Editor's note. Hamelin et al. have published "Genomic biosurveillance detects a sexual hybrid in the sudden oak death pathogen." We featured this first report of a *Phytophthora ramorum* sexual hybrid in our December 2021 issue. The abstract and a figure from the paper may be found below under "Research". Also under "Research", LeBoldus et al. published a review paper on sudden oak death in Oregon. Follow the included links to learn more.

SUDDEN OAK DEATH AND CALIFORNIA'S CARBON CREDIT MARKET

Badgley, G.; Chay, F.; Chegwidden, O.S.; Hamman, J.J.; Freeman, J. and Cullenward, D. Preprint. California's forest carbon offsets buffer pool is severely undercapitalized. bioRxiv. https://doi.org/10.1101/2022.04.27.488938. (Not yet peer reviewed).

The market for carbon credits allows purchase of offsets as an alternative to cutting emissions from burning oil, gas, or other polluting activities. Investments to designate forests as carbon sinks are commonly used to enhance carbon capture. But a recent analysis from the non-profit "CarbonPlan" found "that potential carbon losses from a single forest disease, sudden oak death (SOD), could fully encumber all credits set aside for disease and insect risks." They argue that California's credit market underestimates damage from pests and wildfire so is unlikely to be able to guarantee the environmental integrity of California's forest offsets program for 100 years. The study, "California's forest carbon offsets buffer pool is severely undercapitalized" has not yet been fully peer reviewed but raises many important questions about the future impacts of wildfire, drought, insects, and pathogens' ability to erode carbon capture in California forests.

For forest disease, Badgley and colleagues consider the potential effects of large-scale tanoak, *Notholithocarpus densiflorus*, mortality events on the buffer pool -- carbon capture reserves set aside to cover unforeseen losses in carbon stocks. Using the SOD Blitz database they calculated the distance between positive *P. ramorum* detections and forest carbon offset projects. Of the 20 projects that report at least 5% tanoak basal area, one carbon capture project has a positive *P. ramorum* sample within its boundaries and five are within 5 km of a recorded positive. The authors point out that "Critically, our analysis of the disease and insect component of the buffer pool only considers a single pathogen (*P. ramorum*) and the potential biomass losses of a single species (tanoak). There is growing evidence, however, that U.S. forests are likely to experience increased mortality pressure due to continuing globalization which brings with it more frequent opportunities for the introduction and spread of invasive pathogens."

How sudden oak death, wildfire, climate change, and other factors will impact carbon balance and carbon market efficacy is a complex question. Some of the assumptions in this analysis may not hold true. For example, the most conservative estimate of damage from sudden oak death assumes a 50% reduction of tanoak biomass. However, the analysis outlines factors that need to be carefully evaluated for their potential impacts on the ability of California forest carbon investments to capture adequate amounts of carbon to limit adverse environmental impacts from excess atmospheric CO_2.

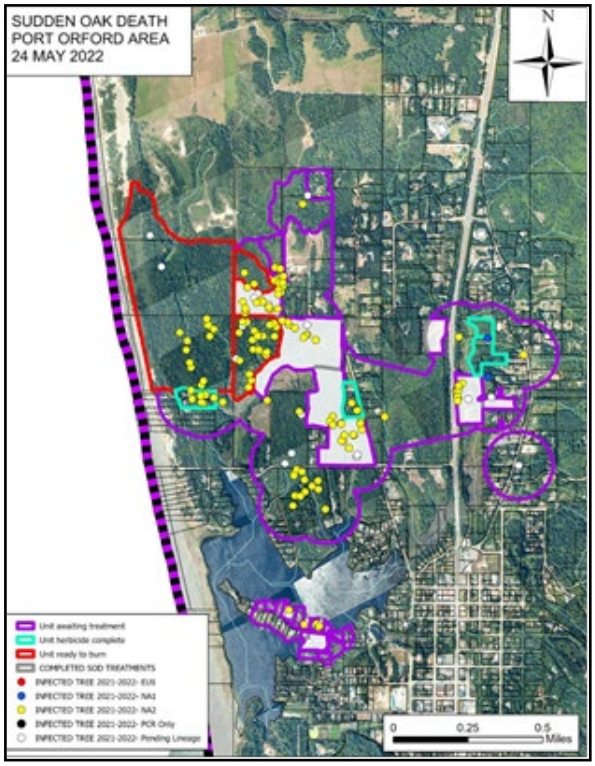
OREGON SUDDEN OAK DEATH UPDATE - WILDLANDS

