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Foreword: Innovation and dedication underpin management of sudden oak death (*Phytophthora ramorum)* in California and Oregon forests

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This special issue of **Forest Phytophthoras** serves as part of the proceedings from the Sixth Sudden Oak Death Science Symposium held June 21 - 23, 2016 at Fort Mason Center in San Francisco, CA, USA. The symposium marked almost 16 years to the day that David Rizzo (UC Davis) and Matteo Garbelotto (UC Berkeley) identified the cause of sudden oak death to be a previously unknown *Phytophthora* species, later named *Phytophthora ramorum*. Many of the approximately 200 participants at the conference have dedicated the past 15 years, a large portion of their life's work, to protect U.S. forests from this new invasive pathogen.

The papers collected in this issue focus on direct actions taken in the forest to arrest *P. ramorum* infestations in California and Oregon. Despite mixed success in terms of pathogen eradication or suppression, these efforts comprise the most comprehensive fight against a forest pathogen in the U.S. since the campaigns, from about 1915 – 1970, to remove *Ribes* to control white pine blister rust (*Cronartium ribicola*) (Maloy 1997, Geils et al. 2010).

Taken together, these papers show how difficult it is to cure even a single tree, let alone prevent spread, manage, and control a new, invasive forest pathogen. Despite technological leaps in diagnostics, our management tools and strategies remain somewhat primitive, focusing primarily on hot spot eradication which removes individuals of the host species that we are trying to save. For successful pathogen eradication, the pest must be detected very early, before it spreads further (Hansen et al. 2008), which remains challenging not only for *P. ramorum* but for other highly damaging invasive species such as Asian longhorned beetle (*Anoplophora glabripennis*) and emerald ash borer (*Agrilus planipennis*) (GAO 2006).

So if the post-establishment management approaches described in this issue, primarily eradication, silvicultural manipulations, or pesticide treatment, haven't been totally successful, how effective are indirect approaches or preventive measures, such as quarantine regulations? Federal and state regulations (ODA 2001, USDA 2002, CDFA 2003) were enacted to prevent human-assisted long-distance pathogen spread; they primarily target nursery plant shipments of *Rhododendron*, *Camellia*, *Viburnum, Pieris,* and *Kalmia,* but cover all 100+ plant species known to be *P. ramorum* hosts (USDA 2013). Unfortunately, quarantines have failed to achieve desired results, as shown in Goheen et al. (this volume). Regulations did not prevent the introduction, in about 2014, of a more aggressive lineage (EU1) into an Oregon forest, nor did they prevent the shipment of over 1 million potentially infested plants from a few nurseries in California and Oregon in 2004 (Stokstad 2004). Those 2004 shipments demonstrate the threat large commercial nurseries pose for pathogen dispersal: a California nursery that supplied over 5,000 nurseries nationwide was found to be infested with *P. ramorum* but only after plants had been shipped to more than 20 states (Drew 2010, Kliejunas 2010).

Looking back at the over 20 years since the recognition of unprecedented mortality of tanoaks (*Notholithocarpus densiflorus*) and coast live oaks (*Quercus agrifolia*) on the flanks of Mt. Tamalpais (Marin County, CA), while we have not managed or prevented all *P. ramorum* spread, many technological advances have improved our understanding of *P. ramorum*, and our ability to combat it. The epidemic emerged coincident with a digital and genetic-methods revolution which enhanced all aspects of forest pathogen response. For example, documentation of pathways of long distance spread has improved due to genetically-based pathogen identification (i.e. DNA finger-printing) (Goss et al. 2009, Grünwald et al. 2012, Grünwald et al. 2016). Within the USA, across Europe and between continents, data has proven that *P. ramorum* moved to new areas numerous times on nursery stock, where it then could escape to the adjacent environment or be inadvertently planted in a landscape (Grünwald et al. 2012, Kamvar et al. 2015).

Other innovations include the sequencing of *P. ramorum*'s genome, just a few years after the microbe's discovery, which provided insights into pathogen biology (Tyler et al. 2006); development of an online, publically accessible geographic information system (GIS) map, oak mapper (www.oakmapper.org, Kelly, 2017) and a mobile application, SOD map (Garbelotto et al. 2014); and improved statistical models that account for epidemiology, vegetation composition, spatial and topographic factors (Václavik et al. 2010, Meentemeyer et al. 2011, Meentemeyer et al. 2012, Cunniffe et al. 2016). Molecular host–pathogen interactions were elucidated in the first reference transcriptome for tanoak, allowing the preliminary identification of disease-related genes (Hayden et al. 2014). The value of large ecological datasets has been demonstrated dramatically, showing fire and *P. ramorum* interactions in Big Sur (Monterey Co.), when wildfires burned through infested areas containing previously established plots (Metz et al. 2011, Metz et al. this volume).

Also creative were new sources of financial support: sudden oak death marked the first time that emergency funds from the USDA Farm Service Agency, Commodity Credit Corporation, supported research to respond to a forest health emergency (Shea 2006). In 2001-2002, those funds, along with a supplemental appropriation from Congress, enabled the establishment of the USDA Forest Service, Pacific Southwest Research, Sudden Oak Death Research program (Shea 2006, COMTF 2017). Foundation awards (e.g. The Gordon and Betty Moore Foundation) and partnerships played a larger role in supporting and coordinating research than in previous pathogen epidemics.

Conclusions

Progressive hops in understanding keep us headed forward, yet our society's ability to control *P. ramorum* or other invasive forest pathogens remains limited. To control a new, invasive wildland pathogen requires a complex, costly and logistically challenging campaign. Coordinated efforts are required of local, state, regional and federal legislators, administrators and stakeholders to support financial and human resource investments for regulation design and enforcement, management, research, monitoring, policy development, education and outreach. Each step requires decisions to be made within numerous organizations and collectively, across agencies and disciplines, since no single entity alone has responsibility or resources to address a forest health epidemic. Additional research to measure and record the efficacy of control operations is needed and could help inform development of a broad consensus to more clearly define action thresholds, both for initiation and termination of management actions. The management experience and incremental advances achieved during our fight against *P. ramorum* provide a stronger foundation for future invasive species incursions.

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