STATE OF CALIFORNIA–THE NATURAL RESOURCES AGENCY

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EFFECTIVENESS MONITORING COMMITTEE

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Effectiveness Monitoring Committee
Completed Research Assessment

EMC Members: Jessica Leonard (CA State Water Board), Ben Waitman (CA Dept. of Fish and Wildlife)

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1. **Fulfills and addresses scientific question(s) posed in proposed research? If no, request revisions.**

   A. Does the study inform the intended rule, numeric target, performance target, or resource objective?

   If Yes, go to the next question. If No, provide a short explanation on the purpose of the study.

   B. Does the study inform the Forest Practices Rules?

   If Yes, describe briefly what rules, guidelines, key questions, critical question, resource objectives, performance targets, etc. the study informs, preferably in bulleted format. If No, provide a short explanation on the purpose of the study.

The study informs the resource objective identified in the proposal, management of Heterobasidion root disease (Heterobasidion) expansion post-harvest and decades after harvest in timberlands. The study does not directly inform specific Forest Practice Rules (FPRs). However, the results of the study further the intent of forest management outlined in the FPRs (FPR Section 897 (1)), and the intent of an exemption of the requirement to prepare a harvest plan for the limited removal of dead, dying, and diseased trees (FPR Section 1038(b)) by evaluating methods to control disease of commercially important species and documenting the spread of disease in managed timber stands.

The study proposal contained multiple goals informing the management of Heterobasidion infection in true fir (*Abies sp.*) stands. Heterobasidion is a complex of fungal species that can occur as a parasite on healthy trees and a saprophyte on dead stumps and roots, causing root and butt rot in conifers. True fir species, red fir (*Abies magnifica)* and white fir (*Abies concolor*) in California, are susceptible to *Heterobasidion occidentale* infection while other commercially important species such as Ponderosa pine are susceptible to other species of Heterobasidion.

Infection can cause reduced vigor and mortality as trees mature. Timberlands are particularly susceptible to Heterobasidion infection due to the presence of stumps that can serve as persistent sources of infection through spore dispersal and root to root contact. The study's goals included evaluation of the effectiveness of post-harvest chemical and biological control methods to reduce infection, evaluation of the role of mechanical wounding in post-harvest Heterobasidion infection and beetle attack, and to estimate the stand level biomass that might be conserved using post-harvest treatments.

The study was successful in evaluating chemical and biological stump treatments for efficacy in mitigating Heterobasidion infection in stumps post-harvest. The study was not able to completely address the objectives laid out in the proposal to the EMC, largely due to an unexplained Heterobasidion colonization failure in the field and low prevalence of beetle infestation.

In addition, the study provided valuable information on the prevalence, long-term (45-60 years) rate of spread, and stand level effects of Heterobasidion infection on community composition in true fir (*Abies* sp.) and mixed conifer stands at several eastern California sites.

2. **Scientifically sound? If no, request revisions.**

   Was the study carried out pursuant to valid scientific protocols (i.e., study design, statistical analysis, peer review)?

Yes, the study made use of long-term monitoring plots with a documented history of Heterobasidion infection and used established methods for detection. Each experiment was replicated and included appropriate experimental controls. Field studies were paired with laboratory studies to evaluate the efficacy of experimental treatments where appropriate. Statistical analyses were appropriate to the data. The studies also followed survey and analysis methods that have yielded robust results in previous work (Slaughter and Rizzo 199, Rizzo et al. 2000, Rizzo and Slaughter 2001). In addition, one publication resulting from this work has been published in a peer-reviewed journal (Poloni et al. 2021) and at least two additional manuscripts are in preparation for publications and will follow the peer-review process.

3. **Scalable?**

   What does the study tell us? What does the study not tell us? Do findings apply to other areas of the State?

   Describe in detail the study and its relationship to rules, guidance, and targets. Consider technical findings; study limitations; and implications to rules, guidance, resource objectives, functional objectives, and performance targets; in addition to other information.

The study consisted of two separate efforts evaluating Heterobasidion control treatments at the time of harvest and the long-term results of infection on forest stands after harvest. First, an experimental study evaluated the efficacy of post-harvest stump treatments in preventing or reducing Heterobasidion colonization in the stumps of recently cut white fir in field and laboratory trials. This study evaluated the efficacy of borate, urea, and two strains of *Phlebiopsis gigantea* (*Phlebiopsis*) in reducing the occurrence of Heterobasidion in cut stumps one year after harvest.

Phlebiopsis is a soil-dwelling fungus that can occur as a saprophyte on cut stumps and can outcompete Heterobasidion for substrates. *Phlebiopsis* is used commercially in European timber operations to mitigate Heterobasidion infection in cut stumps (Oliva et al 2017, Pellicciaro et al 2021), but local strains had not yet been isolated for use or evaluated for efficacy in the Mediterranean climate of the Western United States.