In Oregon, until 2021, sites infested by the EU1 *P. ramorum* lineage were the highest priority areas targeted for complete eradication treatment. The state strategy has shifted its highest priority to treating the more recent NA2 *P. ramorum* infestation in Port Orford (Curry County). Plant pathologists approved this strategy shift based on lab studies that demonstrated NA2 as the most aggressive *P. ramorum* strain and the infestation's proximity to the Curry/Coos county line. The state strategy for the NA1 *P. ramorum* lineage is to 'slow the spread' by targeting sites with the greatest potential to expand beyond the overall disease boundary.

A tentative 600 ft treatment buffer has been placed around the confirmed positive trees in the Port Orford area totaling 581 acres. Oregon Department of Forestry (ODF) has completed treatment on 141 acres and has 102 acres currently undergoing treatment. ODF SOD treatment crews will continue work as weather and fire risk conditions allow. Upon further molecular analysis, two of the confirmed positive samples collected in the Port Orford area, one from tanoak and one from rhododendron, were determined to be the NA1 *P. ramorum* lineage.

Despite the Port Orford infestation being outside the current official SOD Quarantine area, the area is covered under the current Oregon Department of Agriculture SOD rules, which require establishment of a quarantine on any area in the state where a *P. ramorum* infestation occurs (OAR 603-052-1230(2)(d). Oregon's SOD Program will be in consultation with stakeholders regarding a potential quarantine expansion in the future. Since September 2021, ODF has expended $624,000 on SOD treatment work in the Port Orford area. Based on current treatment rates from recent expenditures, the remaining acreage will cost $1,247,400 to treat over the next year. Current treatment funding for the SOD Program sits at $1,197,000. ODF does not have the treatment budget or staff time to complete treatments within the SOD quarantine zone at this point given the priority placed on the Port Orford treatment area.

Figures 1 & 2. Left. Map of Port Orford SOD area as of May 24, 2022. ODF crews were able to complete more burning in April and May due to late season rains.
Below. NA2 lineage canker on tanoak with staining in the sapwood. Credits: ODF.



NURSERIES AND MANAGED LANDSCAPES

California Department of Food and Agriculture (CDFA) *P. ramorum* program update. Spring compliance inspections at regulated nurseries are underway. Seven California nurseries that were previously positive for *P. ramorum* were inspected, sampled, and found to be free from *P. ramorum* during spring 2022 inspections. One previously positive nursery is still awaiting its spring inspection. Annual inspections at nurseries in quarantined counties that haven't been positive for *P. ramorum* are also underway. There have been no *P. ramorum* detections in California nurseries yet in 2022. For more information contact Carolyn Lambert, Carolyn.Lambert@cdfa.ca.gov.

Oregon Department of Agriculture *P. ramorum* Nursery Program update. Currently, there are six nurseries participating in the Oregon *P. ramorum* Nursery Program. All nurseries are interstate shippers under federal compliance agreements (7 CFR 301.92). The nurseries are in the following counties: Washington (2), Columbia (1), Linn (1), and Marion (2).

Compliance surveys for the 2022 spring season began on March 22nd with five nursery inspections. A sixth nursery in Linn County (Nursery A) was added to the program in April and is currently undergoing delimitation surveys and completing mitigation measures. Compliance inspections have been completed at the remaining five nurseries. One nursery was confirmed positive for *P. ramorum* (Nursery B), results are pending for another, and the other three compliance surveys were completed with no *P. ramorum* detected.

Nursery B was involved in a trace-forward investigation triggered by a positive confirmation in another state. As a result of the trace inspection, three foliar samples were found to be positive. As part of the first delimitation survey, 300 foliar samples were taken. One was confirmed positive for *P. ramorum*. The nursery destroyed all the material in the destruction and quarantine zones and mitigated the ground using methods approved by the Confirmed Nursery Protocol (CNP). All foliar samples collected during the second delimitation survey came back negative for *P. ramorum*. Trace-back investigations were completed at two other Oregon nurseries with no additional nurseries being added to the program - all samples were negative.

