Spatial distribution and impacts of *Phytophthora ramorum* and Sudden Oak Death in Point Reyes National Seashore

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EXECUTIVE SUMMARY

Sudden oak death (SOD), an emerging disease caused by the non-native pathogen *Phytophthora ramorum*, is currently impacting Point Reyes National Seashore (PRNS) and the North District of Golden Gate National Recreation Area (GGNRA-n). In order to assess this dynamic situation, a multifaceted research project was initiated in the spring of 2007. The first two phases were completed as of the fall of 2007, and the results are presented in this document. Phase 1 examined the current distribution of *P. ramorum* within PRNS and GGNRA-n, while Phase 2 focused on the impacts of SOD-induced tanoak mortality, with respect to vegetation dynamics and fuel loading.

Phase 1

Phase one consisted of rapid plot-based assessment, stream baiting, and foliar sampling for the pathogen *Phytophthora ramorum* across susceptible vegetation within PRNS and GGNRA-n. Plot measurements were taken at 48 locations within the following three major vegetation types: Redwood-tanoak (RDW), Douglas-fir (DGF) and California bay-coast live oak (CLO). Stream baiting was performed at seven perennial creeks within PRNS. Foliar samples were taken at 74 locations within PRNS. The following are the major findings of Phase 1.

- Of the 74 different foliar sample locations, 29 (39%) tested positive for *P. ramorum*. The pathogen was found in all three major vegetation types sampled. Results were consistent with prior opportunistic testing done by the NPS and park volunteers. Centers of infection appear to be Bolinas Ridge, Bear Valley/Limantour Road, and Five Brooks areas.
- If we infer from the proportions of our randomly located plots that tested positive for infection, as much as 63% of RDW forests, 45% of CLO forests, and 24% of DGF forests may be infected with *P. ramorum*.
- In terms of susceptible species, 15 plots (31%) had some component of tanoak, while 17 plots (35%) contained some coast live oak.
- Positive tests for *P. ramorum* did not appear to be correlated with slope, aspect, elevation or broad cover classes of vegetation. We were able to predict infection with some accuracy using a five-point "likelihood of infection" rating.
- Baiting of perennial streams west of the crest of Inverness Ridge all resulted in negative tests for *P. ramorum* infection. Results may have been influenced by a relatively dry preceding winter and spring.
- Patchiness of the disease was on the order of tens to hundreds of meters in forests with a tanoak component, suggesting the use of "paired" plots for Phase 2. Proportions of tanoak (by basal area) varied as well, suggesting the use of maxima and minima of tanoak basal area for Phase 2, in order to effectively compare plots.

Phase 2

Phase two consisted of an intensive plot-based measurement scheme within forests containing tanoak (*Lithocarpus densiflorus*). The primary objectives of Phase 2 were to detect short-term effects and predict long-term impacts of SOD-induced tanoak mortality within redwood and Douglas-fir forests within PRNS and GGNRA-n. The following major findings do not apply to all redwood and Douglas-fir forests within PRNS and GGRNA-n, but rather only to areas with a considerable tanoak component.

- Tanoak comprises an average of one third of total basal area within our redwood and Douglas-fir plots. If all tanoak trees eventually succumb to SOD, a substantial proportion of total basal area will be lost.
- In several plots, tanoak mortality is greater than 95% by basal area. Our protocol systematically excluded the most severely impacted areas of the park and thus it is entirely possible that tanoak mortality has reached 100% in some locales.
- Disease progression appears to be more advanced in the redwood forests of Bolinas Ridge (GGNRA-n) than in the Douglas-fir forests of Inverness Ridge (PRNS).
- Total canopy cover is reduced in our diseased redwood plots, as compared to healthy redwood plots, and a regenerative response is evident. Such relationships are not yet apparent in our Douglas-fir plots.
- Our data suggest that as tanoak declines in SOD-infested areas, it will be replaced primarily by redwood in redwood forests, and primarily by California bay in Douglas-fir forests. However, because a full regenerative response has not yet occurred, this finding should be regarded as preliminary.
- Tanoak regeneration is currently dwarfing regeneration by all other species in both healthy and diseased plots. However, research by others suggests that tanoak is unlikely to survive to maturity in areas infested with SOD.
- Tanoak represents a substantial proportion of tree species richness and total woody species richness in both redwood and Douglas-fir forests. In our redwood plots, which are species-poor in comparison to our Douglas-fir plots, tanoak accounts for an average of one third of tree species richness and one fifth of total woody species richness. If tanoak is eventually eliminated by SOD, the species richness of redwood forests will be severely reduced.
- Douglas-fir plots exhibit, on average, a greater number of broadleaf tree species than redwood plots. As such, the loss of tanoak will impact the functional diversity of redwood forests more than that of Douglas-fir forests.
- We have not found evidence that SOD-induced tanoak mortality has increased the threat of exotic plant invasion. However, as disease progression continues, opportunities for invasion may increase and therefore we do not recommend dismissing this threat.
- Mean total fuel loading (1, 10, 100, and 1000 hour fuels, litter and duff) for all transects was not different between healthy redwood and healthy Douglas-fir plots. It was greater in diseased redwood plots than in healthy redwood plots. Total fuel loading was greater in healthy Douglas fir plots than in diseased Douglas-fir plots. Much of the variation in fuel weights can be accounted for by variation in 1000 hour fuels and duff. In terms of fire hazard, SOD may be impacting redwood-tanoak forests by increasing 1000 hour fuels.

The threat of sudden oak death in PRNS and GGNRA-n is apparent, but the ultimate severity and precise nature of the impacts are yet to be known. Continued monitoring of disease location, progression, and impacts is highly recommended.

Table of Contents

INTRODUCTION

Sudden oak death (SOD), an emerging disease caused by the non-native pathogen *Phytophthora ramorum*, is currently impacting Point Reyes National Seashore (PRNS) and the North District of Golden Gate National Recreation Area (GGNRA-n). The research described below represents the first two phases of a project designed to assess interactions between SOD and fire in these areas. These phases are broadly aimed at assessing the current distribution of *P. ramorum* (Phase 1), and examining the current and long-term impacts of SOD-induced tree mortality (Phase 2), within PRNS and GGNRA-n.

The widespread decline of SOD affected species such as tanoak (*Lithocarpus densiflorus*) and coast live oak (*Quercus agrifolia*), will almost certainly result in both short- and long-term ecological impacts. A significant decrease in acorn production is likely to affect native animal species that feed upon acorns, as well as to cascade up the food chain to keystone species such as the northern spotted owl (Courtney et al. 2004). Decline of tanoak and coast live oak may also lead to serious structural changes and the loss of crucial wildlife habitat. Major reductions in the populations of common tree species could facilitate the establishment of exotic plants that were previously unable to compete, as well as trigger shifts in native plant communities. Widespread mortality and short-term increases in fuel loads may also affect the frequency and/or severity of fire or other disturbances, and could even lead to alternative stable states. In addition, several recent publications have suggested the possibility of accelerated erosion and nutrient depletion, invasion by exotic animals and microorganisms, and disruption of mycorrhizal networks (Rizzo et al. 2005). Finally, large numbers of highly visible dead trees may have a negative aesthetic impact on the landscapes of PRNS and GGNRA-n.

In this report, we first provide broad geographic information on which areas of PRNS and GGNRA-n were infested with *P. ramorum* as of the summer of 2007, while relating pathogen presence to vegetation type. Second, we present specific findings on the current effects of SOD-induced tanoak mortality, as well as predictions of long-term impacts, with a particular focus on vegetation characteristics and fire hazards. While many native tree species are affected by the disease, we focus on tanoak because it is common in the coniferous forests of PRNS and GGNRA-n, and it is the most severely impacted species (Rizzo et al. 2005). It is our hope that our examination of pathogen distribution, vegetation dynamics, and fire hazard will serve to prioritize protective, restorative and/or ameliorative efforts and help to minimize the ecological impacts of SOD.

Study Area

Point Reyes National Seashore (PRNS) is located on the California coast approximately 40 miles north of San Francisco (Figure A). The National Park Service administers both Seashore lands and the North District of the Golden Gate National Recreation Area (GGNRA-n) as one unit, hereafter referred to collectively as PRNS or the Seashore. The 35,631 hectare (88,046 acre) Point Reyes peninsula makes up most of the area of the Seashore. Other major geologic features include Inverness Ridge to the west and Bolinas Ridge to the east, which both run northwest to southeast and are separated by the San Andreas Fault. The Seashore straddles the fault, which is the boundary between the Pacific and North American tectonic plates. Major vegetation types of PRNS include mixed evergreen, bishop pine, Douglas-fir, and redwood forests, coastal scrub, and California annual grasslands. Grazing for dairy and beef production, an historic land use, still occurs on portions of the Seashore. Climate at PRNS is Mediterranean in character, with dry summers and cool wet winters, and a significant fog-marine influence. Temperatures range approximately from 5-25° C (low 40's to mid 70's F) in the summer months, and from 3-18° C (high 30's to mid 60's F) in winter months. Average annual precipitation ranges from 51 cm (20 in) near the coast to as much as 102 cm (40 in) near the Bear Valley visitor center, with additional precipitation provided by fog drip.

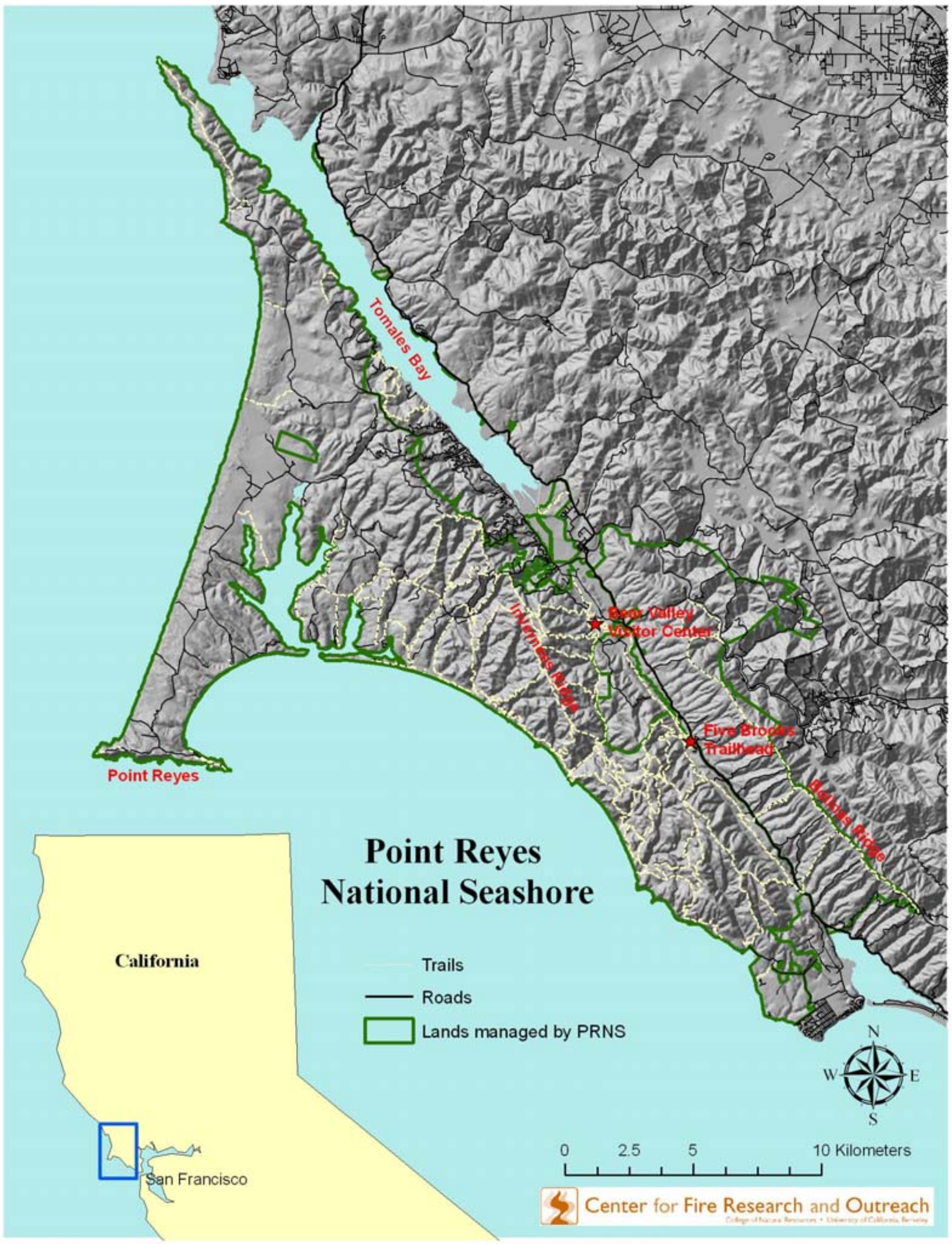

Figure A: Point Reyes National Seashore and vicinity.

CHAPTER 1

Rapid Assessment of *Phytophthora ramorum* and Sudden Oak Death

at Point Reyes National Seashore and the North District of the Golden Gate National Recreation Area

Tadashi Moody, Benjamin Ramage, Max Moritz

INTRODUCTION

It is not known when *P. ramorum* infections first occurred at PRNS. However it appears that while Marin County is geographically at the epicenter of this disease, PRNS was affected somewhat later than other heavily impacted areas, such as China Camp State Park in San Rafael, CA where dying tanoaks were first noticed in the mid-1990's. It wasn't until 2004 that the first symptomatic trees were observed at PRNS. These trees, which were located on Bolinas Ridge, were tested by UC Davis researchers and the presence of *P. ramorum* was confirmed. PRNS staff conducted opportunistic sampling of SOD susceptible species for presence of *P. ramorum* in 2005 and 2006. This sampling effort was centered primarily along trails within California bay/tanoak habitat and led to the detection of *P. ramorum* in the vicinity of the Bear Valley Visitor Center, Five Brooks trailhead, and along the Randall, McCurdy, and Teixeira trails (see Appendix III for detailed map of prior sampling efforts). However, prior to this study, no systematic survey for *P. ramorum* had been undertaken within the Seashore.

