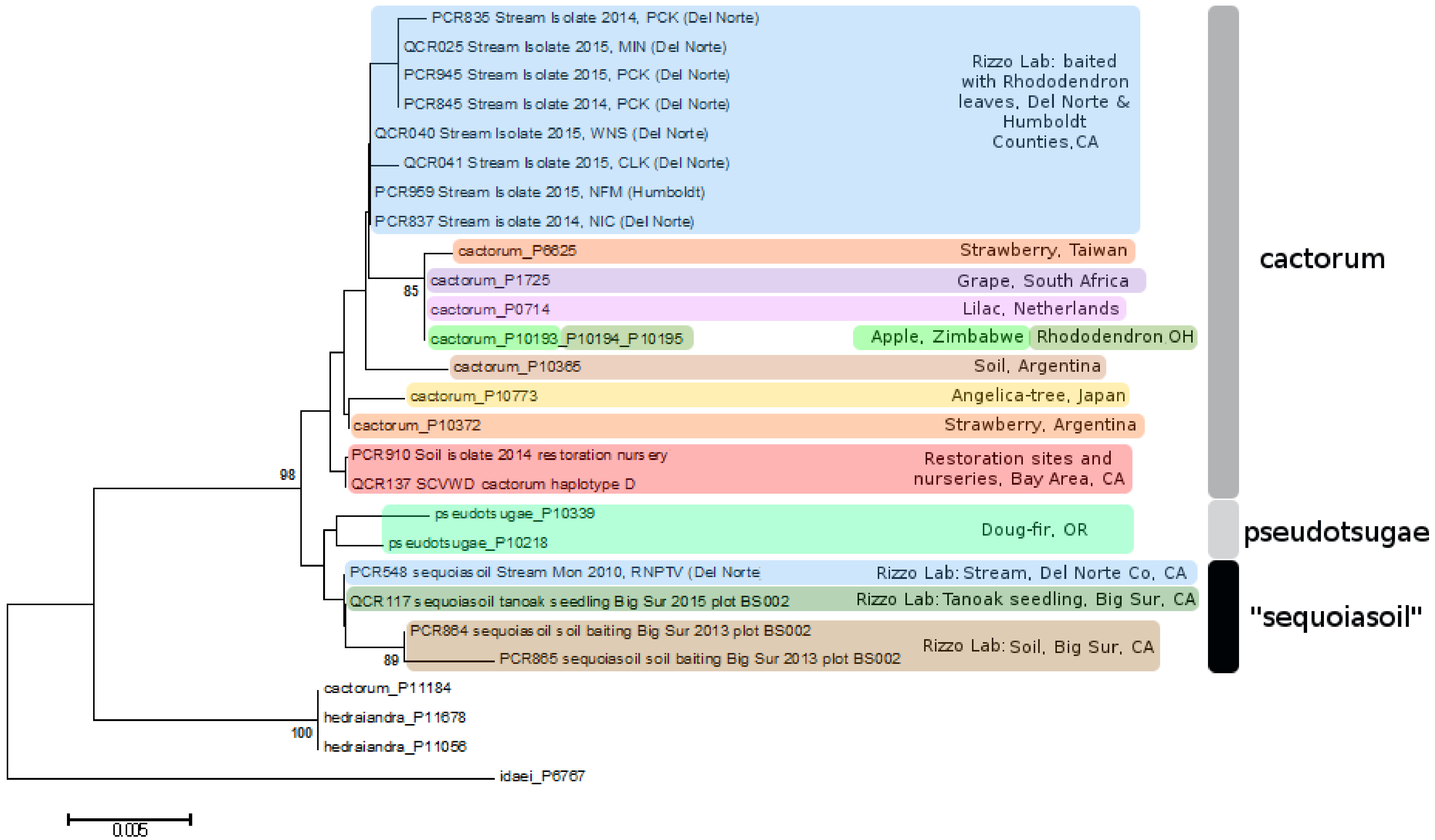
# Ongoing work

- Correlate baiting success with edaphic factors, vegetation data & plot history
- Determine if the psychrophilic *P. nemorosa* can be reliably baited at room temperature
- Soil metagenomics
- In vitro investigations of spore hardiness: subject oospores to heat and desiccation stress followed by viability tests
- **Phylogenetic studies of *Phytophthora* clade 1a**






Maximum likelihood tree of *Phytophthora* clade 1 inferred from the mtCOXII locus. Support value percentages >70 from 1000 bootstrap iterations are shown. Tree created with MEGA6 using default settings with GTR+G nucleotide evolutionary model