Figure 3. *P. ramorum* positive plants were detected in this area in Nursery B.

Nursery A was confirmed positive for *P. ramorum* for the first time in April due to a single foliar sample taken during a routine annual nursery inspection. A CNP/delimitation survey found 18 more positive foliar samples. One water sample was collected and tested negative for *P. ramorum*. A second delimitation inspection was completed, and sample results are pending. Five nurseries were impacted as part of the trace-back investigations. One nursery is in Canada, and the rest are in Oregon. Results from trace-back investigations are pending.

Figures 4 & 5. Two positive *Rhododendron* plants from the Linn County delimitation inspection.

To be released from the program, nurseries must have six consecutive negative results from compliance inspections over three years. No nurseries will be eligible to be released from the program this spring. For more information, please contact Chris Benemann, chris.benemann@oda.oregon.gov, or Kaitlin Gerber, kaitlin.gerber@oda.oregon.gov.

Washington State Department of Agriculture (WSDA) *P. ramorum* program update.
This spring, WSDA has been busy following up on trace-forward shipments from out-of-state positive nurseries. Two separate investigations involved plants sent to big box stores. All samples collected were negative for *P. ramorum*. A third investigation is still in progress, with trace-forward plants installed in landscapes at residential sites in Washington. So far, samples have been negative.

A spring certification survey was conducted at Washington's only regulated interstate shipping nursery in early May. All plant samples were negative for *P. ramorum*. Water samples from the survey are still pending lab results. The next certification survey will take place in fall of 2022. For more information contact Scott Brooks, SBrooks@agr.wa.gov.

RESEARCH

Espindola, A.S.; Cardwell, K.F.; Martin, F.N.; Hoyt, P.R.; Marek, S.; Schneider, W. and Garzon, C.D. 2022. A step towards validation of high-throughput sequencing for the identification of plant pathogenic oomycetes. Phytopathology. https://apsjournals.apsnet.org/doi/abs/10.1094/PHYTO-11-21-0454-R. (Early View.)

The advancement in high-throughput sequencing (HTS) technology allows the detection of pathogens without the need for isolation or template amplification. Plant regulatory agencies worldwide are adopting HTS as a pre-screening tool for plant pathogens in imported plant germplasm. The technique is a multipronged process, and often the bioinformatic analysis complicates detection. Previously we developed E-probe Diagnostic Nucleic acid Analysis (EDNA), a bioinformatic tool that detects pathogens in HTS data. EDNA uses custom databases of signature nucleic acid sequences (e-probes) to reduce computational effort and subjectivity when determining pathogen presence in a sample. E-probes of *Pythium ultimum* and *P. ramorum* were previously validated only using simulated HTS data. However, HTS samples generated from infected hosts or pure culture may vary in pathogen concentration, sequencing bias, and data quality, suggesting that each pathosystem requires further validation. Here we used metagenomic and genomic HTS data generated from infected hosts and pure culture respectively, to further validate and curate e-probes of *Py. ultimum* and *Ph. ramorum*. E-probe length was found to be a determinant of diagnostic sensitivity and specificity; 80-nucleotides e-probes increased the diagnostic specificity to 100%. Curating e-probes to increase specificity affected diagnostic sensitivity only for 80-nucleotides *Py. ultimum* e-probes. Comparing e-probes with alternative databases and bioinformatic tools in their speed and ability to find *Py. ultimum* and *Ph. ramorum* demonstrated that while pathogen sequence reads were detected by other methods, they were less specific and slower when compared with e-probes.

Hamelin, R.; Bilodeau, G.; Heinzelmann, R.; Hrywkiw, K.; Capron, A.; Dort, E.; Dale, A.; Giroux, E.; Carleson, N.; Grünwald, N. and Feau, N. 2022. Genomic biosurveillance detects a sexual hybrid in the sudden oak death pathogen. Communications Biology. 5: 477. https://doi.org/10.1038/s42003-022-03394-w.