Objectives

The objectives of the rapid assessment phase of the project were several-fold. First, we wanted to determine the spatial distribution of SOD infestation within the Seashore and to establish better coverage of testing than had been achieved by opportunistic sampling in the past. We chose random locations within our sampling strata to facilitate valid statistical analyses of these samples. Second, we wanted to gather information on basic environmental variables that may or may not be related to SOD presence or absence. Third, we wanted to generally examine variability of vegetation characteristics within SOD susceptible vegetation types, in order to determine criteria for selecting locations of long term monitoring plots. Finally, we wanted to establish potential sites for long-term monitoring plots.

METHODS

Study area

The study area for the rapid assessment was defined by several criteria. Only areas managed by Point Reyes National Seashore, including the North District of the Golden Gate National Recreation Area, were selected for study. Within these lands we examined only areas classified in the National Park Service 1994 vegetation map as one of three vegetation superalliances: *Sequoia sempervirens-Lithocarpus densiflorus* (redwood-tanoak, RDW), *Pseudotsuga menziesii* (Douglas-fir, DGF), and *Umbellularia californica-Quercus agrifolia* (California bay-coast live oak, CLO). For time and access reasons, the rapid assessment was limited to areas between 50 and 500m from trails and roads. The minimum distance of 50m was chosen to minimize effects of humans on plant community composition and structure. The maximum distance of 500m was a realistic limitation due to slow cross-country travel and the size of the study area. Plots were located only on slopes less than 60%, according to the USGS 30m digital elevation model of the area and field measurement, for the safety of the field researchers and to reduce soil erosion impacts.

Plot selection and survey

After three pilot plots were surveyed, total sample size was pre-determined to be at most 55 plots, due to time and staffing constraints. The final 55 potential plots were divided proportionally between the three superalliances according to their areal extent (13 CLO, 32 DGF, and 10 RDW). These plots were randomly placed within each superalliance stratum in a Geographic Information System (Figure 1.5). UTM coordinates were extracted from the GIS for navigation (see Appendix IV for coordinates of Rapid Assessment Plots).

Navigation to each plot location was accomplished with a handheld GPS unit and topographic maps. Plot center was deemed located once we were closer to the pre-determined coordinates than the accuracy of the GPS at the time. If a sample location did not meet the criteria as determined in the GIS (e.g. too steep, incorrect vegetation typing), we traversed 50m in one of the four cardinal directions (randomly chosen on a compass). The new location was examined, and the process repeated if necessary. If it was obvious that neither the original plot location nor another location within approximately 200m would meet the original plot criteria, the plot was thrown out. In several instances plots were not assessed due to time constraints or difficult access. A final total of 48 plots were assessed.

Once a plot location was selected, a temporary stake was installed at plot center and measurements were made of precise slope and aspect. Photos were taken from plot center in the four cardinal directions. One tree was tagged facing plot center, and the distance and azimuth from the tree to plot center were noted. Elevation was determined using GPS. From plot center to a radius of 12.62m, all woody species were identified and their overall cover of the plot was classified using Braun-Blanquet cover classes (Barbour et al., 1987). Other species of note, including herbaceous species were recorded. Total cover of overstory canopy, shrub cover, and herbaceous vegetation cover were also estimated. The canopy stratum was defined as any woody individuals greater than three meters height. Herbs were defined as all non-woody vascular plant species. Shrubs and trees were separated by species, as opposed to physical measures such as height or DBH.

Additionally, each plot was given two ratings: likelihood of *P. ramorum* infection (LOI), and SOD severity index (SSI). Likelihood of infection was rated on a five-point scale: highly likely (5), likely (4), possible (3), unlikely (2), and highly unlikely (1). A rating of “highly likely” was given to plots in which host specimens in the plot and surrounding area exhibited classic symptoms of infection, and/or were obviously recently dead or dying. A rating of “highly unlikely” was given to plots in which host specimens within and nearby either did not exist or showed no symptoms whatsoever (see Appendix V for complete rating scale). SOD severity was rated on a scale from zero to ten, based on the number of dead and/or dying trees in the canopy and understory. A rating of zero was given to plots with no dead or dying trees within a 42m radius of plot center, and a rating of ten was given to plots with greater than 90% of overstory canopy cover dead or dying within a 42m radius of plot center (see Appendix V for complete rating scale). These ratings were intended to aid in selection of long-term monitoring plots.

Classification tree analysis was used to examine whether any of the measured environmental variables (elevation, slope, aspect), cover classes, likelihood of infection ranking, or SOD severity index rating would help predict infection (Breiman et al., 1984). One-way analysis of variance was used to make comparisons of variables between major vegetation types (Zar, 1999).

P. ramorum sampling

The two primary methods of sampling for presence of *P. ramorum* are 1) taking leaf or twig samples of California bay or tanoak (hereafter referred to as "foliar sampling"), and 2) cambial sampling of SOD affected species, which requires removing bark from the suspect tree (Storer et al., 2002). We used only the first method, as it is quick and has less visual impact. Each 12.62m radius plot (referred to as R1, 0.05ha area) was surveyed for symptoms of *P. ramorum* infection and SOD. Foliar and twig specimens were collected following a priority scale, based on potential host species, on which plant species *Phytophthora ramorum* tends to sporulate, and proximity to plot center. First, if symptomatic California bay or tanoak existed within R1, a collection was taken. If no symptomatic California bay or tanoak existed within R1, a secondary search was conducted out to 28.21m (called R2, 0.25ha) for symptomatic California bay and tanoak. Finally, if no symptomatic specimens of California bay or tanoak existed within either R1 or R2, samples were taken of other known host species within the R1, if symptomatic. For California bay, 10-15 symptomatic leaves were sampled. For tanoak, symptomatic twig samples and 5-10 leaves were collected. Samples were bagged and sent to the University of California Davis Plant Pathology Laboratory (PI Rizzo) for testing. Plant clippers were sanitized with Lysol disinfectant spray after each plot (95% ethanol or 10% bleach water solutions can also be used). Several additional opportunistic samples were taken in areas of interest not covered by the rapid assessment plots. Including samples at rapid assessment plots, opportunistic samples, and samples taken at long-term plot locations (during Phase 2), foliar samples were taken at a total of 74 separate locations.

Stream baiting

In addition to foliar samples, stream baiting (Murphy et al., 2005) was undertaken to determine presence or absence of *P. ramorum* on the western side of Inverness Ridge. Bait bags were constructed of mesh screen and PVC piping (see Appendix VI for photos). Ten Rhododendron leaves were placed in each of two locations near the mouth of seven perennial streams: Arroyo Hondo, Alamere Creek, Coast Creek, Santa Maria Creek, and three unnamed streams (see Figure 1.6 and Appendix IV for locations). Locations were chosen out of sight of trails to prevent vandalism and preserve visitor experience. Water temperature was measured to the nearest 0.5 degree Celsius, and precise locations were noted using a GPS unit. Bait bags were submerged, anchored to nearby rocks or trees to prevent them from washing away, and left in the stream for between 8 and 21 days. The amount of time bait bags were left in the stream was based on water temperature (see Appendix VI for times). Two rounds of baiting were performed at each stream site. Recovered samples were bagged and sent to the UC Davis Plant Pathology Lab for testing. In several instances, additional foliar samples of symptomatic California bay or tanoak were taken from near or above the stream sites. After accessing streams suspected of infection, any soil or mud left on boots was brushed off, and boots were sanitized with Lysol disinfectant spray. Hand sanitizer was used before and after handling bait leaves.

<u>RESULTS</u>

Plot measurements

Rapid Assessment plot measurements were made at 48 locations throughout PRNS (11 CLO, 29 DGF, and 8 RDW). Cover classes were assigned to 20 different woody species. Overall, canopy cover and shrub cover were consistent between vegetation types, but herbaceous cover was significantly lower in RDW forests ($p < 0.05$) (Figure 1.1). In terms of susceptible species, 15 plots

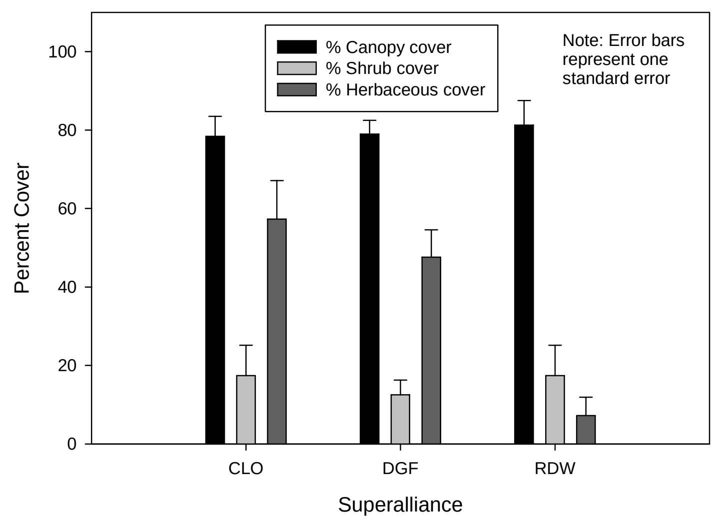

Figure 1.1: Mean percent canopy, shrub, and herb cover for major vegetation types, estimated visually. CLO = California bay-coast live oak, DGF = Douglas-fir, RDW = redwood. Values were estimated as midpoint of Braun-Blanquet cover classes.

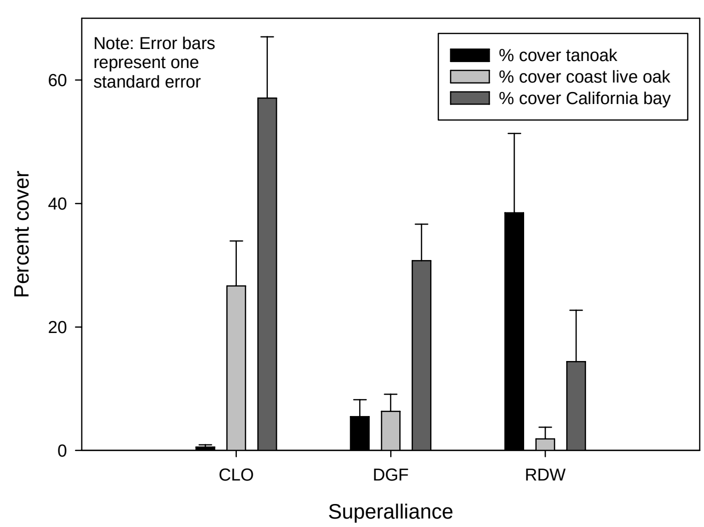

Figure 1.2: Percent cover of SOD susceptible species (coast live oak and tanoak) and primary *P. ramorum* sporulation hosts (tanoak and California bay) by major vegetation type. CLO = California bay-coast live oak, DGF = Douglas-fir, RDW = redwood. Values were estimated as midpoint of Braun-Blanquet cover classes

(31%) had some component of tanoak, while 17 plots (35%) contained some coast live oak. As expected, average cover of tanoak was highest in RDW plots (38.5 %), lowest in CLO plots (0.5%) and in between for DGF (5.5%) The reverse was true for coast live oak (Figure 1.2) with coast live oak covering an average of 26.6% in CLO plots, 1.9% in RDW plots and 6.3% in DGF plots. Sixteen of 48 plots (33%) were given a LOI rating of either "likely" (4) or "highly likely" (5) and 14 of these 16 plots (88%) tested positive for *P. ramorum.* Only 3 of 32 plots given a LOI rating of "possible" (3) or lower tested positive for *P. ramorum..* Ten of 48 plots (21%) were given a SSI rating of 4 or greater, meaning that at least 25% of overstory canopy cover was symptomatic, or that at least dead 5% of overstory canopy cover was dead (Figure 1.3).

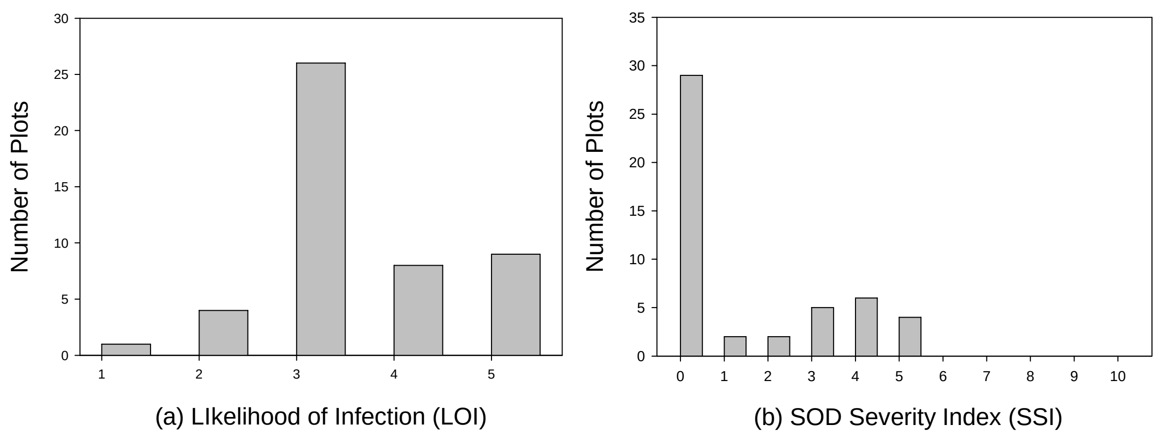

Figure 1.3: Likelihood of Infection (a) and SOD Severity Index ratings (b) for 48 rapid assessment plots

Pathogen testing

Of 104 individual foliar samples (taken from 74 different random and opportunistic locations across PRNS), 29 samples (28%) tested positive for *P. ramorum* only. Five samples (5%) tested positive for both *P. ramorum* and *Phytophthora nemorosa*, a relative of *P. ramorum.* Twenty samples (19%) tested positive for *P. nemorosa* only.

