STATE OF CALIFORNIA~~-~~THE NATURAL RESOURCES AGENCY

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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.

Yes, the study informs the resource objective identified in the proposal, management of *Heterobasidion* expansion post-harvest and decades after harvest in timberlands.

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 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 *Heterobasidion* 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 *Heterobasidion* 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 known history of *Heterobasidion* infection and established methods for detection. Each experiment was replicated and included appropriate 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 methods that have yielded robust results in previous work. In addition, one publication resulting from this work has been published in a peer-reviewed journal 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 several separate efforts addressing two conceptual areas. First, an experimental study evaluated the efficacy of post-harvest stump treatments in preventing or reducing *Heterobasidion* infection 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*.

Phlebiopsis is a common soil-dwelling fungus that can occur as a saprophyte on cut stumps and can outcompete *Heterobasidion* for stump substrates. *Phlebiopsis* is used commercially in Europe to mitigate *Heterobasidion* infection in cut stumps (Oliva et al 2017, Pellicciaro et al 2021), but local strains had not previously 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* a year after harvest (Figure 1). In addition, all treatments were effective in significantly reducing the area of stumps 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 Western North America.

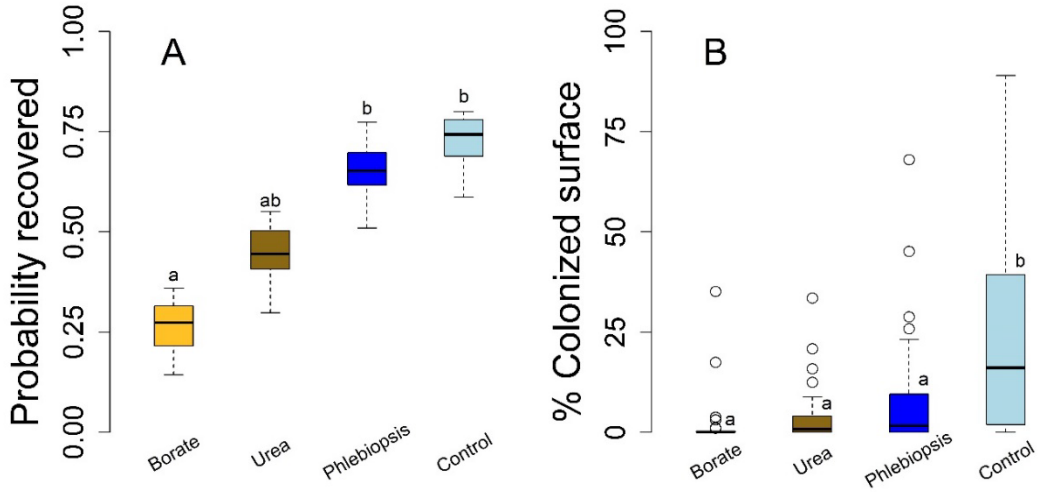

Figure 1. Reproduced from Poloni et al 2021. Box and whisker plots of *Heterobasidion occidentale* treatments to control pathogen establishment on *Abies concolor* stumps with the probability of pathogen recovery on a per-stump basis (pathogen colonization or infection, **A**) and the proportion of sample 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 made use of long-term data sets to evaluate the persistence and spread of *Heterobasidion* in several locations in the Sierra Nevada and Cascade Ranges. The authors visited sites that had been surveyed for *Heterobasidion* infection extent and severity for over 45 years in three disease systems: mixed conifer stands in the relatively wet Yosemite Valley, mixed conifer stands in the dryer east side of the Sierra Nevada (spanning an area from Modoc to Inyo County), and true fir dominated stands in the Sierra Nevada (within the Stanislaus and El Dorado National Forests). Stands evaluated 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 from 2019-2020 to determine the spatial extent (or gap size) of *Heterobasidion* infection. This study found that rates of *Heterobasidion* 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 *Heterobasidion* gap expansion was best predicted by the early rate of infection (first 5-10 years) (Figure 2). 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* expansion correlated well with both the extent and severity of tree loss to *Heterobasidion* in true fir, giving further weight to the value of preventive methods that limit colonization after harvest.

