

Effects of Sudden Oak Death on the Crown Fire Ignition Potential of Tanoak (*Lithocarpus densiflorus*)¹

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Abstract

In the face of the sudden oak death (SOD) epidemic, decreasing foliar moisture content (FMC) of tanoak (*Lithocarpus densiflorus*) has land managers, fire managers, and property owners concerned with the increased possibility of crown fire in affected areas. A need exists to link local SOD-affected foliar moisture content (FMC) values and current FMC data to decision support tools, allowing managers to better predict crown fire in areas where SOD-affected tanoaks are prevalent. We tracked FMC of live (uninfected) tanoaks, *Phytophthora ramorum*-infected tanoaks, dead tanoaks, and surface litter for 12 months. We found that FMC values differed significantly among the three categories of uninfected, *P. ramorum*-infected and dead leaves. FMC of live tanoaks averaged 82.3 percent for the year whereas FMC of infected tanoaks had a lower average of 77.8 percent (ANOVA, $P = 0.04$). Dead trees had a significantly lower FMC, averaging 12.3 percent (ANOVA, $P < 0.01$) for the year. During fire season (June to September), dead tanoak FMC reached a low of 5.8 percent, with no significant difference between dead canopy fuels and surface litter (ANOVA, $P = 0.44$). Application of low FMC values to a crown ignition model results in extremely high crown base height (CBH) values to escape crown ignition. Remote estimation of dead leaf moisture using 10-hour fuel moisture shows promise. Preliminary results indicate a strong relationship between remote automated weather station (RAWS) 10-hour fuel moisture data and the FMC of dead leaves ($R^2 = 0.78$, $P < 0.01$).

Results from this on-going study will aid the decision support process for fire managers in SOD-affected areas and may also be applicable to conditions in other ecosystems where diseases and insect epidemics have altered forest canopy fuels.

Introduction

As sudden oak death (SOD), caused by *Phytophthora ramorum*, continues its spread throughout coastal California, changes in foliar moisture content of tanoaks (*Lithocarpus densiflorus* [Hook. and Arn.] Rehd.) has land managers, fire managers, and property owners concerned with the possibility of crown fire in forests that have been largely crownfire resistant. At this point, no research has been completed to determine if there is an increase in crown fire potential resulting from *P. ramorum*-infected and/or killed tanoaks.

Crown fire potential can be predicted using fire modeling software such as FVS Fire and Fuels Extension (Reinhardt and Cookston 2003), Crown Mass (Carlton 2005), BehavePlus (Andrews and others 2008), FARSITE (Finney 2004), and NEXUS

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(Scott 1999, Scott and Reinhardt 2001). All of these models use Van Wagner's (1977) crown fire initiation and spread model. Aside from weather and topography, this model is dependent on three principle factors: surface fireline intensity (related to flame length); crown base height (CBH); and foliar moisture content (FMC) (Van Wagner 1977).

Relative to flame length and CBH, the effect of FMC has been considered minor, hence the majority of fire modeling programs recommend using a default foliar moisture value = 100 percent (Scott and Reinhardt 2001, Cruz and others 2006). Given that infected tanoaks die and retain their leaves for months to years post-death (D. Rizzo, professor of plant pathology, University of California at Davis, personal communication 2007), FMC values fall far below the normal range of expected FMCs, reaching values as low as 5 percent (Kuljian and others, in press). What is needed is a means to link localized SOD affected FMC values and currently available FMC data to decision support tools so that managers can better predict crown fire in areas where SOD-affected tanoaks are a considerable forest component.

The purpose of this study was: (1) to measure and track the FMC of healthy tanoaks, tanoaks infected with *P. ramorum*, and dead tanoaks with leaves attached for 1 year; (2) to evaluate the effects of low FMC to crown fire potential of using Van Wagner's (1977) crown fire model to predict crown fire ignition with these values; and (3) to investigate the potential of using 10 hour fuel moisture data obtained from remote automated weather station (RAWS) to predict the FMC of dead tanoak leaves.