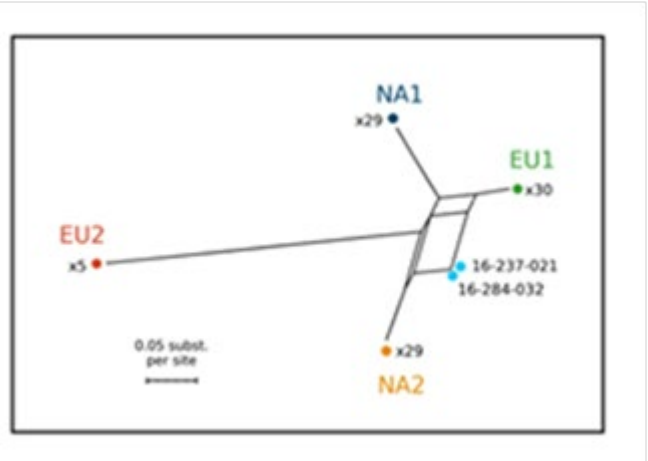


Figure 6. Neighbor-net phylogenetic network reconstructed from a matrix of pairwise Nei's genetic distances between isolates of *P. ramorum*. Samples 16-237-021 and 16-284-032 are the two putative hybrids. (From Hamelin et al. 2022).

Invasive exotic pathogens pose a threat to trees and forest ecosystems worldwide, hampering the provision of essential ecosystem services such as carbon sequestration and water purification. Hybridization is a major evolutionary force that can drive the emergence of pathogens. *Phytophthora ramorum*, an emergent pathogen that causes the sudden oak and larch death,

spreads as reproductively isolated divergent clonal lineages. We use a genomic biosurveillance approach by sequencing genomes of *P. ramorum* from survey and inspection samples and report the discovery of variants of *P. ramorum* that are the result of hybridization via sexual recombination between North American and European lineages. We show that these hybrids are viable, can infect a host and produce spores for long-term survival and propagation. Genome sequencing revealed genotypic combinations at 54,515 single nucleotide polymorphism loci not present in parental lineages. More than 6,000 of those genotypes are predicted to have a functional impact in genes associated with host infection, including effectors, carbohydrate-active enzymes and proteases. We also observed postmeiotic mitotic recombination that could generate additional genotypic and phenotypic variation and contribute to homoploid hybrid speciation. Our study highlights the importance of plant pathogen biosurveillance to detect variants, including hybrids, and inform management and control.

LeBoldus, J.M.; Navarro, S.M.; Kline, N.; Ritokova, G. and Grünwald, N.J. 2022. Repeated emergence of sudden oak death in Oregon: Chronology, impact, and management. Plant Disease. https://doi.org/10.1094/PDIS-02-22-0294-FE. (Early View.)

It has been two decades since the first detection of the sudden oak death pathogen *Phytophthora ramorum* in Oregon forests. Although the epidemic was managed since its first discovery in 2001, at least three invasions of three separate variants (clonal lineages), NA1, EU1 and NA2, are documented to have occurred to date. Control of this epidemic has cost over $32 million from 2001-2020. This is dwarfed by the predicted cost of the closure to the Coos Bay export terminal estimated at $58 million per year, if the epidemic was allowed to spread unchecked. Management efforts in Oregon have reduced inoculum and limited the spread of the pathogen. An outreach and citizen scientist program has been piloted to help in early detection efforts and search for disease-resistant tanoak. This feature article documents the repeated emergence, impact, costs, and lessons learned from managing this devastating invasive pathogen.

Shamoun, S.F. and Elliott, M. 2022. Comparative efficacy of *Chondrosterum purpureum* and chemical herbicides for control of resprouts in tanoak and bay laurel. Pathogens. 11(5): 485. https://doi.org/10.3390/pathogens11050485.

The invasive Oomycete pathogen *Phytophthora ramorum* has killed millions of susceptible oak and tanoak trees in California and southern Oregon forests and is responsible for losses in revenue to the nursery industry through mitigation activities. In addition, infestation of forests in the United Kingdom by this organism has resulted in the destruction of many hectares of larch plantations. Resprouting stumps can be a reservoir for the inoculum of *P. ramorum* persisting on a site. In areas where the application of herbicides is not permitted, a biocontrol treatment would be an indispensable alternative. Treatment of stumps with the sap-rotting fungus *Chondrostereum purpureum* (Pers.) Pouzar has been shown to be an effective tool for the suppression of resprouting on several species, most notably red alder. In this project, the ability of *C. purpureum* to suppress resprouting was evaluated on stumps of two host species, tanoak (*Notholithocarpus densiflorus*) and California bay laurel (*Umbellularia californica*). Laboratory testing of three California isolates of *C. purpureum* indicated that the fungus can colonize bay laurel stems. Field trials were established near Brookings, Oregon, on tanoak and on bay laurel near Soquel, California. Early results of field testing showed that *C. purpureum* was able to