Neighbor joining tree from mtCOXII + COXII-COXI spacer

Forest Pathology WILEY-BLACKWELL

For. Path. doi: 10.1111/efp.12239


# Widespread *Phytophthora* infestations in European nurseries put forest, semi-natural and horticultural ecosystems at high risk of Phytophthora diseases

T. Jung[1,2,38], L. Orlikowski[3], B. Henricot[4], P. Abad-Campos[5], A. G. Aday[6], O. Aguín Casal[7], J. Bakonyi[8], S. O. Cacciola[9], T. Cech[10], D. Chavarriaga[11], T. Corcobado[12], A. Cravador[1], T. Decourcelle[13], G. Denton[5], S. Diamandis[14], H. T. Doğmuş-Lehtijärvi[7], A. Franceschini[15], B. Ginetti[16], M. Glavendekić[17], J. Hantula[18], G. Hartmann[19], M. Herrero[20], D. Ivic[21], M. Horta Jung[1], A. Lilja[18], N. Keca[17], V. Kramarets[22], A. Lyubenova[23], H. Machado[24], G. Magnano di San Lio[9], P. J. Mansilla Vázquez[7], B. Marçais[25], I. Matsiakh[22], I. Milenkovic[17], S. Moricca[16], Z. Á. Nagy[8], J. Nechwatal[26], C. Olsson[27], T. Oszako[28], A. Pane[9], E. J. Paplomatas[29], C. Pintos Varela[7], S. Prospero[30], C. Rial Martínez[7], D. Rigling[30], C. Robin[13], A. Rytkönen[18], M. E. Sánchez[31], B. Scanu[15], A. Schlenzig[32], J. Schumacher[33], S. Slavov[23], A. Solla[12], E. Sousa[24], J. Stenlid[27], V. Talgø[20], Z. Tomic[21], P. Tsopelas[34], A. Vannini[35], A. M. Vettraino[35], M. Wenneker[36], S. Woodward[11] and A. Peréz-Sierra[37]

# Discussion

- Variability within *P.* “sequoiasoil” suggest it is a native species
- *P. cactorum* represents many lineages;
  - isolates from streams in Northern CA form a unique lineage
  - so do Bay area nursery/restoration strains
- Are these lineages exotic or native?
- Is there gene flow?