Methods

Foliar Moisture

In March 2008, we began tracking FMC for live tanoak leaves (uninfected), live *P. ramorum*-infected tanoak leaves, dead tanoak leaves, and surface leaf litter. Individual tanoak trees were selected in an area of known *P. ramorum* infestation on Cal Fire Eel River Camp and adjacent properties near Redway, California (40° 08' 29.12" N, 123° 49' 29.80" W) where SOD has been known to exist since 2004 (Y. Valachovic, Humboldt County Cooperative Extension Agent, University of California, personal communication, 2007). A total of 25 tanoak trees (eight live uninfected tanoaks, 10 live *P. ramorum* infected tanoaks, and seven standing dead tanoaks with leaves on) were selected for monthly sampling. Each sample tree was sampled each month for 12 months (March 2008 to February 2009). All foliar samples were removed from the lower 1/3 of the canopy on the south aspect of each tree (Agee and others 2002) between 1300 and 1600 hours to minimize possible diurnal variation (Philpot 1965). Collected foliage was sealed in polyethylene bags, weighed wet, then oven-dried at 70 °C until no further weight loss was evident (typically 48 hours).

Data were analyzed across three categories of infection (non-infected, infected, and dead) using repeated measures ANOVA. Additionally, surface litter moisture was compared to dead leaf moisture for each month. For each collection date, the moisture content of each category was compared using Tukey-Kramer post-hoc means separation. All statistical tests held the α level of 0.05.

Crown Ignition

Critical crown base height (CBH_t) for tanoak was calculated using a reformulation of Van Wagner's canopy ignition equation:

$$CBH_t = [FLI(1/1.5)] / [(0.010)(460+26*FMC)]$$

where: CBH_t is the crown base height (in meters) below which ignition is probable given a predicted flame length. Values of FMC were derived from the sample data collected. We used flame lengths of 0.5, 1, and 2 m based on fuel loading and resultant fire behavior typical of these forests.

RAWS Data

The relationship between data from local RAWS 10-hour fuel moisture and dead leaf moisture (FMC_{dead}) was examined using data from the RAWS unit at the Cal Fire Eel River Camp, located less than 1 km from all dead tanoak sample trees. RAWS 10-hour fuel moistures were averaged for four different time periods starting at 1200 hours. Linear regression analysis was used to verify the most significant window of time during the day as a predictor of FMC_{dead}. The response variable (FMC_{dead}) was transformed using natural log to normalize the residuals.

Results

FMC Across Tanoak Infection Status

The FMC values differed significantly among the three categories of uninfected, infected, and dead trees ($P < 0.01$). The 1-year mean FMC for uninfected tanoak leaves was 82.3 percent (SE = 1.5 percent) with a range from 79.5 percent in May to 86.7 percent in December. The FMC of the *P. ramorum*-infected tanoaks maintained a lower average of 77.8 percent (SE = 1.3 percent; $P = 0.04$) across the sampling period with a range from 72.7 percent in September to 83.0 percent in December. The FMC of dead leaves was significantly lower than both uninfected and infected leaves for all months with a mean of 12.6 percent across the 12-month sampling period (SE = 1.4 percent, $P < 0.01$; fig. 1).

Surface Litter

Fuel moisture of surface leaf litter varied significantly among months with a high of 40.3 percent in December to a low of 7.1 percent in July ($P < 0.01$). Across the year, leaf litter moisture was significantly different than dead leaf FMC; however, in fire season months (June to September), there was no significant difference between dead leaf FMC and surface litter ($P = 0.44$; fig. 2).

CBH_t

These low values of FMC in *P. ramorum*-killed tanoaks resulted in dramatic changes in CBH_t (fig. 3). Critical crown base height rises radically below an FMC of 70 percent. For example, given a 1 m flame length, CBH_t for an FMC of 80 percent is 1.6 m. As FMC drops to 5 percent, the CBH_t increases to 6.9 m. Note that for values below 70 percent FMC, a transition zone is included showing an assumed error of ± 5 percent sequentially for every 10 percent decrease in FMC.