Of the 74 different random and opportunistic sample locations, 29 (39%) tested positive for *P. ramorum*. Positive tests for *P. ramorum* were generally grouped around the Bear Valley area (including along Limantour Road), along Bolinas Ridge, and around the Five Brooks trailhead (Figure 1.5). None of the locations on the western side of Inverness ridge tested positive for *P. ramorum*, although some tested positive for *P. nemorosa*. Positive tests for *P. ramorum* were found in all three major vegetation types sampled. Results were consistent with prior opportunistic testing done by the NPS and park volunteers (Figure 1.5 and Appendix III).

When examining the 48 randomly located plots by major vegetation type, 5 of 11 plots (45%) in the CLO superalliance tested positive for *P. ramorum* infection. 7 of 29 plots (24%) in the DGF superalliance were infected, and 5 of 8 plots (63%) of plots in the RDW superalliance tested positive. Many of the DGF samples were on the western side of Inverness ridge, which contains California bay but otherwise little SOD susceptible vegetation. In terms of SOD susceptible species, 8 plots contained some symptomatic or dead coast live oak, and 6 of these 8 tested positive for *P. ramorum.* Fourteen plots contained some symptomatic or dead tanoak, and 10 of these 14 tested positive for *P. ramorum.*

In classification tree analysis, environmental and vegetation variables (e.g. slope, aspect, elevation and vegetation cover classes) had very little power for predicting presence of *P. ramorum*. However, a rating of 4 or 5 for Likelihood of Infection ("likely" or "highly likely") did hold some predictive power for a positive test result (r^2 = 0.65), suggesting that this rating system worked reasonably well (Figure 1.4). When constructing a classification tree from only plots with SOD susceptible vegetation (tanoak or coast live oak), LOI was able to predict presence of *P. ramorum* with an r^2 of 0.79. When constructing trees only on environmental variables and vegetation cover classes, presence of tanoak (>1.5% cover) was the only significant factor (r^2=0.29), and when removing plots without susceptible vegetation from the classification tree, herbaceous cover was the only significant factor (r^2=0.43). This could have been due to differences in herbaceous cover between RDW and other vegetation types, since RDW plots had the highest proportion of infection and the lowest herbaceous cover.

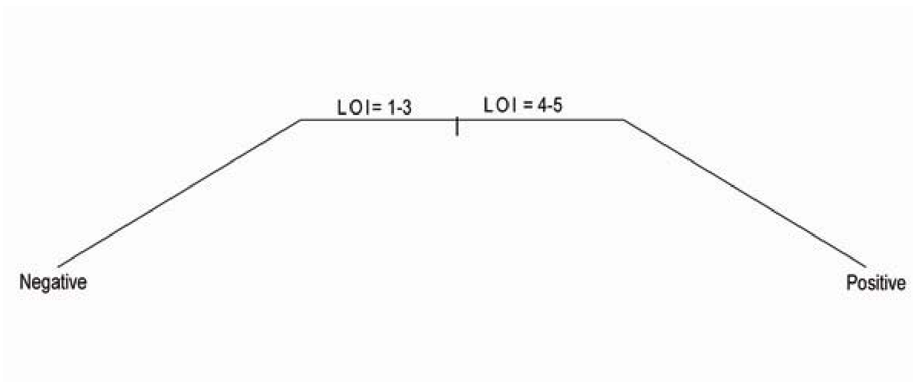

Figure 1.4: Classification tree run with presence of *P. ramorum* as the response variable, and LOI, SSI, slope aspect, and cover of each woody species as predictors. R^2 = 0.65.

Stream baiting

Tests of all stream baiting samples were negative for *P. ramorum*. This could mean that *P. ramorum* is not on the west side of Inverness Ridge. However, the negative test results do not necessarily mean absence of the pathogen. They may also have been due to the relative lateness of testing (May-June), or related to the fact that the preceding winter and spring had been relatively dry, resulting in low water flow and possibly reduced sporulation of the pathogen. In other stream baiting efforts around the state, several streams that had tested positive for *P. ramorum* in the past tested negative in 2007 (Murphy, 2007), possibly due to reduced sporulation.

Determining Long term plot criteria and location

After collecting Rapid Assessment data, it was decided that the first year of the long-term portion of this project (Phase 2) would focus specifically on the effects of SOD on tanoak in the Douglas-fir and redwood vegetation types. We chose not to examine SOD in California bay-coast live oak vegetation types at this time for several reasons. First, tanoak is a major component of both the redwood-tanoak and Douglas-fir vegetation superalliances, which collectively cover 74% of the study area (Figure 1.5). Second, previous SOD research has identified tanoak as the species most susceptible to SOD (Rizzo et al., 1995). Third, our observations during this phase of the project

(Rapid Assessment) indicated that tanoak is currently experiencing the most substantial mortality within PRNS. Fourth, because tanoak is a significant component of both the Douglas-fir and redwood vegetation types, focusing on tanoak would allow us to examine the comparative effects of SOD-induced mortality between these two systems. Finally, time and staffing constraints

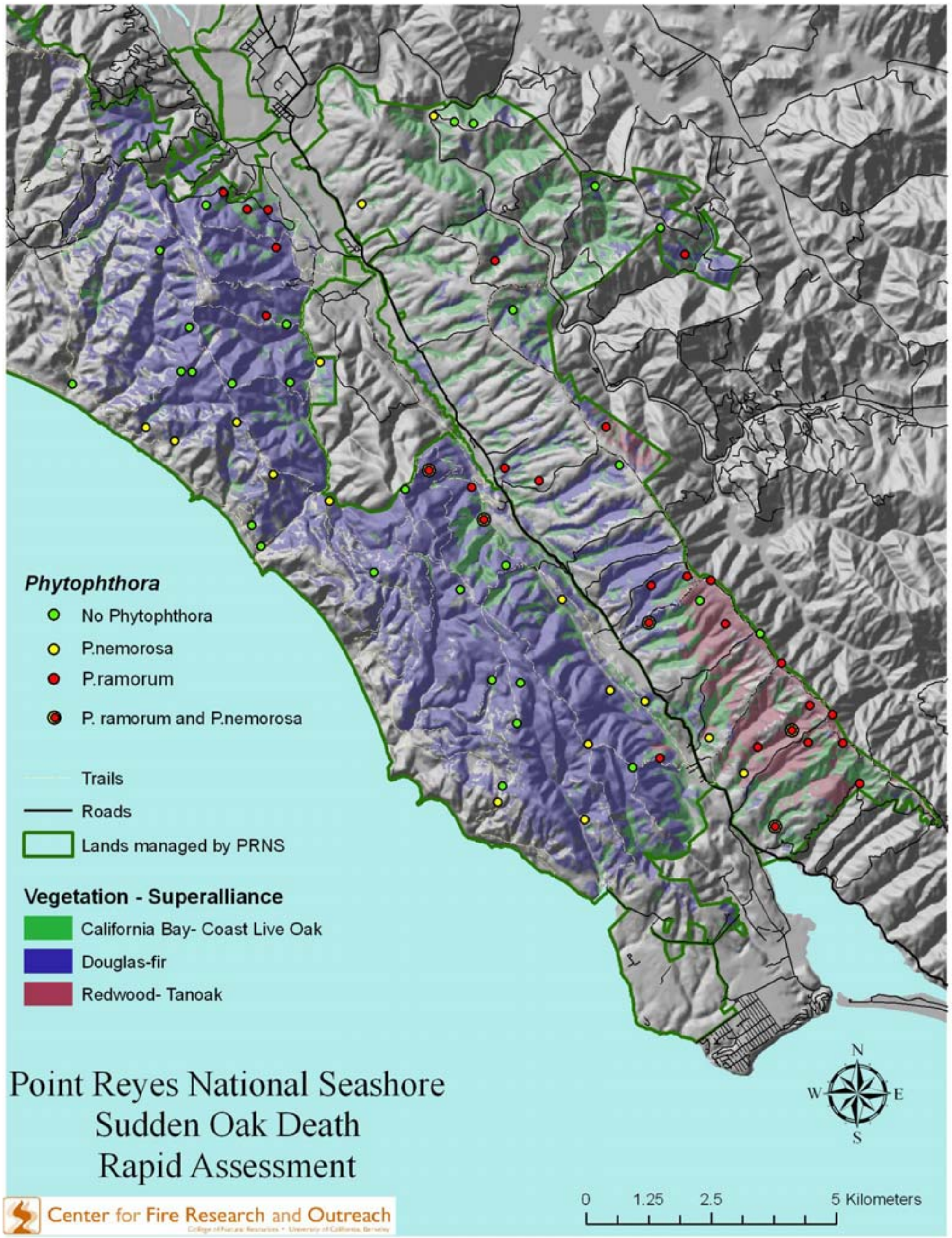

Figure 1.5: Rapid Assessment plots and results of 2007 *Phytophthora ramorum* testing

allowed for a limited number of long-term plots to be installed during this first field season, so we chose to focus our efforts on tanoak only.

The estimated cover class of tanoak, likelihood of infection rating and quick basal area estimates were used to determine which of the Rapid Assessment plots would serve as origins for long-term monitoring plot-pairs. The observed variability in tanoak basal area and dominant species basal area within the redwood and Douglas-fir vegetation types clearly necessitated a minimum basal area of tanoak and of the dominant species within each long-term plot, in order to effectively make comparisons.

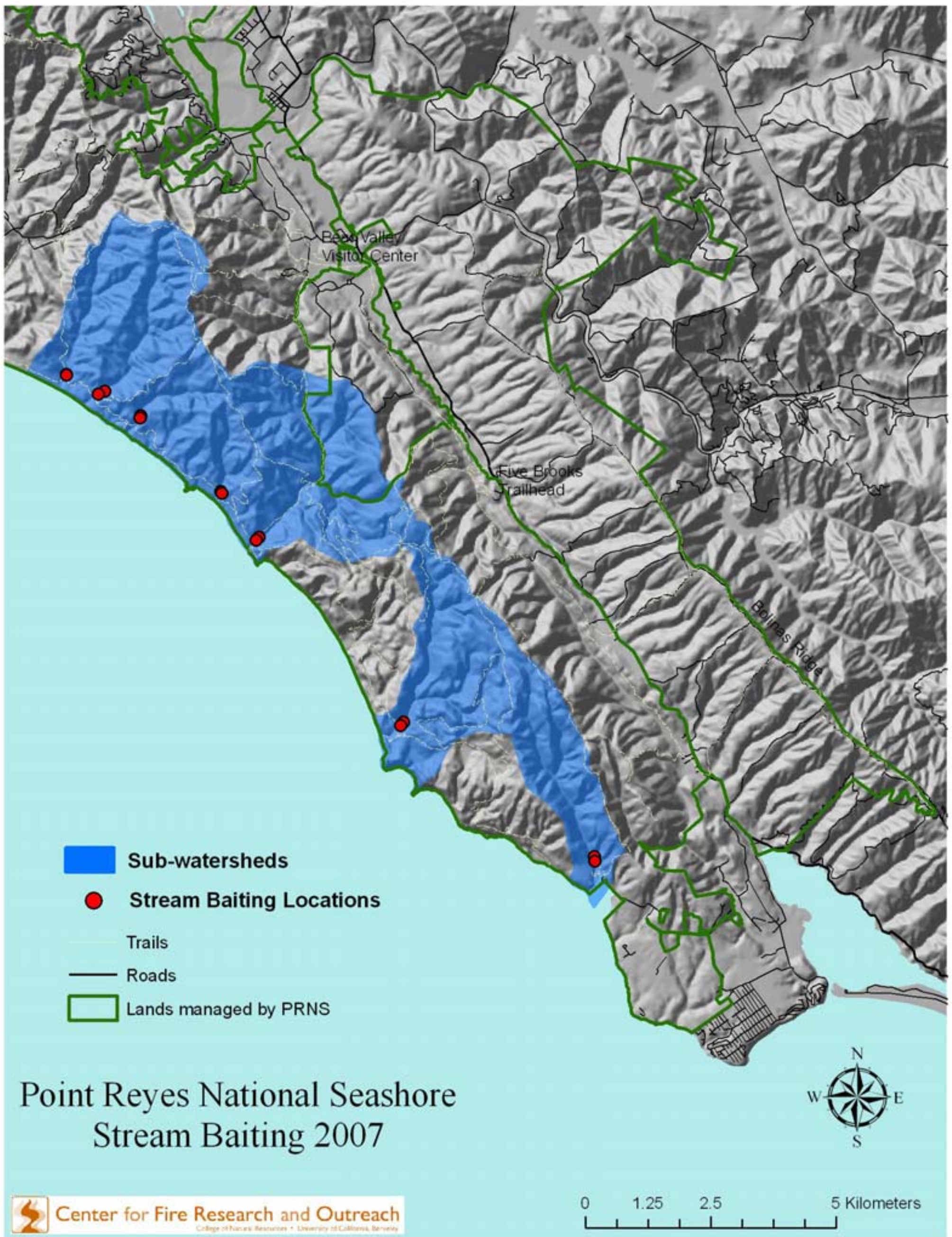

Figure 1.6: Stream baiting locations

DISCUSSION

All three major vegetation types examined in this study tested positive for *P. ramorum.* The pathogen was detected at locations spanning nearly the entire north-south range of potential host vegetation within the Seashore. While many samples did test negative, nearly all areas visited in this study containing tanoak, and many areas with coast live oak, showed some symptoms of possible infection, ranging from small dead trees in the understory, to large dead or dying overstory trees with bleeding, *Hypoxylon* fungus, and/or other classic SOD symptoms. If we infer from the proportions of our randomly located plots that tested positive for infection, as much as 63% of RDW forests, 45% of CLO forests, and 24% of DGF forests may be infected with *P. ramorum*.

