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# Disease, fuels and potential fire behavior: Impacts of Sudden Oak Death in two coastal California forest types

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ABSTRACT

In the Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) and redwood (*Sequoia sempervirens* (D. Don) Endl.) forests of the central California coast, Sudden Oak Death (SOD) has led to landscape-scale mortality of tanoak (*Notholithocarpus densiflorus* (Hook. and Arn.) Manos, Cannon and S.H. Oh). As tanoak mortality progresses, fuel loads and potential fire behavior in these forests are changing. We documented increases in fuel loads over time in long-term monitoring plots in infested forests at Point Reyes National Seashore. Throughout the study, we observed a significant positive relationship between dead tanoak basal area and surface fuels. We used the fire behavior modeling program BehavePlus to compare potential fire behavior between diseased and healthy stands. Model outputs indicated the potential for longer flame lengths, higher rates of spread and more intense surface fire in diseased stands. The potential for increased fire intensity in diseased redwood and Douglas-fir forests may create additional challenges for fire and natural resources managers and may affect the ecology of these forests into the future.

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## 1. Introduction

Losses or dramatic declines of forest species, populations, or age classes due to pests and pathogens can have major impacts on ecosystems. These impacts include changes in ecosystem structure, decreased biodiversity, changes in hydrology and nutrient cycling, and cascading impacts throughout the food web (Ellison et al., 2005; Loo, 2009). The potential for forest pests and pathogens to interact with other ecological perturbations and yield unexpected or nonlinear responses is of particular concern (Paine et al., 1998; Turner, 2010).

Forest pathogens or insect pests have the potential to interact with wildfire by changing fuel loads and thereby fire behavior (Dale et al., 2001; Lundquist, 2007; Simard et al., 2011). Increased fuel loads from disease or pest-related mortality may lead to increased fire intensity and fire effects (Lynch et al., 2006; Metz et al., 2011). Changes in fire intensity can in turn shift the trajectory of post-fire succession and potentially create opportunities for invasion by non-native plants (Sugihara et al., 2006). Additional ecological impacts of changes in fire intensity could include below-ground impacts to microbial communities or soil structure, increased erosion and sedimentation, changes in plant community structure and composition, and cascading effects up the food chain (Brown and Smith, 2000; Neary et al., 2005). However, the relationship between pests, pathogens and fire behavior is complex, varying with the pest or pathogen in question, the temporal trajectory of the pest or pathogen outbreak, the ecosystem that is impacted, and local fire regimes and climate (Parker et al., 2006; Jenkins et al., 2008). In some cases, forest pests or pathogens may actually dampen the potential effects of wildfire by thinning canopy fuels as trees die (e.g. Simard et al., 2011).

Several studies, mostly focused on interactions between mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreaks and wildfire, have documented the trajectory of fuels and fire behavior over time following a pest outbreak. In some cases, fine dead fuels and potential surface fire intensity increased over the short term (2–20 years post-outbreak) and then began to return toward pre-outbreak conditions over the longer term (20+ years post-outbreak) (Hicke et al., 2012; Schoennagel et al., 2012). These same studies report coarse woody debris continuing to increase over the long term (Hicke et al., 2012; Schoennagel et al., 2012). Similarly, the potential for crown fire in areas of mountain pine beetle outbreaks changes over time, with high uncertainty about the effects of the pest outbreak in the short term and strong evidence for a decrease in crown fire potential in the longer term (Simard et al., 2011; Harvey et al., 2014). This study examines potential

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interactions between Sudden Oak Death and wildfire over a five year period in a coastal California ecosystem.

Landscape-scale mortality of true oaks (*Quercus* spp.) in the black oak group as well as tanoak (*Notholithocarpus densiflorus* (Hook. and Arn.) Manos, Cannon and S.H. Oh), referred to as Sudden Oak Death, is caused by the pathogen *Phytophthora ramorum* (S. Werres, A.W.A.M. de Cock). This pathogen is likely non-native and introduced from Asia via the nursery trade; symptoms were first observed in Marin County, California in the mid-1990's (Rizzo and Garbelotto, 2003; Mascheretti et al., 2009). *P. ramorum* causes lethal bole cankers in oaks in the black oak group and tanoaks. Dozens of other species act as foliar hosts. *P. ramorum* sporulates on these species but has little or no effect on their health. Coast live oak (*Quercus agrifolia* Née), the most impacted true oak species in Marin County, has some natural resistance, with 30% mortality observed over one 8-year study (McPherson et al., 2010). Tanoak mortality was reported at 50% in the same long-term study (McPherson et al., 2010) and others have documented tanoak mortality close to 100% (Davis et al., 2010; Ramage et al., 2011b). Mortality rates are higher for tanoak in part because it is the only species that supports both sporulation and bole canker formation (Rizzo and Garbelotto, 2003; Rizzo et al., 2005). Several studies have found evidence that suggests dramatic losses of tanoaks are likely and that extirpation may be avoided only through resprouting and augmenting natural populations with plantings (Rizzo and Garbelotto, 2003; Rizzo et al., 2005; Cobb et al., 2012; Dodd et al., 2013). Genetic studies of tanoak throughout coastal California have found some resistance to *P. ramorum* and research on the feasibility of a resistance breeding program is ongoing (Hayden et al., 2011,2013).