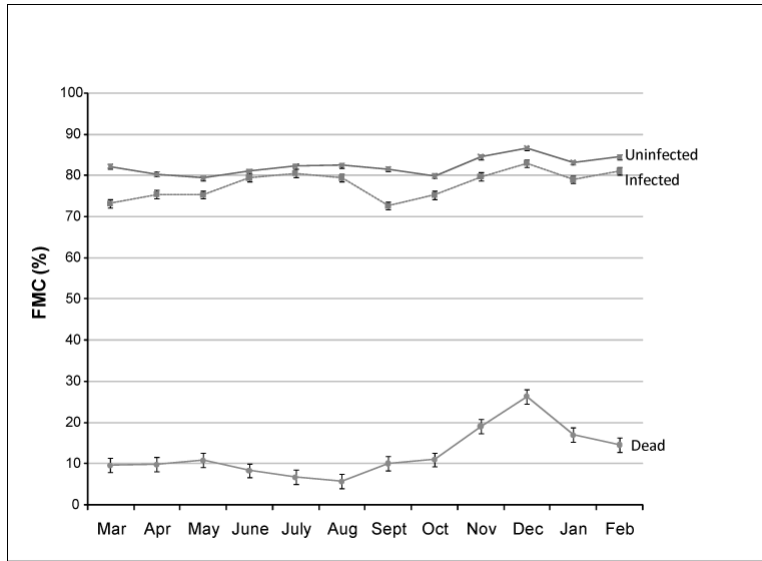


Figure 1—Monthly leaf moisture of Eel River Camp tanoaks across three categories of infection status: Uninfected, *P. ramorum*-infected, and Dead. Mean FMC of *P. ramorum*-infected and non-infected tanoaks did not differ more than 10 percent for the 12-month sampling period. Mean FMC of dead tanoaks was significantly lower than infected and non-infected groups (SE = 1.4 percent, $P < 0.01$).

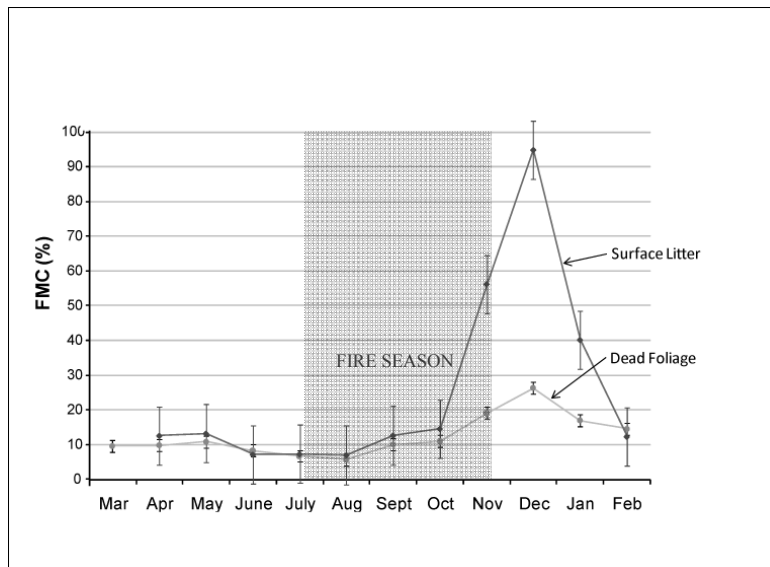


Figure 2—Monthly dead leaf moisture of tanoaks and surface litter moisture of Eel River Camp tanoaks. Months June through September show no significant difference in moisture content (SE = 0.6; $P = 0.44$).

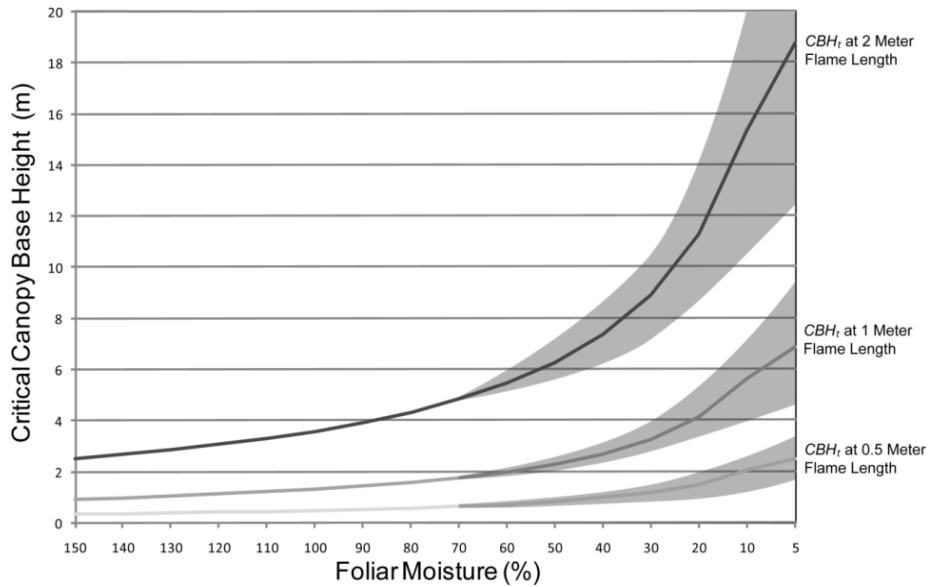


Figure 3—Critical crown base height (CBH_t) rises radically below a foliar moisture of 70 percent. The shaded area around the CBH_t less than 70 percent indicates a zone of assumed error due to lack of empirical data for these observed low FMC values.