Because we apportioned our sampling efforts based on the aerial extent of vegetation types, the majority of Rapid Assessment plots were in DGF forests. Additionally, in Phase 2 of the project, we focused on DGF and RDW forests, gathering additional samples from these forest types. Future *P. ramorum* testing efforts may focus on CLO forests in the northeast portion of the Seashore, which were the least sampled areas after the two phases of this project and prior sampling efforts (Figure 1.5 and Appendix III).

During the Rapid Assessment we noted several areas of the park that seemed to have the heaviest and most obvious impacts from SOD. The southern portion of Bolinas Ridge, near the top of the McCurdy Trail, appears to have been affected for some time. While areas farther north on Bolinas ridge tested positive (i.e. near the top of the Randall Trail), there appeared to be less SOD-induced tanoak mortality there. This may suggest that the pathogen is moving northward along the ridge. Additionally, portions of the mixed evergreen forests along the Horse trail were heavily impacted, with many large dead tanoaks. Many of these trees however did still have their leaves on, suggesting that it may be earlier in the disease progression than areas on Bolinas ridge. It is possible that the two forest types have different rates of reaction to *P. ramorum* infestation and SOD. Mixed evergreen forests with tanoak in the vicinity of the Five Brooks trailhead, and along Limantour Road also appear to have been affected by SOD. Of plots that had a tanoak or coast live oak component, 36% were rated with a SOD Severity Index of 4 or greater, meaning there was a considerable amount of dead or symptomatic overstory trees. Overall, plots in the RDW and CLO vegetation types received the highest SOD Severity Index ratings, which was expected because they have the highest proportion of susceptible species.

The two primary species on which *P. ramorum* sporulates are California bay and tanoak. The presence of infected bay has been shown to be correlated with occurrence of SOD (Rizzo and Garbelotto, 2003). Since California bay is common to all three major forest types in the study, we were able to sample for *P. ramorum* across a wide area, including locations that do not support tanoak. Most notably this included the area west of the crest of Inverness Ridge. Excluding one small ~¼ acre stand on the Woodward Valley trail, we found no tanoak on this western aspect during the course of the study. (Coast live oak does exist as a minor component of the Douglas-fir mixed evergreen forests there.) Our stream baiting also tested for the pathogen's presence on the ridge's western aspect. While the presence of bay does provide a host on the western side of the ridge, none of the samples from that area tested positive in this study, including those taken from stream baiting. Some tested positive for *Phytophthora nemorosa* however, a possibly native relative to *P. ramorum*, which does not have the fast spreading and severe impacts of SOD (Hansen et al., 2003; Wickland and Rizzo, 2005) . It may be that the pathogen simply has not spread that far west. However it is also possible that there is some other factor limiting its spread. *P. ramorum* is a waterborne pathogen, and spores have been found to travel by windblown rain (Davidson et al., 2005). Prevailing wind patterns during wet months in PNRS may be inhibiting its westward movement. The closest known infected location to the crest of Inverness Ridge (plot 044) lies along the Greenpicker Trail, near the Seashore/Vedanta property boundary (Figure 1.5).

As assessed by classification tree analysis, the lack of power of the stand-level variables slope, aspect, elevation or vegetation cover class in predicting presence of *P. ramorum* is consistent with previous findings (Kelly and Meentemeyer, 2002, Rizzo et al., 2005). Our analysis implies that the pathogen is not restricted by these factors, at least in the ranges of these factors within PRNS. Spatially, the absence of the pathogen on the western slope of Inverness Ridge might suggest a westward direction of progression, but again may also imply some physiographic barrier to its movement.

The Rapid Assessment was beneficial in establishing criteria and potential locations for long-term monitoring of sudden oak death in PRNS. It became apparent early on that tanoak was the most heavily SOD-impacted species. Additionally, the presence of tanoak in both RDW and DGF superalliances provided a unique opportunity to compare the effects of SOD on two systems. These two factors primarily led us to choosing tanoak as the subject of the first year of long-term monitoring. Thus the primary research question for Phase 2 of this project became, "What are the short-term effects and potential long-term impacts of SOD-induced tanoak mortality?"

We noted significant variability or patchiness in the disease (e.g. levels of mortality, proportions of symptomatic trees) within the affected areas. The scale of this variability was on the order of tens to hundreds of meters, which is consistent with previous remotely sensed surveys (Kelly and Meentemeyer, 2002). This led us to the idea of "pairing" diseased and healthy plots – establishing two plots within a certain distance of each other that would be similar in composition but in different stages of disease progression. It also became apparent that establishing minimums for tanoak basal area, levels of disease (symptomatic tree basal area), and dominant species basal area would be necessary to facilitate comparisons of a host of ecosystem characteristics (e.g. fuel loads, regeneration, species composition etc.) between "healthy" and "diseased" plots, and between RDW and DGF vegetation types.

Continued testing for presence of *P. ramorum* throughout PRNS is recommended. In particular, testing in the California bay – coast live oak vegetation type in the northeastern regions of the park would be beneficial, as these areas were not tested heavily in this project. Continued, denser testing in regions of the park already identified as infected, such as near the Bear Valley Visitor Center, the Five Brooks trailhead, Limantour Road, and Bolinas Ridge, would allow for closer tracking of disease progression. While the western slope of Inverness Ridge has little susceptible vegetation, continued testing there would be beneficial for understanding disease progression and possibly physiographic regulators of the pathogen spread. Stream baiting could be used as a quick assessment for the presence of the pathogen in that area, followed by foliar sampling if the pathogen is found to exist within the watershed.

The potential for change in forests at PRNS is quite significant. Given the SOD effects seen in places like Bolinas Ridge, changes resulting from loss of hardwood species in these ecosystems may range from immediate to long-term. Phase two of this project is an initial attempt to quantify these impacts in DGF and RDW systems.

CHAPTER 2

Impacts of Sudden Oak Death-induced tanoak mortality

at Point Reyes National Seashore & the North District of the Golden Gate National Recreation Area

Benjamin Ramage, Tadashi Moody, & Max Moritz

INTRODUCTION

The primary objectives of this research were to detect short-term effects and predict long-term impacts of sudden oak death-induced tanoak (*Lithocarpus densiflorus*) mortality within the lands managed by Point Reyes National Seashore (PRNS). This study focuses specifically on SOD-induced tanoak mortality, as opposed to other SOD-impacted species such as coast live oak (*Quercus agrifolia*), because previous research has identified tanoak as the most susceptible species (Rizzo et al., 2005), and our observations from the first phase of this project (Rapid Assessment) indicate that tanoak is currently experiencing the most substantial mortality within PRNS. We collected data on mortality and SOD symptoms, forest structure, regeneration, species richness, and fuel loading, within plots randomly located in redwood (*Sequoia sempervirens*) or Douglas-fir (*Pseudotsuga menziesii*) forest types. Plots were stratified by both vegetation type (redwood vs. Douglas-fir) and disease status ("Healthy" vs. "Diseased"), in order to assess and compare the impacts of sudden oak death (SOD) on both of these forest types. Additionally, the information collected via this study is intended to serve as first-year data for a long-term monitoring effort, and as such, all sample plots were permanently marked.

Healthy and diseased plots have been spatially paired in most cases, an approach that was made possible by the patchy distribution of the disease throughout the park. Current evidence suggests that the current locally patchy distribution of SOD in conifer forests of coastal California is a result of introduction events and stochasticity, as opposed to abiotic or biotic constraints (Rizzo et al., 2005), and as such, comparisons between diseased and healthy areas should be relatively free of confounding factors. Therefore, by comparing healthy and diseased plots, we are able to estimate impacts immediately. Furthermore, if long-term monitoring ensues, healthy and diseased plots will provide two different starting points from which to analyze time-series data.

Our hypotheses were that Douglas-fir plots, as compared to redwood plots, would exhibit **a.** no difference in basal area of the dominant species (redwood or Douglas-fir), **b.** greater basal area of trees other than the dominant species and tanoak, **c.** less regeneration of the dominant species, **d.** more hardwood regeneration, **e.** greater native species richness, **f**. no difference in exotic species richness, **g.** no difference in downed fuels, and **h.** no difference in any tanoak variables. With regard to disease status, we hypothesized that Healthy plots, as compared to Diseased plots, would exhibit **a.** lower percentage of tanoak basal area that is dead (this variable is controlled by the constraints of our experimental design), **b.** greater canopy cover, **c.** less regeneration (tanoak and non-tanoak), **d.** lower species richness (both native and exotic), and **e.** less fuels.

The results of this study enable direct examination of impacts such as increased fire hazard, invasion by exotic plants, reductions in native plant diversity, and altered forest structure and composition. In addition, the data presented in this report may help to improve the accuracy of forecasts regarding many other potential SOD-induced impacts. Several recent publications have indicated the possibility of accelerated erosion and nutrient depletion, greater landslide risk, loss of native animal diversity, invasion by exotic animals and microorganisms, disruption of mycorrhizal networks, decline in aesthetic and recreational values, and local extinctions of host species (Davidson et al.2005, Maloney et al. 2005, McPherson et al. 2005, Meentemeyer et al. 2004, Rizzo et al. 2005).

METHODS

Plot selection

Our area of interest was generally defined as forested land (either redwood or Douglas-fir associations), with a substantial tanoak component, where *P. ramorum* infection is either known or highly probable. The specific areas designated for potential sampling were defined through the Rapid Assessment phase and by using Geographic Information Systems (GIS) data. All study areas are designated on GIS data layers as having vegetation associations with either Douglas-fir or redwood as the primary component (excluding Douglas fir-coyote brush association).

Random points were selected within stratified vegetation types (Douglas-fir or redwood); points are either randomly-located plots from the Rapid Assessment phase or supplemental random locations. All points are at least 500 meters from all other points, at least 50 meters from trails/roads, and on slopes less than 60% (for worker safety and minimization of erosion). Each random point served as a “plot-pair origin” (PPO), a location from which a rigorous in-field protocol was followed to establish a pair of “Healthy” (H) and “Diseased” (D) plots, or a sole H or D plot, in the event that a pairing was impossible from a given PPO. One PPO was selectively assigned to the intersection of two trails, in an area that none of our random points fell, but that we deemed as an important area of study due to the severity of SOD infestation and high visibility to park visitors.

From each PPO, a radial search was employed to locate the nearest acceptable position for an H or D plot, whichever condition was encountered first. The PPO itself became the first of the paired plots if all conditions were met at this initial location. If neither an H nor D plot was identified within 200 meters of the PPO, the PPO was discarded. After locating the first plot of the pair, a new radial search was conducted from this first plot to identify the nearest location satisfying the opposite condition (either “Healthy” or “Diseased”). If the second plot of the pair could not be located within a radius of 200 meters, the first point became a stand-alone (unpaired) plot. Plots are circular with a radius of 12.62 meters (.05 hectares in area) from plot center, and surrounded by a buffer zone (28.21 meters in radius from plot center), which encloses a total area of .25 hectares. All data were recorded within the 12.62 meter radius plot (R1), but certain requirements were established for the buffer zone (R2). Throughout this document, the word “plot” refers to R1.

The criteria used for the in-field plot locating protocol are as follows. Within all plots (redwood and Douglas-fir, H and D), **a**. the dominant species (redwood or Douglas-fir) must provide at least 25% canopy cover within the area enclosed by R2, estimated visually, **b**. at least 0.46 square meters (5 square feet) of basal area (BA) of the dominant species must be present within R1, **c**. no “mature representatives” (greater than 10 cm DBH) of the <u>other</u> dominant species may be present within 20 meters of the plot center, and a maximum of 2 mature individuals may be present within the remainder of R2 (i.e. the ring between a 20 meter and a 28.21 meter radius), **d**. no planted species (e.g. eucalyptus, Monterey pine) may be present within R2/R1, **e**. slope must not exceed 60%, **f**. paired plot centers will not be closer than 40 meters, and not farther than 200 meters from each other, **g**. plot centers will be at least 28.21 meters from roads or trails, **h**. R1 must contain at least

0.93 square meters (10 square feet) BA of total tanoak (any health condition); downed trees will not be counted toward the total of tanoak BA (in any category) if they are considerably decayed (more than 50% of bark falling away from bole wood and/or bole wood compacts when stepped on), as we are assuming that the ecosystem has already responded to the loss of these trees.

Note that we opted to impose a rigid minimum on the amount of tanoak basal area within each plot, as opposed to sampling randomly within Douglas-fir and redwood-tanoak superalliances, which would have provided an estimate of the abundance and distribution of tanoak throughout the park. This approach was utilized in order to standardize tanoak abundance across strata, thereby reducing the likelihood of this potentially confounding factor, and facilitating inferences regarding the specific impacts of SOD in two different vegetation types. In order to maximize our chances of detecting the influence of SOD-induced tanoak mortality, we defined a minimum acceptable tanoak component that was perhaps higher than the average abundance of tanoak throughout the sampled superalliances. Therefore, any inferences we make may not apply to redwood forest or Douglas-fir forest in general, but only to areas with a similar minimum tanoak component.

