Nov. 29, 2018, V.1 Compiled by Chris Lee, christopher.lee@fire.ca.gov>

DRAFT Compilation of Information on Spread of *Phytophthora ramorum* in Soil and Water

Cooper, M.; Cushman, H. 2006. **Effects of recreation on the dispersal of exotic forest pathogen, *Phytophthora ramorum*.** In: The sixth California oak symposium: today's challenges, tomorrow's opportunities. https://www.fs.fed.us/psw/publications/documents/psw_gtr217/psw_gtr217.pdf

- Pathogen was recovered from soil on shoes
- 7% of hikers and bikers carried the pathogen into the designated area
- 23% of hikers and bikers carried the pathogen out of the designated area
- There was trend that hiking and biking longer distances resulted in higher levels of pathogen recovery
- Pathogen could not be recovered after 24 hours if soil dried; could not be recovered after 72 hours if soil was kept moist

Cushman, J.H.; Meentemeyer, R. 2006. **The importance of humans in the dispersal and spread of *Phytophthora ramorum* at local, landscape, and regional scales.** In: Frankel, S.J.; Shea, P.J.; Haverty, M.I., tech. coords. Proceedings, sudden oak death second science symposium: the state of our knowledge. Gen. Tech. Rep. PSW-GTR-196. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 161–163.

- In stands with many *P. ramorum* hosts (bay and coast live oak), the pathogen was found equally in locations along trails and 2m away from trails; but in stands with no *P. ramorum* hosts (grasslands and white oak woodlands), the pathogen was found commonly in samples collected on trails but not in samples ("virtually absent") collected 2m away from trails
- Out of 202 plots, there was a greater proportion of bays with pathogen symptoms in plots with high human activity levels than in plots with low human activity levels. The same was not true of tanoaks or coast live oaks
- In a GIS analysis, plots in areas with greater density of human population had a greater likelihood of pathogen presence than plots in areas with lower population density

Cushman, J.H.; Cooper, M.; Meentemeyer, R.K.; Benson, S. 2008. **Human activity and the spread of *Phytophthora ramorum*.** In: Frankel, S.J.; Kliejunas, J.T.; Palmieri, K.M., tech. coords. 2008. Proceedings of the sudden oak death third science symposium. Gen. Tech. Rep. PSW-GTR-214. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 179–180.

- Hikers carried soilborne inoculum 60 to 100m into areas with no inoculum sources present
- 5-10% of Marin County hikers and bikers carried the pathogen into the designated area
- 20-30% of Marin County hikers and bikers carried the pathogen out of the designated area

Davidson, J.M.; Wickland, A.C.; Patterson, H.A.; Falk, K.R.; Rizzo, D.M. 2005. **Transmission of *Phytophthora ramorum* in mixed evergreen forest in California**. Phytopathology. 95: 587–596.

- *P. ramorum* was recovered from soil beneath infected coast live oaks during the wet spring period (3 years of sampling), but not during the summer
- *P. ramorum* was recovered from soil taken from hikers' shoes after they walked 2.4 km (33-47% recovery) in April
- *P. ramorum* inoculum was spread from infested soil to bay leaves lying on the soil surface and misted weekly for 8 weeks: 2 trials—first trial, 6 of 15 leaves were infected, second trial, 1 of 15 leaves was infected
- *P. ramorum* inoculum was spread from infested green leaf litter (bay leaves) to aerial parts of bay seedlings when rainfall was simulated: misted for 20 sec. every 2 hours, then sprinkled with water from above for 25 sec. twice a week—3 leaves from 6 seedlings infected in first trial, 10 leaves from 6 seedlings infected in second trial

Eyre, C.A.; Garbelotto, M. 2015. **Detection, diversity, and population dynamics of waterborne *Phytophthora ramorum* populations.** Phytopathology 105: 57-68.

- PCR was an effective means of detection of *P. ramorum* propagules in stream water during times of year when culturing was unable to detect it
- Genotype populations of *P. ramorum* in water appear highly variable from year to year and highly dependent on the contribution of genotypes from aerial sources
- *P. ramorum's* population genetic structure resembles that of *P. capsici,* another aerially dispersed *Phytophthora* species, for which infestation patterns have been observed to follow irrigation rows; therefore, perhaps water has a more important epidemiological role than has yet been observed

Fichtner, E.J.; Lynch, S.C.; Rizzo, D.M. 2006. **Summer survival of *Phytophthora ramorum* in forest soils.** In: Frankel, S.J.; Shea, P.J.; Haverty, M.I., tech. coords. Proceedings, sudden oak death second science symposium: the state of our knowledge. Gen. Tech. Rep. PSW-GTR-196. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 165–166.

- The pathogen, contained in inoculated leaf disks, generally did not survive longer than 1 week at the top of the leaf litter (1% survival)
- The pathogen survived longer at the litter-soil interface and beneath the soil surface: 65% recovery at the interface after 8 wk; 80% recovery from the subsurface after 8 wk and 60% recovery from the subsurface after 24 wk

Fichtner, E.J.; Lynch, S.C.; Rizzo, D.M. 2007. **Detection, distribution, sporulation, and survival of *Phytophthora ramorum* in a California redwood-tanoak forest soil.** Phytopathology 97: 1366-1375.