10-Hour RAWS Fuel Comparison

A strong relationship appears to exist between RAWS 10-hour fuel moisture and daily FMC_{dead}. Using a time period between 1600 to 2300 hours was highly correlated with FMC (R = 0.88, P < 0.01; fig. 4).

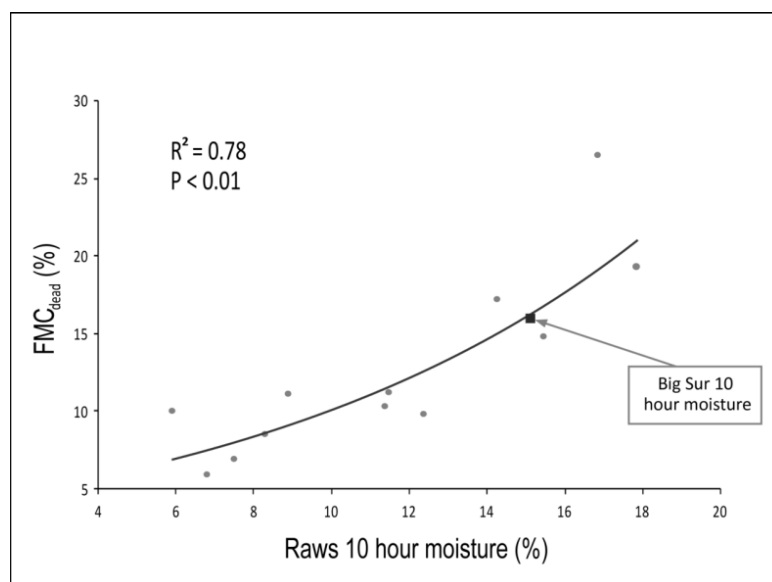


Figure 4—Relationship linking RAWs 10-hour moisture (average from 1600 to 2300 hours) and dead leaf FMC. The equation of the line shown is: $\ln \text{Dead Leaf FMC percent} = (1.3486) + (0.0955) \text{ RAWs 10-hour moisture percent}$.

Discussion

In this study, trees suffering from *P. ramorum* did not show a significant drop in FMC in the early infection stage. Throughout the sampling period, FMC remained almost unchanged, with ranges of ± 2 percent in uninfected leaves and ± 4 percent in infected leaves. The largest difference among the three infection categories was between the foliage of the dead trees and the leaves of uninfected/infected categories. Mean dead leaf FMC levels dropped as summer (fire season) progressed, allowing moisture to drop below 6 percent in August. Surface litter moisture beneath these same trees was only slightly higher than dead leaf FMC, averaging 7 percent moisture during the mid-summer months.

In current modeling of crown fire potential, the FMC range for most North American trees is between 75 percent and 250 percent. Values below 70 percent have not been reported. Extremely low FMC values, such as those found in the dead tanoak, exceed the range of data that generated Van Wagner's (1977) model. With FMC values approaching 5 percent, a "transition zone" is implied, since empirical data do not exist to verify this relationship. In this study we assumed a sequential error of ± 5 percent for every 10 percent decrease in FMC below 70 percent. Future work will investigate the relationship of extremely low foliar moisture and CBH_t .

The relationship between RAWs 10-hour fuel moisture and FMC_{dead} is encouraging in that RAWs data may be a possible indicator of FMC of dead leaves. Due to the inherent lag of 10-hour fuel moisture, these values are capturing what has already transpired earlier in the day. This technique could be applied to evaluate an overall trend in foliar moisture pattern in dead tanoaks. More sample data are needed to verify the power of this relationship. It is interesting to note that samples take in the Basin Complex Fire (Big Sur, California, 2008) fit well on the prediction line (fig. 4).

On-going work will link increases in surface fuel loads generated by SOD (Moritz and others 2008; Valachovic and others, these proceedings) to coincident changes in canopy fuels. Results from this research will not only aid the decision support process for fire managers in SOD-affected areas, but may also be applicable to conditions in other ecosystems where diseases and insect epidemics have set up forests for future conflagrations.

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