All H plots (redwood and Douglas-fir) were selected to contain **a**. at least 0.74 square meters (8 square feet) BA of "healthy" tanoak, **b**. at least 0.19 square meters (2 square feet) BA of "healthy" tanoak in each of 2 separate quadrants (i.e. it is unacceptable for all "healthy" tanoak to be in a single quadrant), and **c**. at most 0.28 square meters (3 square feet) BA of total dead, only 0.19 square meters (2 square feet) of which may include advanced standing dead and/or broken/fallen trees, and only 0.09 square meters (1 square foot) of which may be broken/fallen. "Healthy" tanoak trees were defined as having a full canopy with at least 50% of leaves green. Other symptoms were considered irrelevant for the purposes of this study. For example, a tree with boring dust, *Hypoxylon*, and/or bleeding was considered "healthy" provided it had a full, green canopy. We decided to ignore bole symptoms in our plot selection criteria because of the difficulty in finding locations without bole symptoms, and because of our focus on forest response and impacts (e.g. regeneration, fuel loading). We believe that in areas where tanoak trees still retained the majority of their canopy leaves in healthy condition, light and moisture levels on the forest floor were not appreciably altered, and thus response to SOD-induced tanoak mortality had not yet occurred. Therefore, we assert that plots in which some bole symptoms were present can still be interpreted as exhibiting "baseline conditions", for the purposes of this study.

We initially planned for D plots to be consistent across redwood and Douglas-fir vegetation types (as we succeeded with for H plots), but because of greater disease severity and/or tanoak presence in redwood vegetation types, as compared Douglas-fir vegetation types, we were unable to accomplish this goal. Our initial criteria had to be modified for Douglas-fir D plots, allowing for a reduced amount of dead and diseased tanoak trees. As such, our D plots represent conditions that are near the current extreme of disease severity for each vegetation type. Alternatively, we considered modifying our redwood D criteria to match what was feasible in Douglas-fir communities, but decided it was more worthwhile to capture the greater severity of the disease in redwood forests than to facilitate direct comparison of D plots between redwood and Douglas-fir forests. We also considered eliminating Douglas-fir D plots entirely from our study, because little change has yet to occur in most cases, and thus we did not expect to detect differences associated with disease status in Douglas-fir plots. However, given that this project is also intended to serve as first-year data for long-term monitoring research, we decided it would be beneficial to install plots in areas that are highly symptomatic, even if minimal mortality is currently exhibited. In this first year of measurement, Douglas-fir D plots may be indistinguishable from Douglas-fir H plots with regard to most our response variables, but our plot selection criteria nearly ensures that all Douglas-fir D plots will have experienced considerable mortality by the time of next measurement.

Redwood D plots were selected to contain **a**. at least 0.65 square meters (7 square feet) BA of total dead tanoak, excluding standing dead trees with more than 50% of leaves still clinging to canopy branches (standing dead tanoak with most leaves still attached to the tree were excluded here to insure that tree death has already increased light levels within the plot), **b**. at least 0.19 square meters (2 square feet) BA of dead tanoak (excluding standing dead trees with more than 50% of leaves still clinging to canopy branches) in each of 2 separate quadrants (i.e. it is unacceptable for all dead tanoak to be in a single quadrant), **c**. at least 0.28 square meters (3 square feet) BA of broken/fallen dead tanoak (to be labeled "broken", a tree's main stem must be broken at a thickness of at least 3"), and **d**. at least 0.19 square meters (2 square feet) BA of standing dead tanoak (excluding standing dead trees with more than 50% of leaves still clinging to canopy branches) **–** plots where all dead tanoak is broken/fallen were excluded, as disease progression was considered too advanced in these plots (this requirement was established to maintain consistency between diseased plots). Note, however, that we did not impose any lower or upper limit to the BA of "healthy" tanoak in a D plot.

Douglas-fir D plots were selected to contain **a**. at least 0.65 square meters (7 square feet) BA of tanoak that is dead (standing, broken, or fallen) <u>or</u> showing advanced canopy symptoms (at least 50% of canopy leaves dead), and **b**. at least 0.19 square meters (2 square feet) BA of tanoak that is dead or showing advanced canopy symptoms in at least 2 separate quadrants. Note that Douglas-fir D plots, like redwood D plots, are not constrained to any lower or upper limits on "healthy" tanoak BA.

In summation, comparisons of "baseline conditions" (H plots) between redwood and Douglas-fir plots are valid and directly interpretable. Likewise, H plots can be compared with D plots within a forest type to infer changes resulting from SOD, although relative impacts may be affected by both disease severity and vegetation type. D plots cannot be directly compared across forest types, because of differences in disease criteria between Douglas-fir D and redwood D plots, and hence the confounding of disease severity with vegetation classification. All plots are suitable for long-term monitoring.

Data Collection

Vegetation composition and structure

Modified Braun-Blanquet cover classes were used to estimate overall percent cover of canopy, shrubs, herbs, litter/duff, bare soil, and rock. "Canopy" is defined as all vegetation greater than 3 meters high. Herbs are defined as all non-woody vascular plant species. Shrubs and trees are separated by species, as opposed to physical measures such as height or DBH; for example, very large *Corylus cornuta* specimens are still considered shrubs. In addition, finer estimates of tree, shrub, and herb cover were made by assigning modified Braun-Blanquet cover classes to each species, as well as visually estimating average height of each shrub species. Tree species were further designated as seedlings/sprouts/saplings (S/S/S), and mature trees (TR). Dead trees and shrubs (including tanoak) were not counted in cover classes, even if dead leaves were still clinging to twigs. However, total canopy cover class included anything that blocked sunlight (including leaves and branches of dead tanoaks). Each cover class category was assigned a rating of either r (rare, <0.5%), t (trace, <1%), 1 (1-5%), 2 (5-25%), 3 (25-50%), 4 (50-75%), 5 (75-95%) or 6 (95-100%). Averages for each sampling stratum were calculated by using the midpoint for cover classes 1 through 6; a value of 0.25% was used for "r" and a value of 0.75% was used for "t".

Stems of all trees >3 cm (approx. 1 inch) were mapped by measuring distance and direction from plot center, and for each tree, we also recorded species, DBH, and health status (e.g. alive or dead, SOD symptoms). Boles that were split below DBH were counted as multiple stems. Health status of madrones (*Arbutus menziesii*) was not recorded (other than indicating alive or dead), as madrones are currently being impacted by a wide range of diseases in addition to SOD and additional categorization would be required for accurate data collection. All other SOD susceptible species (primarily tanoak) were indicated as alive or dead, and several categories of symptoms were rated, distinguishing between bole and/or canopy systems, and identifying the degree of canopy decline. Dead tanoaks were classified by the amount of foliage remaining attached to the tree, and by the degree of bole breakage, as a proxy for the amount of time that had passed since death of the tree. Trees not susceptible to SOD (and madrone) were simply recorded as alive or dead. The presence of basal and/or epicormic sprouting was also recorded for all tree species. A tree was considered to be sprouting from the base if sprouts were arising from the lowest 10 cm of the bole or within 10 cm of the bole in duff, litter, or soil.

We measured crown closure using a spherical densiometer. Standing at plot center and facing each of the four cardinal directions, the number of quarter squares open in the densiometer were counted (a quarter-square was considered open if sky was visible in more than half of the quarter-square). This information was later transformed to estimate percent cover.

Regeneration

Counts of all seedlings/sprouts (height less than breast height) and saplings (height greater than breast height, but DBH less than 3 cm) were conducted for all tree species. Individuals as well as clumps were tallied. "Clumps" were defined as groups of seedlings, sprouts, or saplings separated from other seedlings, sprouts, or saplings (of the same species) by at least 9". Also, when a single clump exceeded 2 feet along its longest axis, the clump was split in 2 at a natural break. In a subset of the plots, individual saplings were distinguished from those which occurred in seedling/sprout clumps, in order to estimate the number of combined seedling/sprout/sapling clumps. Sprouts were only counted if litter, duff, or soil obscured the base of sprouts, in order to provide a quick and simple measure for tallying numbers of sprouts. Note that this definition of a basal sprout differs from that which was used for the stem map; for the stem map, a tree was considered to be exhibiting "basal sprouting" if sprouts were arising from the lowest 10 cm of the bole or within 10 cm of the bole in duff, litter, or soil.

Fire Fuel Loading

To estimate surface and ground fuels, two planar intercept transects (Brown 1974), 12.62 meters in length, were established, originating at plot center and radiating due north and due south. Along each transect, surface fuels were tallied in timelag-classes. The number of 1-hour fuels (< 0.64cm diam.) and 10-hour fuels (0.64 – 2.54cm diam.) that crossed the transect plane between 10.5 and 12.5 meters were counted, the number of 100 hour fuels (2.54cm – 7.62cm diam.) that crossed the transect plane between 8.5 and 12.5 meters were counted, and the number of 1000-hour fuels (> 7.62cm diam.) that crossed the transect plane between 0 and 12.62m were counted. If no 1000-hour fuels were intersected in the first 12.5 meters of the transect, it was extended to 20 meters. Surface fuels were considered anything dead lower than 1 meter (regardless of whether or not it is attached to a living plant). Additionally, the diameter (cm) and condition (sound or rotten) were noted for each 1000 hour fuel. In situations when a large tree occurred directly N or S of the plot center, blocking the transect, we moved the transect the minimum possible azimuth in a clockwise direction. When an unacceptable amount of poison-oak (*Toxicodendron diversilobum*) occurred between 8.5 and 12.5 on N or S transect, transects were rotated to radiate E and W instead. We recorded all such adjustments. At two points (6m and 9m), we measured surface fuel depth and the depth of ground fuels – litter (loose, recently fallen foliage and plant material) and duff (decomposing plant material above mineral soil). Where poison-oak or a root crown occurred at 6m, we moved the sampling location to 5m, and so on; where poison-oak or a root crown occurred at 9m, we moved to 10m, and so on. All such adjustments were recorded.

Counts of surface fuels were translated into tons/acre and metric tonnes/hectare using Brown's standard equations and composite coefficients for calculating fuel loading in the interior West (Brown 1974, Brown et al., 1982). English units (tons/acre) are presented here, since this is the convention currently used by PRNS. Additionally, for more accurate estimates, we calculated fuel loading using species-specific coefficients developed by the National Park Service Fuels Management team at Point Reyes National Seashore (average squared diameters, specific gravity, and non-horizontal angle correction factor) adjusted for basal area proportion at each transect location. Ground fuel loading (litter and duff) was calculated using bulk density estimates by species developed by the NPS. Ladder fuels were characterized by classifying the height-to-live-crown-base (m) for each stem >3cm DBH in the 12.62m radius plot into one of five categories: 0-1m, 1-3m, 3-5m, 5-10m, and >10m. Live crown was defined as live branching foliage extending horizontally from the bole of the tree in at least two quadrants, and/or continuously into the upper canopy of the tree.

Data Analysis & Graphical Presentation

Variables of interest were compared across strata by testing for differences between each pair with Student's t-tests (with no correction for multiple tests), as well as with Tukey's Honestly Significant Difference (HSD) test, which accounts for multiple comparisons. Fuel loading values were analyzed with pooled variance two-sample Student's t-tests only (Zar, 1999). Response variables were not compared to each other (e.g. shrub species richness vs. herb species richness); each response variable was only analyzed in relation to vegetation type and disease status. All non-normal distributions were transformed as necessary to arrive at distributions approximating normality. However, because of small sample sizes and an abundance of zero values for many response variables, the normality of many post-transformation distributions is still somewhat questionable, and thus statistical results for such distributions should be interpreted with caution. No statistical methods were employed to account for the total number of response variables analyzed. Statistical analysis was performed with JMP IN version 5.1.2 by SAS Institute Inc. and S-Plus 7.0 by Insightful Corp.

On all bar graphs, bars are arranged with healthy strata alongside each other, sandwiched between the two diseased strata, to facilitate meaningful visual interpretation. Comparisons between health conditions within any forest type are useful, as are "baseline" comparisons between healthy redwood and healthy Douglas-fir plots. However, comparisons between diseased redwood and diseased Douglas-fir plots are not easily interpretable, because of differences in disease severity and/or progression between these two strata. Gray lower case letters indicate statistical significance ($p<.05$) for Student's t-tests, and black capital letters indicate statistical significance ($p<.05$) for Tukey's HSD; in both cases, strata that do not share a common letter are statistically different from each other. Statistical significance is not displayed on the figure illustrating fuel loading. Graphs were created with SigmaPlot version 9.0 by Systat Software, Inc.

Timeline

Experimental design of Phase 2 occurred during the spring and summer of 2007, during and subsequent to the execution of Phase 1. All field research was conducted during the summer of 2007. Data analysis and report preparation were completed during the fall of 2007.

RESULTS

A brief summary of our results, with respect to the hypotheses outlined in the introduction to Chapter 2, is shown in Table 2.1. Details are provided in the following pages.

Hypothesis	**Result**
Douglas-fir plots, as compared to redwood plots, will exhibit:	
no difference in basal area of the dominant species	partially confirmed
greater basal area of trees other than dom. species and tanoak	confirmed
less regeneration of the dominant species	confirmed
more hardwood regeneration	confirmed
greater native species richness	partially confirmed
no difference in exotic species richness	insufficient data
no difference in fuels	partially confirmed
no difference in any tanoak variables	partially confirmed
Healthy plots, as compared to Diseased plots, will exhibit	
lower percentage of tanoak basal area that is dead	confirmed
greater canopy cover	partially confirmed
less regeneration (tanoak and non-tanoak)	partially confirmed
lower species richness (both native and exotic)	mostly rejected
less fuels	partially confirmed

Table 2.1: Hypotheses and results

Research plots

Random selection of initial starting points and subsequent in-field plot location resulted in the plots displayed in Figure 2.1. Coordinates for all plots are provided in the appendix.