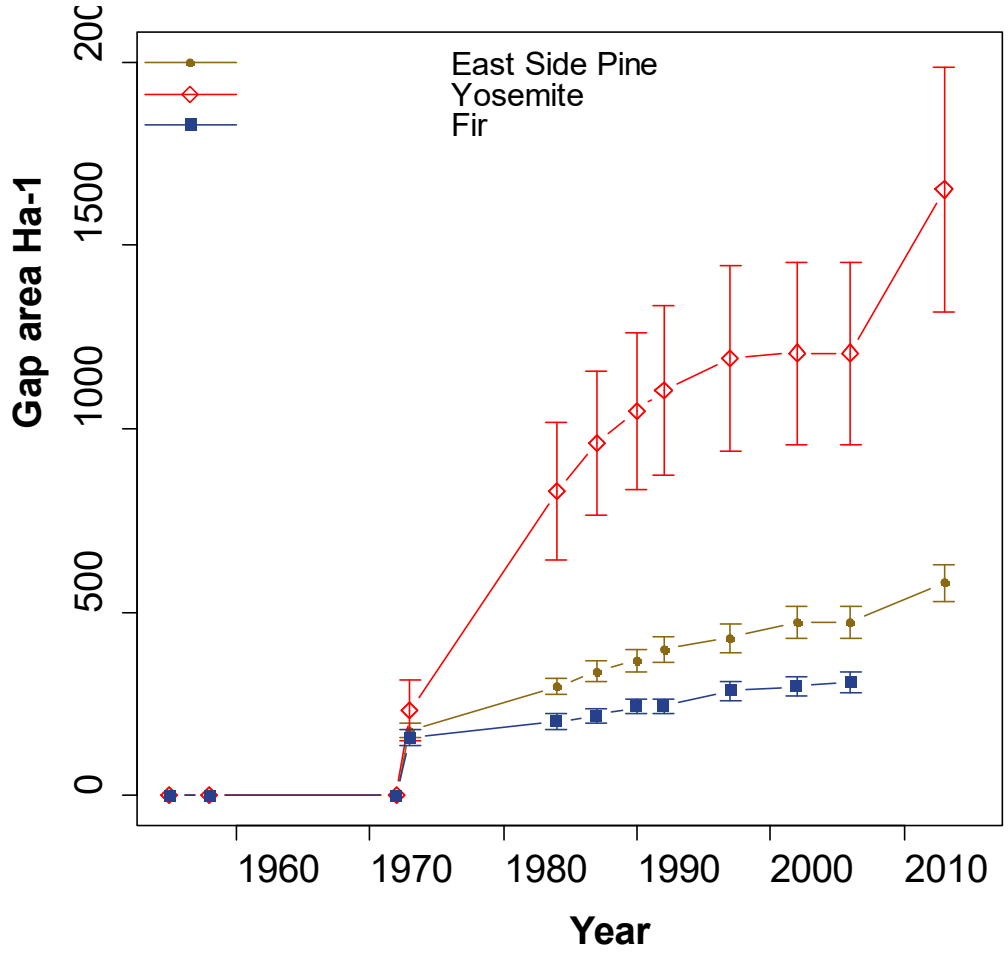

Figure 2. Preliminary data reproduced from a draft manuscript in preparation (R. Cobb): Gap areas over time for three forest types impacted by Heterobasidion. Each forest type had a rapid initial period of gap expansion within the first decade after harvest and and reduced expansion rate afterward.

A third study, conducted by a graduate student at CAL Poly San Luis Obispo, used some of the same long-term monitoring plots and data sets in the Sierra Nevada to quantify changes to stand species composition and canopy dominance due to *Heterobasidion* related mortality. The study found that infection by *Heterobasidion* reduced total basal area in all infected forest types. *Heterobasidion* related mortality 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 *Heterobasidion occidentale,* a fungal species pathogenic in 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.

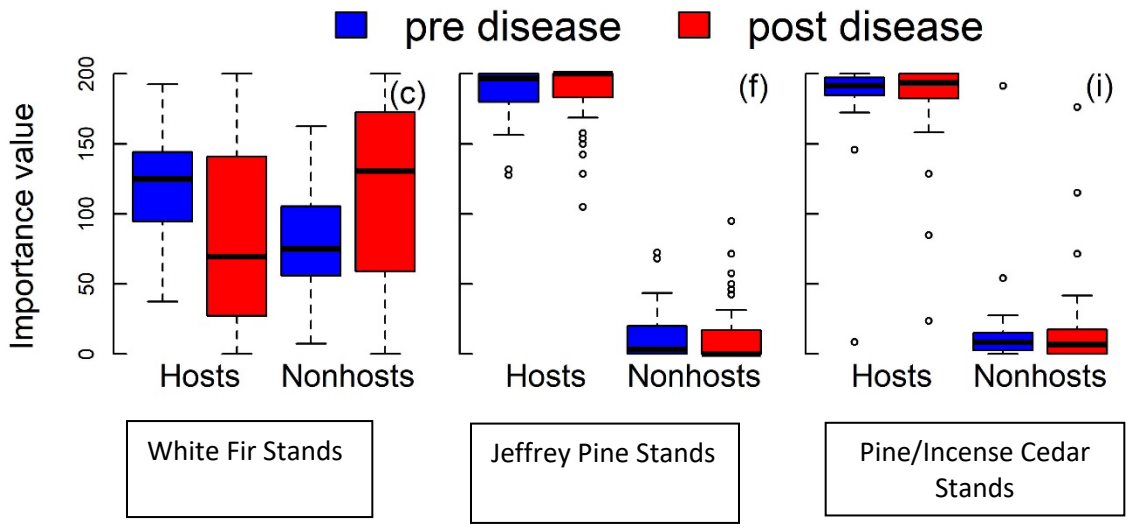

Figure 3. Preliminary data reproduced from a draft manuscript in preparation (R. Cobb): Relative changes in importance value over at least 45 years in *Heterobasidion* infected stands in the Sierra Nevada contrasted between hosts and non-hosts in three epidemiological systems: single host Heterobasidion 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 where *Heterobasidion* occurs 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 *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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