The direct impacts of SOD on coastal California forests, including mortality rates and changes in stand structure and regeneration, have been well documented (Waring and O'Hara, 2008; McPherson et al., 2010; Ramage et al., 2011a, 2011b). However, the potential interactions between SOD and other disturbance agents such as wildfire are less well studied. There is some evidence that SOD infection rates are lower in areas that have recently burned (Moritz and Odion, 2005). A few studies have attempted to quantify the impacts of SOD on wildfire. Metz et al. (2011) took a retrospective approach to investigate the relationship between SOD severity and fire effects in the 2008 Basin Fire in Big Sur, California. The authors found that an overall comparison of healthy versus diseased plots in the Basin Fire showed no differences in burn severity. However, plots with recent SOD infections, where infected tanoaks were still standing with dead leaves, showed higher burn severity than both healthy plots and plots with older infections (Metz et al., 2011). However, this study did not incorporate factors such as weather and topography that would have impacted fire severity and potentially confounded their results. Valachovic et al. (2011) measured fuel loads in healthy and recently infested stands as well as stands where tanoak had been killed with herbicide (a standard forestry practice which was used in this study as a proxy for older SOD-infestations) and did prospective modeling of the potential impacts of SOD on fire behavior. They did not find a significant difference between the fuel loads of diseased versus healthy stands, but they did find differences between herbicide-treated and healthy stands as well as increases in modeled outputs of fire intensity in herbicide-treated stands. Another study looked at potential changes in crown fire ignition of tanoaks killed by *P. ramorum* (Kuljian and Varner, 2010). This study found that foliar moisture content, which is an important predictor of the ability for a surface fire to transition to crown fire, decreased from 82% in healthy tanoaks to 78% in diseased tanoaks and to 12% for dead tanoak foliage. While the change from 82% to 78% would not have a significant effect on fire behavior, the drop to 12% for standing dead tanoaks would result in much higher likelihoods of a fire transitioning from a surface fire to a crown fire (Kuljian and Varner, 2010).

This is the first study to directly measure changes in surface fuels over time associated with Sudden Oak Death and to use those data to model potential changes in fire behavior. We combined direct field observations with fire behavior modeling to assess the impacts of SOD on potential fire behavior of Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) and redwood (*Sequoia sempervirens* (D. Don) Endl.) forests in Point Reyes National Seashore, California, USA. We tracked surface fuels over a five year period in a network of plots and used those data to populate fire behavior models. Our study tests the following hypotheses: 1. Surface fuels initially increase and then level off over time in SOD-infested Douglas-fir and redwood forests and 2. Increased surface fuels lead to increased predicted fire intensity.

## 2. Methods

### 2.1. Study area and plot selection

Fieldwork was conducted in Point Reyes National Seashore and in adjacent areas of Golden Gate National Recreation Area that are managed by Point Reyes National Seashore (referred to collectively here as PRNS). The combined area managed by PRNS is approximately 36,000 hectares and is located in Marin County, California, about 45 km northwest of San Francisco. The climate of PRNS is Mediterranean with mild, wet winters and cool, dry summers. Based on local weather station data from 1964 to 2012, the average minimum and maximum monthly temperatures during summer months ranged from lows of 6 °C to 9 °C to highs of 18 °C to 24 °C. Average winter minimum and maximum temperatures were similar with lows ranging from 2 °C to 4 °C and highs of 15 °C to 17 °C. Average annual precipitation in the study area over this same time period was approximately 100 cm per year (Bear Valley Weather Station 1964–2012). A large majority of the precipitation occurs between October and March although the summer drought is attenuated by coastal fog, which can provide substantial moisture inputs to ecosystems when intercepted by plant canopies. Fog drip has not been quantified for PRNS, but one study further north on the California coast found that fog drip added 22–45 cm of precipitation annually (Dawson, 1998). Elevations in the study area range from 170 m to 480 m. Vegetation at PRNS is characterized by coastal grassland and scrub closer to the Pacific Ocean and Douglas-fir, mixed evergreen and redwood forest along ridge lines and valleys further inland. Inventory plots were located in both redwood/tanoak and Douglas-fir forest types as defined in the PRNS vegetation classification (Fig. 1; Schirokauer et al., 2003). Historical fire regimes in redwood and coastal California Douglas-fir forests were characterized by high frequency, low and moderate severity fires many of which were likely associated with Native American management practices (Lorimer et al., 2009). The redwood and Douglas-fir forests of PRNS are second-growth stands that were logged in the late 19th and early 20th centuries. SOD was first documented in PRNS in 2004. Portions of the study area directly abut the Marin Municipal Water District, which was the likely location of SOD introduction in Marin County, California in the mid-1990s (Rizzo et al., 2002; Mascheretti et al., 2009; McPherson et al., 2010).

Plot selection followed a stratified random split-plot sampling design. Paired plots, one healthy and one diseased, were established at the beginning of the study period. Random points were generated in GIS in both Douglas-fir and redwood vegetation types using the PRNS vegetation GIS layer (Schirokauer et al., 2003). In the field, an expanding radius search starting from these random points was used to locate diseased-healthy plot pairs that met