Field studies confirmed that cut stump treatments of borate and urea were both effective at reducing the probability of recovering Heterobasidion on stumps a year after harvest (Figure 1). In addition, all treatments were effective in significantly reducing the area within a stump colonized by Heterobasidion (Figure 1).

A novel aspect of this study was the use of two local isolates of *Phlebiopsis*. While *Phlebiopsis* application was less effective at preventing initial Heterobasidion infection, it was effective in reducing the magnitude of Heterobasidion colonization. This, potentially lower cost treatment, is effective in European timber operations (Blomquist et al. 2020), can be applied directly to equipment in bar oil, and may have longer lasting effects than single chemical applications due to persistence on cut stumps. These results suggest promise for *Phlebiopsis* use in timber operations in Western North America.

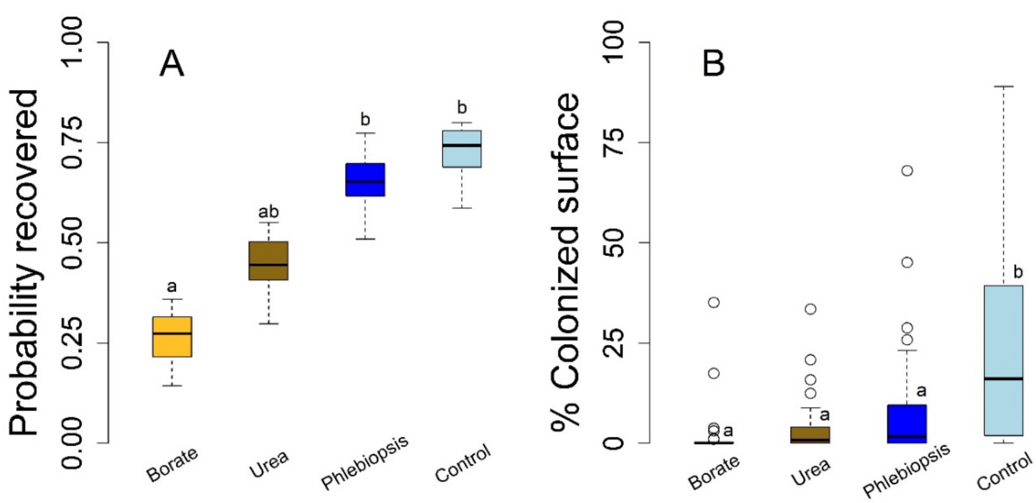

Figure 1. Reproduced from Poloni et al 2021. Box and whisker plots of *Heterobasidion occidentale* treatments to control pathogen establishment on *Abies concolor* stumps with the probability of pathogen recovery on a per-stump basis (pathogen colonization or infection, **A**) and the proportion of sample disc area that was colonized by *H. occidentale* (5cm depth), B) Infection probabilities were predicted values from a mixed general linear model (AUC = 0.725. Letters indicate statistically significant Dunnett's pairwise contracts (P≤0.05)

A separate study (Cobb et al. *in. prep*) made use of long-term data sets to evaluate the persistence and spread of Heterobasidion at three forest types in the Sierra Nevada and Cascade Ranges. The authors visited sites that had been surveyed for Heterobasidion infected trees for over 45 years in three disease systems: mixed conifer stands in the relatively wet Yosemite Valley (19 plots), mixed conifer stands in the dryer east side of the Sierra Nevada (19 plots spanning an area from Modoc to Inyo County), and true fir dominated stands in the Sierra Nevada (26 plots within the Stanislaus and El Dorado National Forests). Research plots had been subject to a variety of silvicultural treatments prior to surveys.

The authors revisited stands initially surveyed from 1965-1972 and most recently surveyed in 2019 or 2020 to determine the spatial extent (gap size) of Heterobasidion infection. All trees within disease centers (gaps) were mapped and surveyed for signs of Heterobasidion. Tissue from highly symptomatic trees were cultured to confirm infection. Surveys were conducted between 5 and 12 years after an initial gap expansion period, and all trees within 2-5 meters of the previous mapped infection boundary were surveyed at each time period. This study found that rates of Heterobasidion gap expansion slowed considerably after 10 years of active host mortality (Figure 2.) Disease severity, the proportion of basal area killed by Heterobasidion infection, was not correlated to gap size or expansion rate. In addition, the total area of the gap expansion was best predicted by the early rate of gap expansion (first 5-10 years of surveys) (Figure 2). The study did not find correlations between disease severity and either host density, tree size, spatial arrangement, or conditions which determined initial inoculum levels. As there was not a correlation between gap size and disease severity, the study concluded that early gap expansion rate may be the most useful predictor for gap size and in turn total basal area killed.