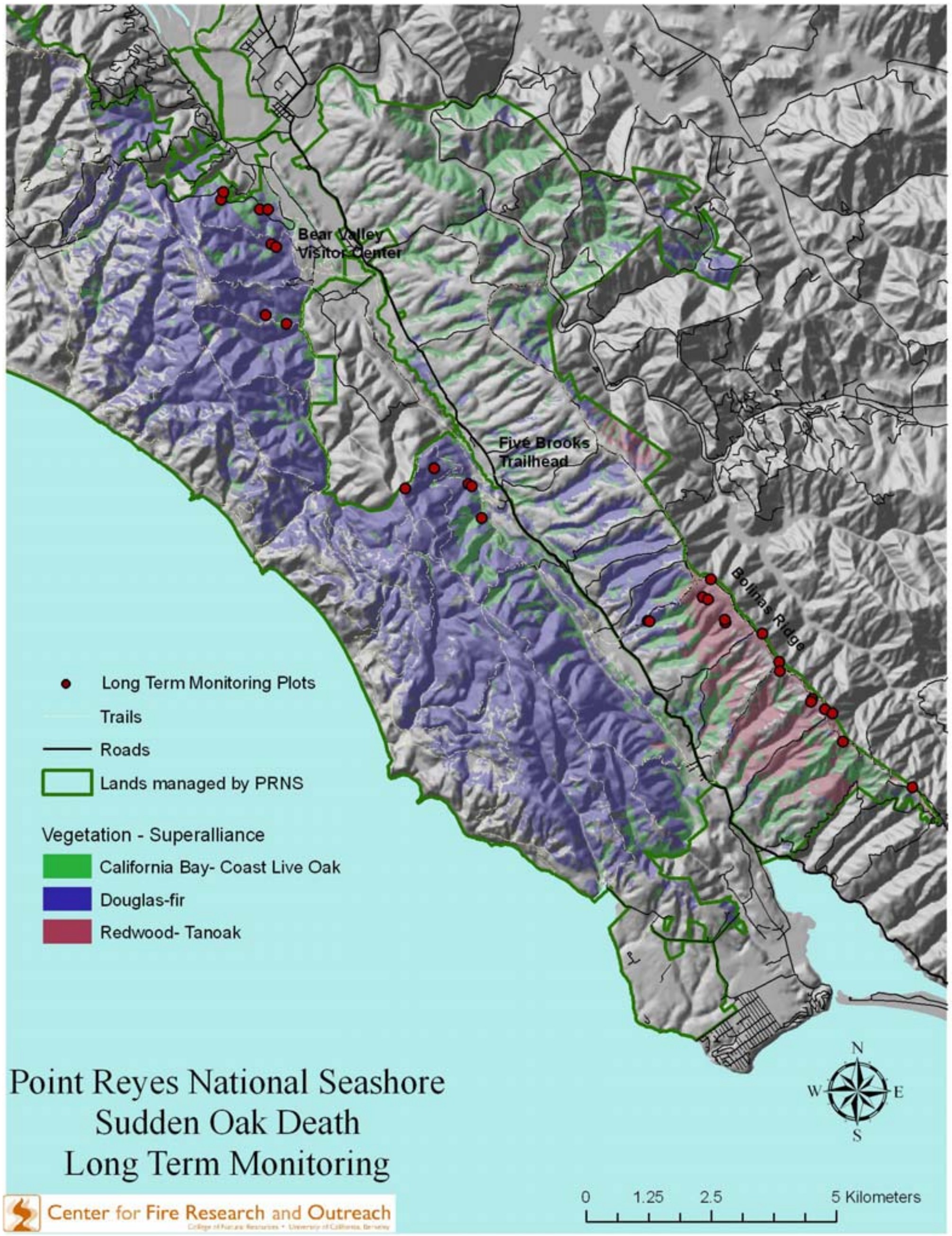

Figure 2.1: Map of study area and plots

Tanoak abundance & health

Many variables regarding the abundance and health of tanoak within our sampling plots were controlled by the requirements of our study design. However, most criteria were either maxima *or* minima, but not both, and thus there existed the potential for considerable variation. The following figures (2.2 through 2.4) are included to show the variability in these criteria, and to illustrate differences between vegetation types and health conditions.

Our results show a clear distinction between healthy and diseased plots in both forest types, although it is also clear that total impacts (e.g. amount of dead tanoak basal area) are currently more severe in redwood forests (see Figure 2.2). Figure 2.3 shows that the amount of dead tanoak with 50% or more of the brown leaves still clinging the to the tree ("Standing, E") is greatest in diseased Douglas-fir plots, while the highest basal area for all subsequent degrees of deterioration occurs in diseased redwood plots. If we view degree of deterioration as a proxy for time of death – an interpretation that is supported by McPherson et al. (2005) – our results suggest that SOD has been established for a longer period of time in our redwood plots. It is also worth pointing out that the distinction between "Broken" and "Fallen" is not particularly meaningful because trees that break low on the main bole, a common occurrence that is facilitated by opportunistic bark beetles and *Hypoxylon* fungi (McPherson et al., 2005), are unlikely to be uprooted as the tree collapses. Finally, Figure 2.4 shows that the percent of total tanoak that is dead is fairly consistent between diseased redwood and diseased Douglas-fir plots, despite the greater absolute amount of dead tanoak in diseased redwood plots.

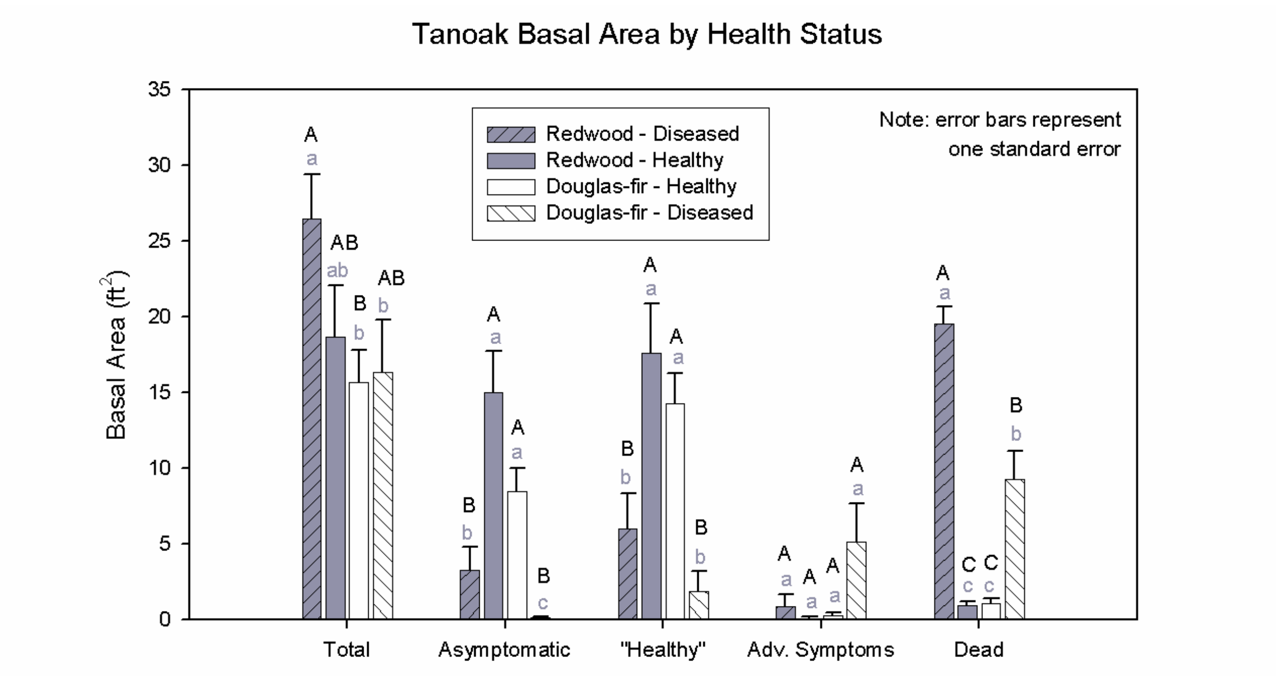

Figure 2.2: Distribution of tanoak basal area by health status. <u>Total</u> = all tanoak, any condition; <u>Asymptomatic</u> = no symptoms of SOD; <u>"Healthy"</u> = full canopy with at least 50% of leaves green (bole symptoms irrelevant); <u>Adv. Symptoms</u> = canopy with less than 50% of leaves green (bole symptoms irrelevant); <u>Dead</u> = canopy entirely dead (basal and epicormic sprouting irrelevant). Distributions for "Adv. Symptoms" and "Dead" deviate considerably from normality, even after transformations.

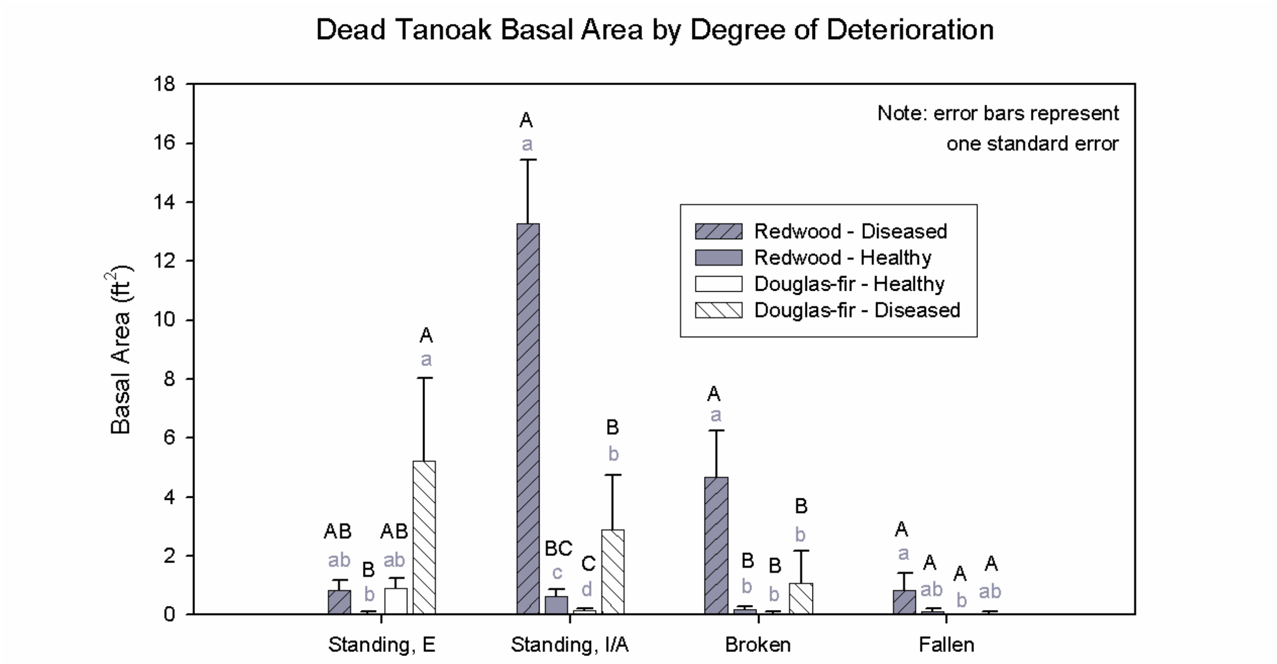

Figure 2.3: Distribution of dead tanoak basal area, categorized by degree of deterioration. Standing, E = more than 50% of leaves still clinging to tree, main bole unbroken; Standing, I/A = less than 50% of leaves still clinging to tree, main bole unbroken; Broken = main bole broken at a diameter of 3 inches or greater; Fallen = entire tree fallen and root system exposed. All distributions in this figure deviate considerably from normality, even after transformations.

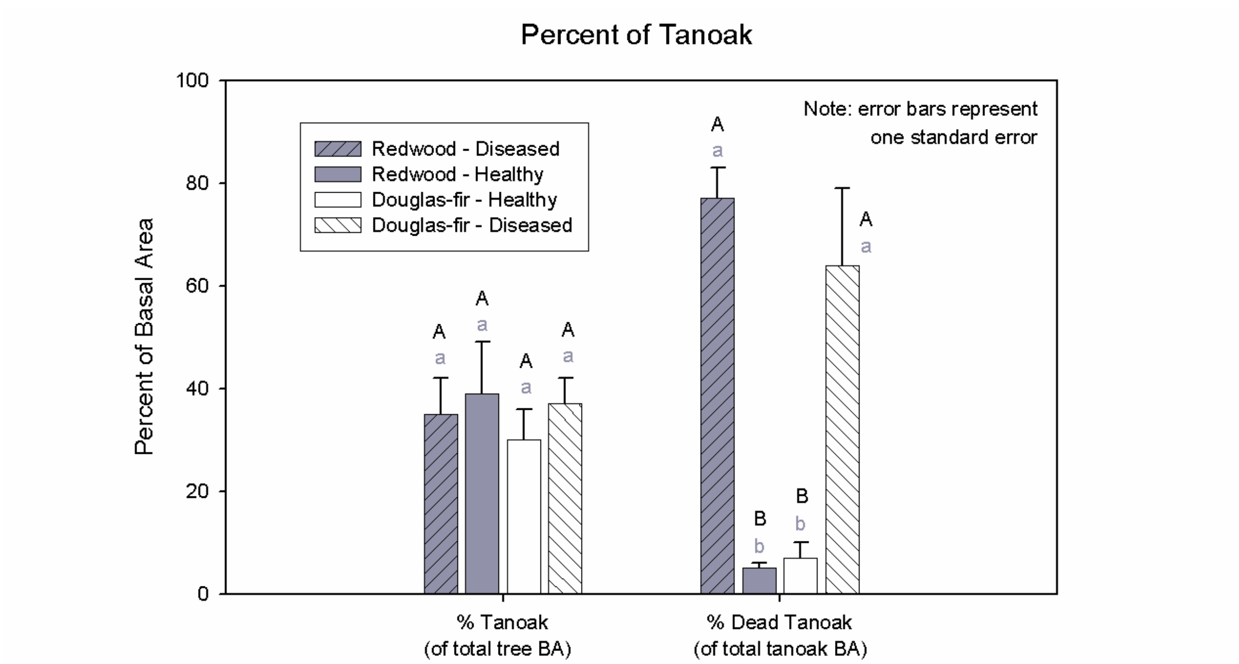

Figure 2.4: Percent of total basal area (all tree species) accounted for by tanoak (any health status), and percent of total tanoak that is dead. The distribution for "% Dead Tanoak (of total tanoak BA)" differs somewhat from normality, even after transformation.