# Acknowledgments

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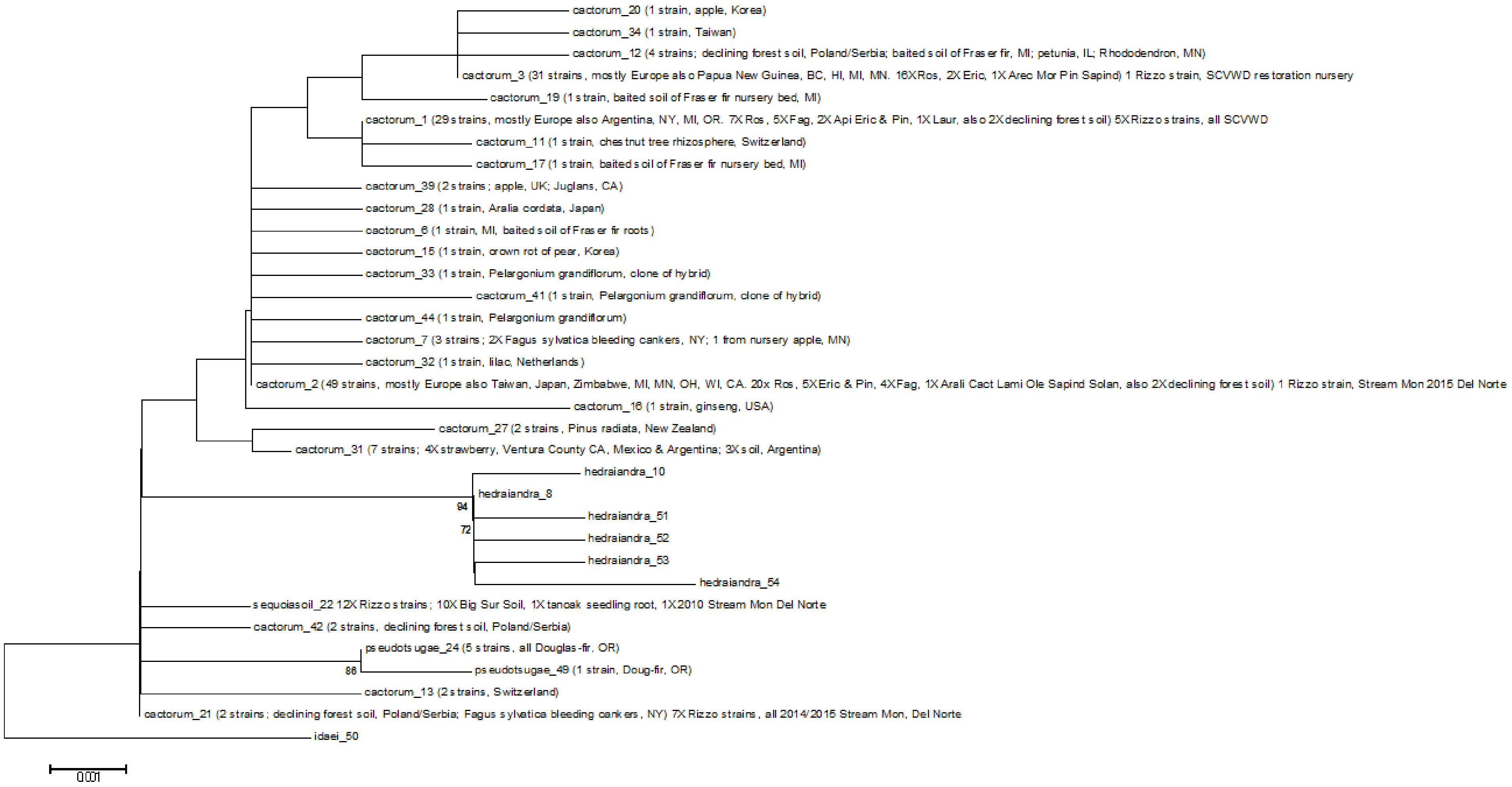
cactorum_20 (1 strain, apple, Korea)
cactorum_34 (1 strain, Taiwan)
cactorum_12 (4 strains; declining forest soil, Poland/Serbia; baited soil of Fraser fir, MI; petunia, IL; Rhododendron, MN)
cactorum_3 (31 strains, mostly Europe also Papua New Guinea, BC, HI, MI, MN. 16XRos, 2X Eric, 1X Arec Mor Pin Sapind) 1 Rizzo strain, SCVWD restoration nursery
cactorum_19 (1 strain, baited soil of Fraser fir nursery bed, MI)
cactorum_1 (29 strains, mostly Europe also Argentina, NY, MI, OR. 7X Ros, 5X Fag, 2X Api Eric & Pin, 1X Laur, also 2X declining forest soil) 5X Rizzo strains, all SCVWD
cactorum_11 (1 strain, chestnut tree rhizosphere, Switzerland)
cactorum_17 (1 strain, baited soil of Fraser fir nursery bed, MI)
cactorum_39 (2 strains; apple, UK; Juglans, CA)
cactorum_28 (1 strain, Aralia cordata, Japan)
cactorum_6 (1 strain, MI, baited soil of Fraser fir roots)
cactorum_15 (1 strain, crown rot of pear, Korea)
cactorum_33 (1 strain, Pelargonium grandiflorum, clone of hybrid)
cactorum_41 (1 strain, Pelargonium grandiflorum, clone of hybrid)
cactorum_44 (1 strain, Pelargonium grandiflorum)
cactorum_7 (3 strains; 2X Fagus sylvatica bleeding cankers, NY; 1 from nursery apple, MN)
cactorum_32 (1 strain, lilac, Netherlands)
cactorum_2 (49 strains, mostly Europe also Taiwan, Japan, Zimbabwe, MI, MN, OH, WI, CA. 20x Ros, 5X Eric & Pin, 4X Fag, 1X Arali Cact Lami Ole Sapind Solan, also 2X declining forest soil) 1 Rizzo strain, Stream Mon 2015 Del Norte
cactorum_16 (1 strain, ginseng, USA)
cactorum_27 (2 strains, Pinus radiata, New Zealand)
cactorum_31 (7 strains; 4X strawberry, Ventura County CA, Mexico & Argentina; 3X soil, Argentina)
hedraiandra_10
hedraiandra_8
94
hedraiandra_51
72
hedraiandra_52
hedraiandra_53
hedraiandra_54
sequoiasoil_22 12X Rizzo strains; 10X Big Sur Soil, 1X tanoak seedling root, 1X 2010 Stream Mon Del Norte
cactorum_42 (2 strains, declining forest soil, Poland/Serbia)
pseudotsugae_24 (5 strains, all Douglas-fir, OR)
86
pseudotsugae_49 (1 strain, Doug-fir, OR)
cactorum_13 (2 strains, Switzerland)
cactorum_21 (2 strains; declining forest soil, Poland/Serbia; Fagus sylvatica bleeding cankers, NY) 7X Rizzo strains, all 2014/2015 Stream Mon, Del Norte
idaei_50
0.001