In this study, the initial rate of Heterobasidion gap expansion correlated well with both the extent and severity of tree loss to disease in true fir stands, giving further weight to the value of preventive methods that limit colonization after harvest.

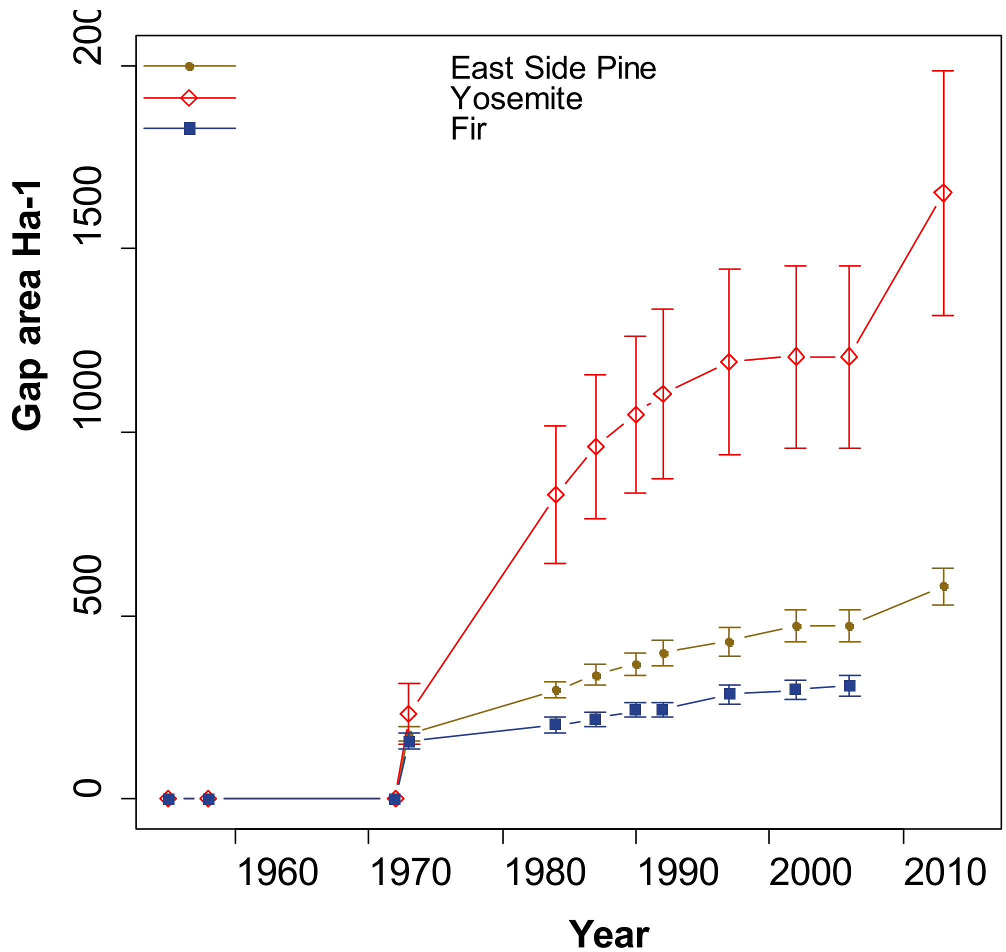

Figure 2. Data reproduced from a draft manuscript in preparation (R. Cobb): Gap areas over time for three forest types impacted by Heterobasidion. Each forest type had a rapid initial period of gap expansion within the first decade after harvest and reduced expansion rate after ~10 years of gap expansion.

A third study (Florez and Cobb, *in prep.*), conducted by a graduate student at CAL Poly San Luis Obispo, used the same long-term monitoring plots and data sets in the Sierra Nevada sites to quantify changes to stand species composition and canopy dominance due to Heterobasidion related mortality. This study used repeated measurements of tree species identity, diameter at breast height, and presence of disease for all trees within disease centers collected in repeat surveys initiated in 1965. The study found that infection by Heterobasidion reduced total basal area in all infected forest types. Heterobasidion related mortality generally reduced the relative dominance of host tree species as compared to non-host tree species. In pine-dominated and mixed conifer forests, mortality from Heterobasidion resulted in a loss of basal area, but did not result in a change in the relative dominance of tree species (Figure 3). Conversely, in fir dominant stands infected by *Heterobasidion occidentale,* a fungal species pathogenic affecting fir, infection caused a decrease in fir canopy cover and dominance. Incense cedar, a species resistant to *H. occidentale*, increased in abundance relative to susceptible fir species (Figure 3). Incense cedar is increasing in relative abundance across the Sierra Nevada (Knapp et al. 2013, Restaino et al. 2019) with multiple potential causes. This study shows that Heterobasidion infection may also play a role in the increasing abundance of incense cedar where *Heterobasidion occidentale* is present.