Distribution of basal area: tanoak, redwood/Douglas-fir, and other species

In addition to the numerous constraints imposed upon tanoak, we specified a minimum of 0.46 square meters (5 square feet) of basal area of the dominant species (either redwood or Douglas-fir). However, we did not impose a maximum basal area for the dominant species, any basal area requirements for other tree species, or any restrictions related to the proportional representation of tree species. Figure 2.4 shows that the percent of basal area attributable to tanoak is consistent across all strata, despite the differences in tanoak basal area, dominant species basal area, and total basal area (Figures 2.2 and 2.5). The average tanoak basal area in redwood plots (healthy and diseased combined) is approximately 2.14 m^2 (23 ft^2) per 0.05 ha, and the average tanoak basal area in Douglas-fir plots (healthy and diseased combined) is approximately 1.49 m^2 (16 ft^2) per 0.05 ha. Also, note that Douglas-fir plots (both healthy and diseased), as compared to redwood plots (both healthy and diseased) contain considerably more basal area of tree species other than tanoak and the dominant species. Our results show that redwood forests, with the specified minimum tanoak component, consist almost entirely of redwood and tanoak.

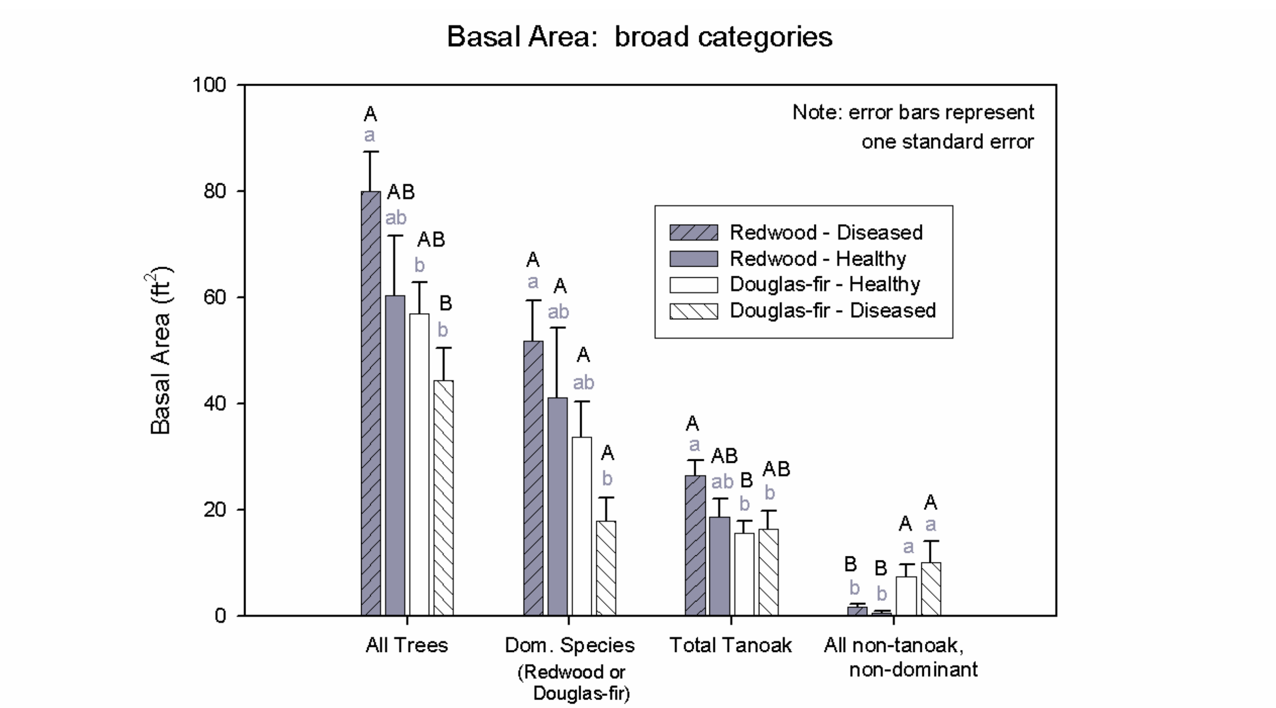

Figure 2.5: Basal area of all tree species combined, dominant species (redwood or Douglas-fir), tanoak (any health status), and all trees other than tanoak or the dominant species. The distribution for "All non-tanoak, non-dominant" deviates considerably from normality, even after transformation.

Cover classes of major vegetation and substrate categories

Figure 2.6 displays average cover classes for major vegetation and substrate categories within our sample plots. Note the differences in total canopy cover for healthy redwood vs. diseased redwood plots. Total canopy cover for healthy redwood plots was significantly higher than for diseased redwood plots, and this relationship was consistent whether measured with a spherical densiometer ("Can – S.D.") or estimated visually ("Canopy").

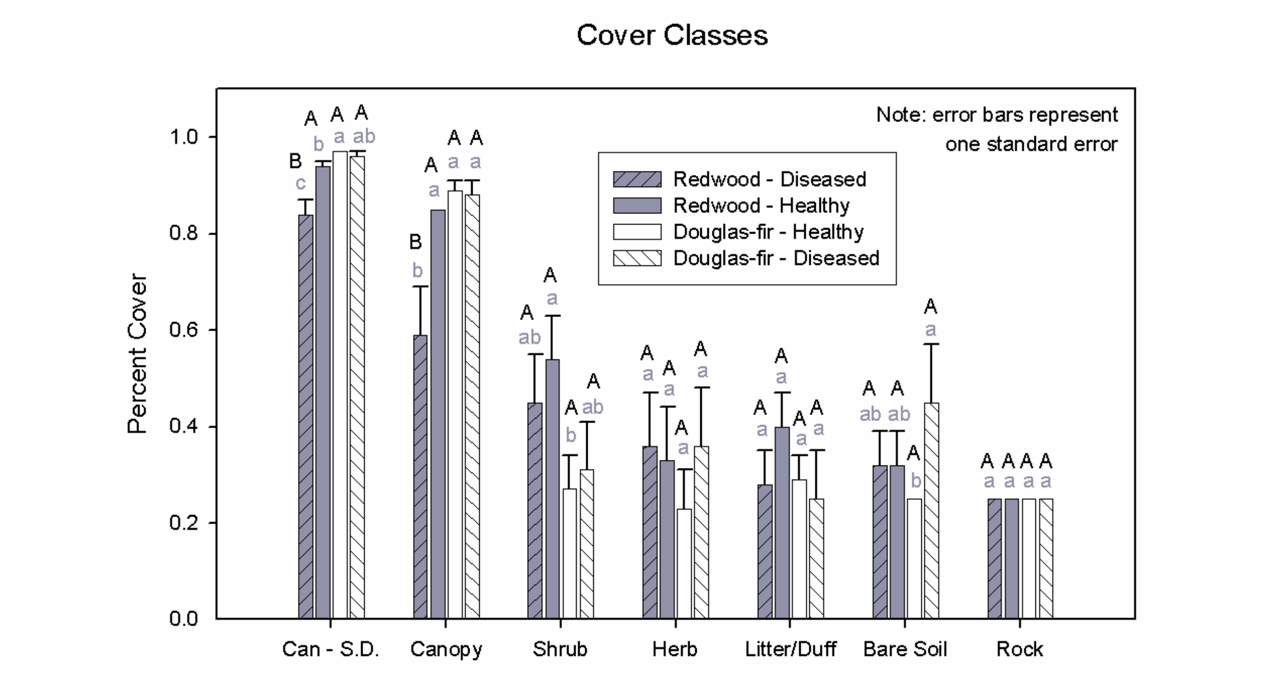

Figure 2.6: Cover classes of major vegetation and substrate categories. Can – S.D. = canopy cover as calculated with a spherical densiometer; all other cover classes (Canopy, Shrub, Herb, Litter/Duff, Bare Soil, Rock) are visual estimates. All distributions deviate somewhat from normality, but only "Herb", "Bare Soil", and "Rock" are severely skewed after transformations.

Regeneration

Figures 2.7 and 2.8 display broad categories of tree regeneration, as well as regeneration of individual species. In all four strata, tanoak regeneration is greater than the sum of all other species. Aside from tanoak, redwood is the most prolific regenerating species in redwood forests, and California bay is the most prolific regenerating species in Douglas-fir forests. It appears as if a regenerative response to tanoak mortality may be occurring in diseased redwood plots, with regard to redwood regeneration, but the difference between healthy redwood and diseased redwood plots is not statistically significant because of the tremendous variability in the diseased redwood stratum.

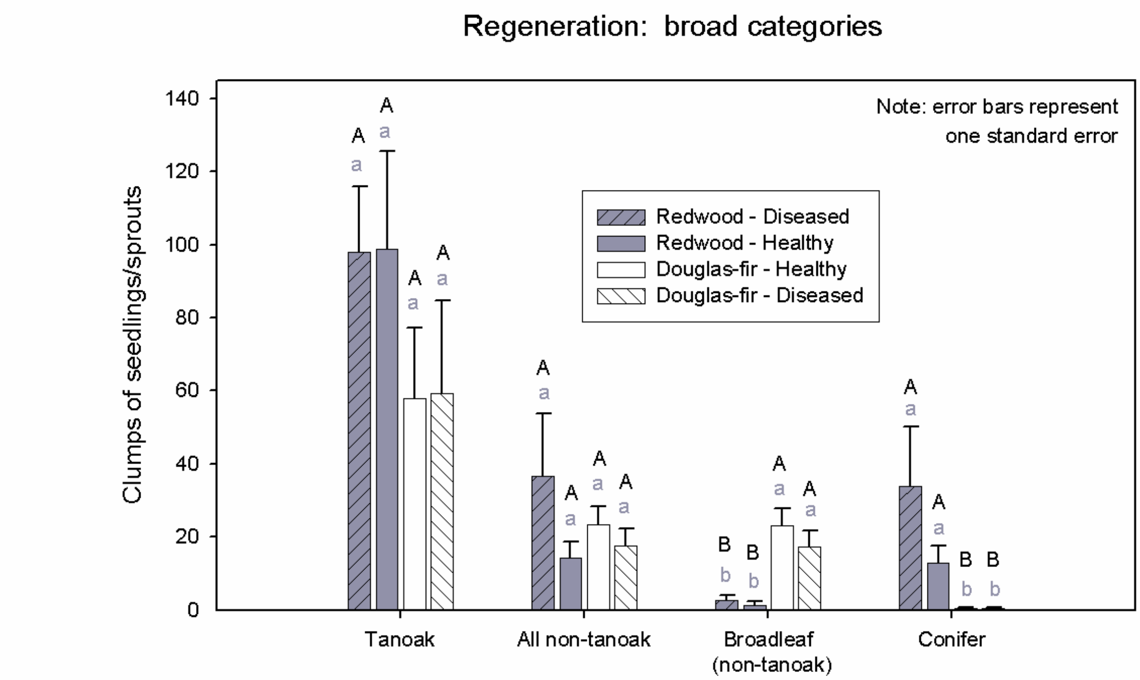

Figure 2.7: Regeneration of tanoak and all other tree species, broadly categorized. Distributions for "Broadleaf (non-tanoak)" and "Conifer" deviate considerably from normality, even after transformations.