colonize the stumps of tanoak following treatment and was found to occur naturally on tanoak logs and stumps. Formulations of *C. purpureum* appear to have some effect on reducing sprout survival in tanoak, but the most effective and rapid treatment for this host is the hack and squirt method of applying the herbicide imazapyr. Sprayed herbicide prevents sprouting on bay laurel, and there was evidence that resprouting was inhibited on stumps treated with *C. purpureum*. Over time, applications of *C. purpureum* may be a more permanent solution as the stumps begin to decay.

RELATED RESEARCH

Casati, M.; Kichey, T.; Decocq, G. 2022. Monographs on Invasive Plants in Europe: *Rhododendron ponticum* L. Botany Letters, pp.1-24. https://doi.org/10.1080/23818107.2022.2052182. (Early View.)

Cobb, R.C. 2022. The intertwined problems of wildfire, forest disease, and climate change interactions. Current Forestry Reports. Current Forestry Reports. https://doi.org/10.1007/s40725-022-00161-2.

Dale, A.L.; Feau, N.; Berube, J.A.; Ponchart, J.; Bilodeau, G.J. and Hamelin, R.C. 2022. Urban environments harbor greater oomycete and *Phytophthora* diversity, creating a bridgehead for potential new pathogens to natural ecosystems. Environmental DNA. DOI: 10.1002/edn3.300. https://onlinelibrary.wiley.com/doi/pdf/10.1002/edn3.300.

Tsykun, T.; Prospero, S.; Schoebel, C.N.; Rea, A. and Burgess, T.I. 2022. Global invasion history of the emerging plant pathogen *Phytophthora multivora*. BMC genomics. 23: 153. https://doi.org/10.1186/s12864-022-08363-5.

PHYTOPHTHORA PLUVIALIS IN THE UK – NEW DISEASE AND *P. RAMORUM* LOOK ALIKE

Severe decline was observed on a mature stand of western hemlock (*Tsuga heterophylla*) in fall 2021 during the UK Forestry Commission's annual aerial surveillance for *P. ramorum* in Cornwall, southwest England. From the plane, affected trees looked like damage from *P. ramorum* on larch, but the problem appeared on western hemlock; all the larch in the area had been previously removed. The trees showed crown dieback, needle drop, cankers and mortality on understory hemlock. *P. pluvialis* was found to be the causal agent. This is the first detection of *P. pluvialis* in Europe, and the first find of *P. pluvialis* causing resinous cankers on western hemlock worldwide.

Figures 7 & 8. Left. Aerial view of western hemlock in Cornwall showing dieback due to *P. pluvialis*. Right. Resinous cankers on western hemlock infected with *P. pluvialis*.
Credit. UK Forestry Commission.

P. pluvialis is known to occur in Oregon, Washington, and California on Douglas-fir (*Pseudotsuga menziesii*) and tanoak (*Notholithocarpus densiflorus*) where it causes needle chlorosis. The pathogen is also found in New Zealand where it causes red needle cast on *Pinus radiata* (radiata pine, Monterey pine).

In the UK, further *P. pluvialis* outbreaks have been found in Cornwall, Devon, Cumbria, Surrey, and at multiple sites in Scotland and Wales. The pathogen is considered a quarantine pest, under mandatory eradication, so infected trees are removed along with surrounding trees.

More information on *Phytophthora pluvialis* is available from the UK Forestry Commission. For a video on symptom identification see *Phytophthora pluvialis* | symptoms in western hemlock – YouTube and **Pérez-Sierra. A.; Chitty, R.; Eacock, A.; Jones, B.; Biddle, M. and others. 2022.** First report of *Phytophthora pluvialis* in Europe causing resinous cankers on western hemlock. New Disease Reports. 45(1). https://bsppjournals.onlinelibrary.wiley.com/doi/full/10.1002/ndr2.12064.