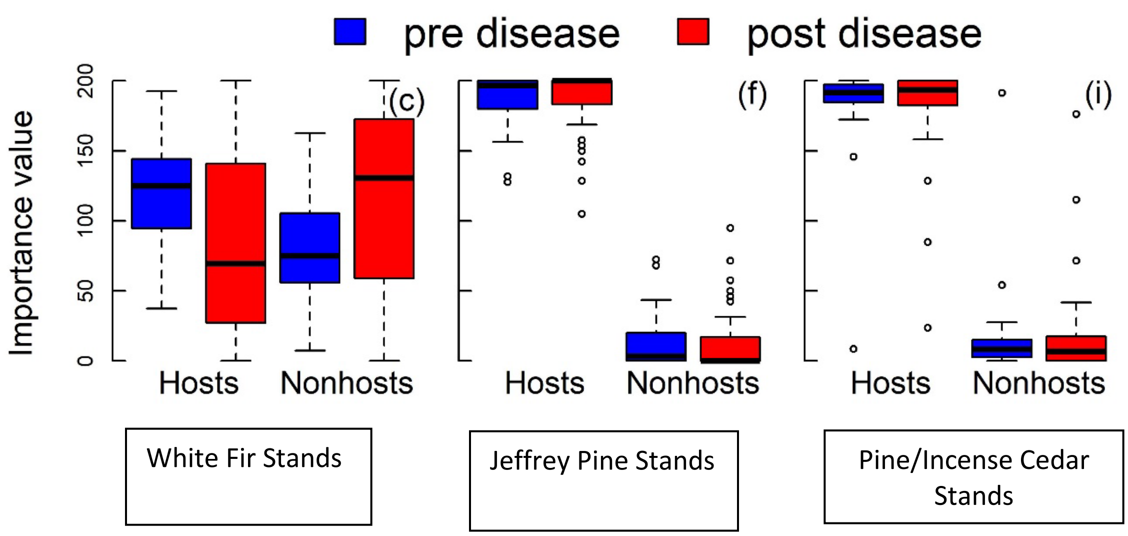

Figure 3. Preliminary data reproduced from a draft manuscript in preparation (R. Cobb): Relative changes in importance value over at least 45 years in Heterobasidion infected stands in the Sierra Nevada contrasted between hosts and non-hosts in three epidemiological systems: single host *Heterobasidion occidentale* (c), single host *Heterobasidion irregulare* (f), and multi-host *H. irregulare* (i). The three systems correspond with white fir (c), Jeffrey pine (f), and incense cedar – ponderosa pine dominated forests (i).

The findings of these studies are likely scalable across the state. The experimental evaluation of stump treatments took place at Blodgett Research Station in the Central Sierra Nevada, but similar results of the efficacy of borate, urea, and *Phlebiopsis* have been confirmed in European forests with diverse climates. The studies documenting the long-term expansion of Heterobasidion disease centers and stand level effects are likely applicable across the Sierra Nevada. The study sites for these observational studies included sites with a range of climatic variables typical of Sierra Nevada forests. However, mortality rates, gap expansion rates, and effects on stand species composition may differ in forests in the coast range or other wetter portions of the state due to differences in climate, nutrient availability, or other factors known to affect fungal growth.

1. **New EMC study recommended to advance research on this topic (e.g., to expand findings and/or temporal or spatial relevance of this study)?**

   A. **Literature review sufficient?**

Yes. The literature review identified in the published and draft manuscripts resulting from these studies was appropriate for their topics and scope. These studies expanded on the work of studies conducted decades ago (Slaughter and Rizzo 1999, Slaughter and Parmeter 1995) and the literature review highlights work conducted in California in addition to relevant published works from managed European forest ecosystems.

B. Recommend funding new EMC study on this topic (e.g., extend temporal or spatial scope, or scope of study in some other way)?

No. At this time additional funding is not required to complete these studies. Future work that builds on the findings of this work could include confirmation and further development of *Phlebiopsis* as a method to prevent Heterobasidion expansion, additional evaluation of harvest practices and their risk in spreading Heterobasidion inoculum, and additional studies on the prevalence of root disease resulting from common harvest treatments.

C. What is the relationship between this study and any others that may be planned, underway, or recently completed?

Factors to consider in answering this question include, but are not limited to:

i. Feasibility of obtaining more information to better inform policy about resource effects.

Dr. Cobb is currently planning on additional studies of Heterobasidion using the network of sites from these studies. A portion of the sites were burned in the Dixie Fire (2021), and Dr. Cobb is planning to resample these sites to evaluate the relationship between Heterobasidion influenced fuel conditions in disease centers and fire severity.

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