- The pathogen was recovered in soil up through July in "normal" winters and through September in years when rains extended through June
- Recovery was greatest from soil beneath bay laurel, then from soil beneath tanoak, then from soil beneath redwood
- Only 3% recovery of pathogen at the litter surface by the end of summer
- Recovery at the litter-soil interface dropped dramatically at the end of 8 wk
- Recovery was consistent from the soil (>60% at the end of summer)
- Significantly more chlamydospores were produced on leaves incubated beneath the surface of the soil than those on top of the litter or at the litter-soil interface

Fichtner, E.J.; Lynch, S.C.; Rizzo, D.M. 2009. **Survival, dispersal, and potential soil-mediated suppression of *Phytophthora ramorum* in a California redwood-tanoak forest.** Phytopathology 99: 608-619.

- Recovery of the pathogen from soil through August in 2005 but was nil in August 2006
- Generally same trends as Fichtner et al. 2007 paper, except:
- Splash infection was assessed at a variety of "target" heights (both bay laurel and tanoak twigs & leaves). Infection was greatest 8 cm above bare soil (75% infection) but reached up to 30 cm. Applying leaf litter to bare soil greatly reduced but did not eliminate infection of the aerial twigs/leaves
- High summer temperatures appeared to reduce viability of pathogen inoculum at or near the soil surface
- Redwood soils (as compared to soils collected under bay or under tanoak) enhanced survival of the pathogen because of their moisture-holding capacity; but they were much more suppressive to chlamydospore production when infected leaf tissue was buried beneath the soil surface. This appears to be abiotic rather than the result of microbial activity—potentially a soluble compound present in redwood soils

Peterson, E.; Hansen, E.; Kanaskie, A. 2014. **Spatial relationship between *Phytophthora ramorum* and roads or streams in Oregon tanoak forests. Forest Ecology and Management** 312: 216-224.

- The hypotheses that *P. ramorum*-positive sites were significantly closer to roads or to streams than expected by chance was tested using statistical randomization procedures; the hypothesis was not supported, indicating no detected relationship between positive sites and roads or streams

Peterson, E.; Hansen, E.; Hulbert, J. 2014. **Source or sink? The role of soil and water borne inoculum in the dispersal of *Phytophthora ramorum* in Oregon tanoak forests.** Forest Ecology and Management 322:48-57.

- 2 years of sampling water from puddles in roads going through infested areas: *P. ramorum* recovered from 2/113 samples
- Along six transects perpendicular to two roads traversing infested areas, 17/135 roadside vegetation samples were positive for *P. ramorum.* All infected understory plants were closely associated with infected overstory tanoak
- One positive puddle was associated with positive roadside vegetation
- *P. ramorum* infection was associated more with transects perpendicular to streams than with streamside (parallel) transects
- Pathogen recovery in known infested sites had a significant negative relationship with distance from the "initial" infected overstory tanoak

Tjosvold, S.A.; Chambers, D.L.; Davidson, J.M.; Rizzo, D.M. 2002. **Incidence of *Phytophthora ramorum* inoculum found in soil collected from a hiking trail and hiker's shoes in a California park**. In: Proceedings of the sudden oak death science symposium, the state of our knowledge. Berkeley, CA: U.S. Department of Agriculture, Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymp/poster/poster46.html. (April 2010)

- Soil was sampled directly from the trail as well as from the bottoms of hikers' shoes following hiking. It was sampled from March through November
- Spring: successful isolation of the pathogen varied from 40-80% from trail soil and 40-95% from shoes
- Summer: no successful isolation of the pathogen
- Fall: following the first rain, the pathogen was detected from 5% of shoe samples but not from trail soil

Tjosvold, S.A.; Chambers, D.L.; Koike, S.T.; Mori, S.R. 2008. **Disease on nursery stock as affected by environmental factors and seasonal inoculum levels of *Phytophthora ramorum* in stream water used for irrigation**. Plant Disease 92: 1566-1573.

- *P. ramorum* could be detected by pear baiting in streams running through infested areas (Santa Cruz County) year-round, but they were at lower levels during the dry season
- Disease on rhododendrons irrigated from infested stream water did occur, but only 3 times over 4 years, and all 3 times were during one spring and coincided with the highest observed levels of *P. ramorum* propagules in stream water
- At the highest propagule concentration modeled in this experiment—0.75 propagules/pear/liter of water—10 hours of leaf wetness were required to facilitate infection. However, in streams,

propagule concentrations observed in streams could range higher than this level at times (up to around 2.5 propagules/pear/liter at times).

Webber, J.F.; Rose, J. 2008. **Dissemination of aerial and root infecting Phytophthoras by human vectors.** In: Frankel, S.J.; Kliejunas, J.T.; Palmieri, K.M., tech. coords. Proceedings of the sudden oak death third science symposium. Gen. Tech. Rep. PSW-GTR-214. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 195–198.

- Soil sampled from walkers' boots—400 samples taken over 3 years from the *Phytophthora kernoviae* Management Zone in Cornwall. Over 30% (n=~120) were positive for *Phytophthora* species, with 10-15% (n=~12-18) of the positive samples being *P. ramorum* or *P. kernoviae*
- Positive samples were most frequent in June-July and October-November. Most negative samples in August-September

Werres, S.; Wagner, S. 2007. **Survival of *Phytophthora ramorum* in recirculating irrigation water and subsequent infection of *Rhododendron* and *Viburnum.*** Plant Disease 91: 1034-1044.

- Established that overhead irrigation using infested water could infect plants
- Infection incidence was 19% of plants irrigated; however, large concentrations of zoospores were used. This incidence of infection is lower than many other waterborne plant pathogens, including other *Phytophthora* species