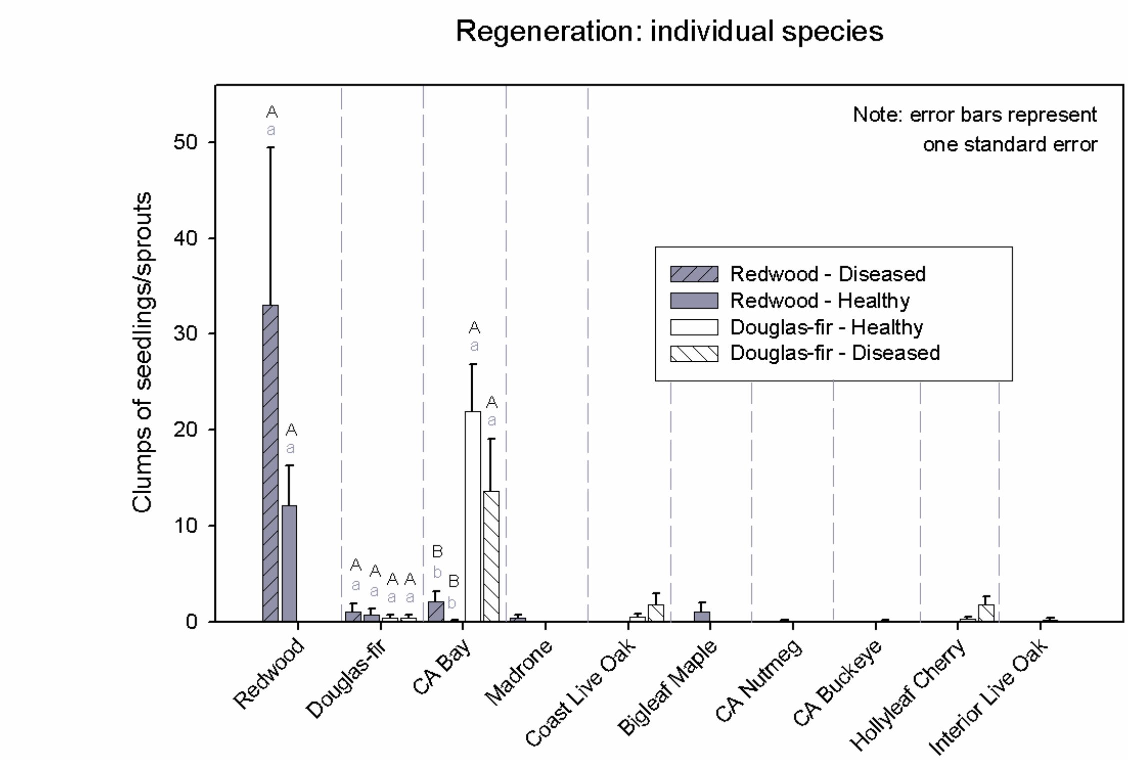

Figure 2.8: Regeneration by species: CA Bay (*Umbellularia californica*), Madrone (*Arbutus menziesii*), Coast Live Oak (*Quercus agrifolia*), Bigleaf Maple (*Acer macrophyllum*), CA Nutmeg (*Torreya californica*), CA Buckeye (*Aesculus californica*), Hollyleaf Cherry (*Prunus illicifolia*), Interior Live Oak (*Quercus*

wislizeni). Statistical tests were only conducted for redwood and California bay regeneration. Douglas-fir plots (both healthy and diseased) were excluded from the analysis of redwood regeneration, because redwood was entirely absent from Douglas-fir plots. Tanoak regeneration is displayed on Figure 2.7. Significance tests across all strata were only conducted for California bay and Douglas-fir, because of an excess of zero values for all other species. Redwood regeneration, which was not observed in any Douglas-fir plots, was tested only between healthy redwood and diseased redwood plots. The distributions for both California bay and Douglas-fir deviate considerably from normality.

Species richness

Native species richness of all trees, broadleaf trees, coniferous trees, shrubs, herbs, and all vascular plants are shown in Figures 2.9 and 2.10. Average tree species richness is between 3 and 4.5 for all strata, indicating that tanoak represents a considerable proportion of native tree species richness, in areas where it is currently abundant. Average richness of tree species is lower in both redwood strata than in both Douglas-fir strata, but the differences are not statistically significant. Richness of shrubs and broadleaf trees is considerably higher in Douglas-fir plots than in redwood plots, and total species richness is substantially higher in diseased Douglas-fir plots than in any other stratum, a pattern that appears to result primarily from the species richness of herbaceous plants. Exotic species richness is not shown on these figures because confirmed presence of exotics was negligible.

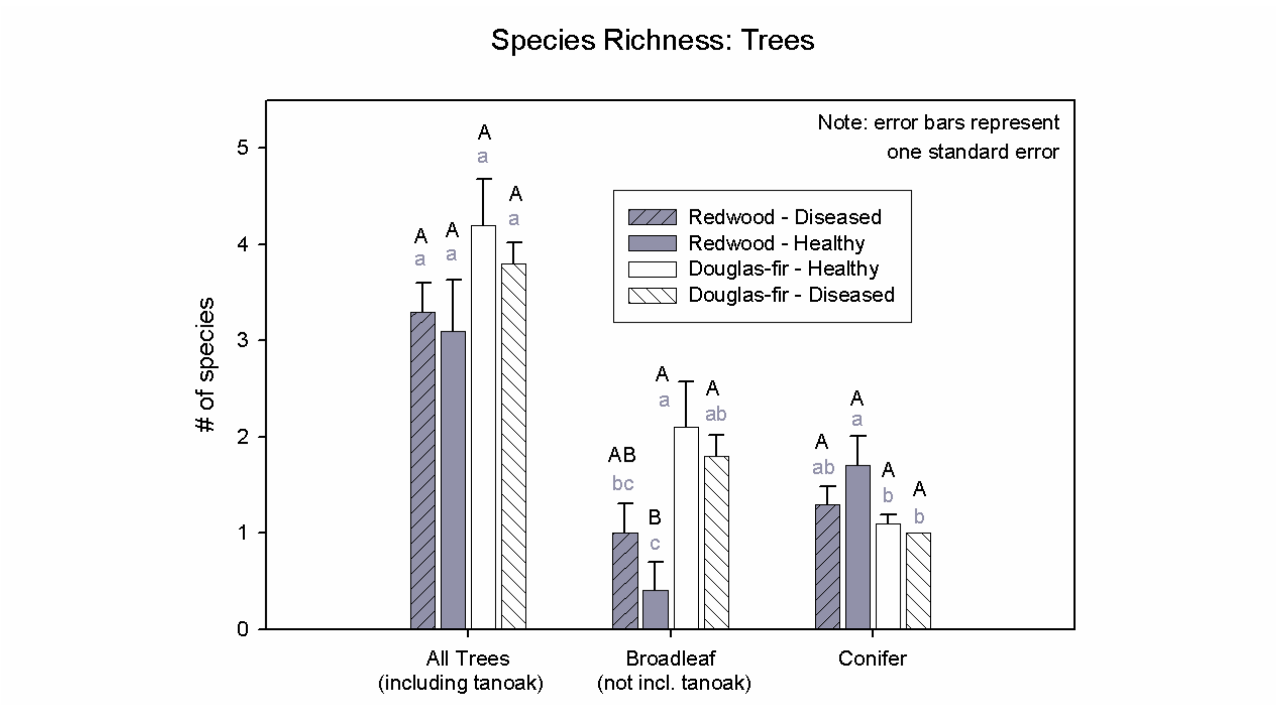

Figure 2.9: Species richness of native trees. Distributions for “Broadleaf (not incl. tanoak)” and “Conifer” deviate considerably from normality, even after transformations.

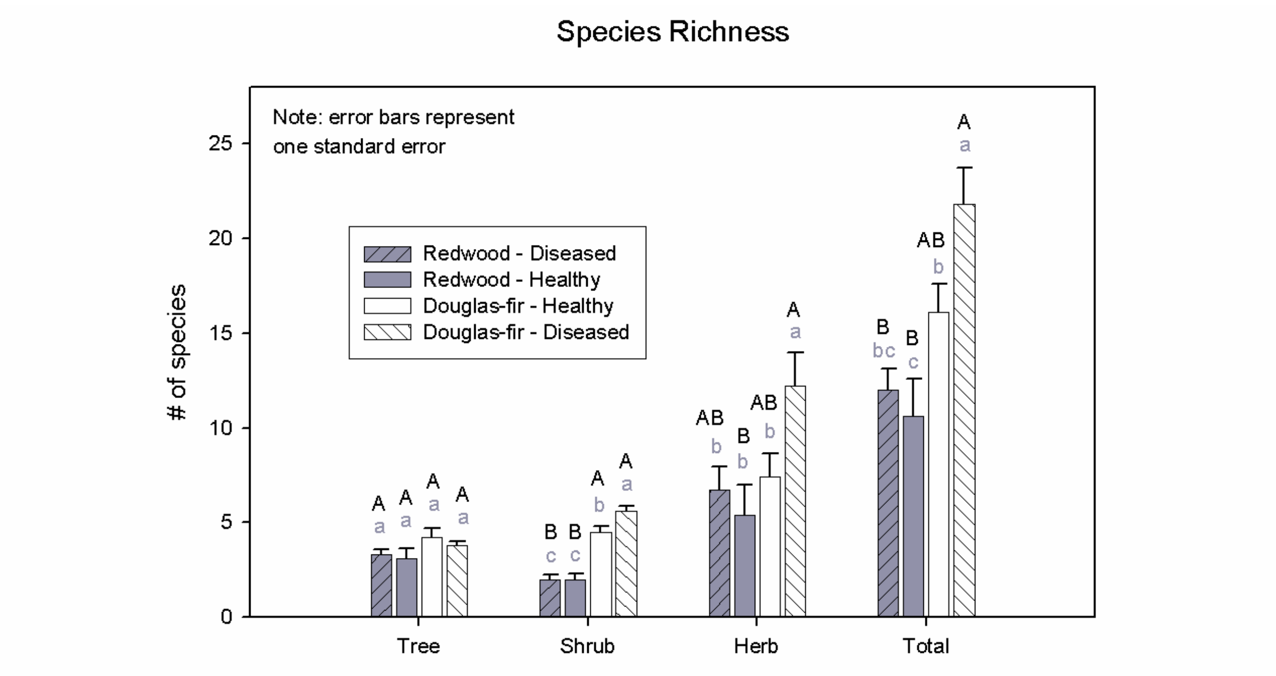

Figure 2.10: Species richness of native plants. "Total" refers to vascular plant species only. All distributions, some of which required transformation, are approximately normal

Species composition: trees & shrubs

All woody species found in our long-term monitoring plots are displayed in Table 2.2, along with indications of the proportion of plots in each stratum in which each species is represented. Results in Table 2.2 are simple presence/absence data; size classes and relative abundance of each species are not provided. Statistical tests were not performed for any measures of species composition. Tanoak and the dominant species (redwood or Douglas-fir) are present in 100% of study plots because of the mandates of our study design. Redwood does not appear in any Douglas-fir plots, but note that Douglas-fir occurs in nearly half of redwood plots. Our plot selection criteria explicitly exclude Douglas-fir individuals greater than 10 cm DBH from redwood plots, but seedlings and small trees were common.

Some species are common throughout all strata (e.g. *Vaccinium ovatum, Lonicera hispidula*), while others seem to be correlated with vegetation type. Several species are much more common in Douglas-fir plots (e.g. *Umbellularia californica, Toxicodendron diversilobum, Rubus ursinus*) than in redwood plots, and some species that are fairly common in Douglas-fir plots are entirely absent from redwood plots (e.g. *Prunus illicifolia, Corylus cornuta, Rhamnus californica*). *Prunus illicifolia* was represented solely as seedlings or saplings; none of our plots contained individuals greater than 3 cm DBH. There are also several uncommon species which appeared only once in our plots (e.g. *Acer macrophyllum, Aesculus californica, Pinus muricata, Quercus wislizenii, Torreya californica*).

The presence of some species appears to be related to disease status. For instance, *Prunus illicifolia, Rubus ursinus, and Ribes* sp. are more prevalent in diseased Douglas-fir plots than in healthy Douglas-fir plots. The occurrence of *Arbutus menziesii* is higher in diseased redwood plots as compared to healthy redwood plots, and the reverse is true for Douglas-fir and "*Prunus/Malus*". Paradoxically, *Umbellularia californica* is more common in healthy plots in our Douglas-fir strata, and more common in diseased plots in our redwood strata. It is important to point out that we are unable to definitively conclude whether these relationships are caused by SOD, have arisen via correlations with undetected factors, or are simply statistical artifacts. Additionally, note that the total number of shrubs occurring in each vegetation type is nearly indistinguishable (redwood = 7, Douglas-fir = 9), despite significant differences in average shrub species richness per plot (see Figure 2.10).

Redwood				**Douglas-fir**			
	All	**H**	**D**		**All**	**H**	**D**
n	(14)	(7)	(7)	**n**	(15)	(10)	(5)
Trees				Trees			
Lithocarpus densiflorus	1.00	1.00	1.00	*Lithocarpus densiflorus*	1.00	1.00	1.00
Sequoia sempervirens	1.00	1.00	1.00	*Pseudotsuga menziesii*	1.00	1.00	1.00
Pseudotsuga menziesii	.45	.57	.29	*Umbellularia californica*	.87	1.00	.60
Umbellularia californica	.36	.14	.57	*Prunus illicifolia*	.40	.30	.60
"*Prunus/Malus*"	.29	.43	.14	*Quercus agrifolia*	.40	.40	.40
Arbutus menziesii	.21	.14	.43	*Arbutus menziesii*	.20	.20	.20
Acer macrophyllum	.07	.14	0	*Aesculus californica*	.07	.10	0
Torreya californica	.07	.14	0	*Pinus muricata*	.07	.10	0
				Quercus wislizenii	.07	.10	0
Shrubs				Shrubs			
Vaccinium ovatum	1.00	1.00	1.00	*Lonicera hispidula*	.93	1.00	.80
Lonicera hispidula	.57	.57	.57	*Toxicodendron diversilobum*	.93	.90	1.00
Rubus ursinus	.14	.14	.14	*Corylus cornuta*	.80	.70	1.00
Hedera helix	.07	.14	0	*Vaccinium ovatum*	.73	.80	.60
Rosa sp.	.07	.14	0	*Rubus ursinus*	.67	.50	1.00
Toxicodendron diversilobum	.07	0	.14	*Rhamnus californica*	.40	.40	.40
Unidentified A	.07	0	.14	*Ribes* sp.	.20	0	.60
				Hedera helix	.07	.10	0
				Unidentified B	.07	.10	0

Table 2.2: Proportion of plots, by stratum, in which each woody species occurs. "*Prunus/Malus*" refers to small woody seedlings that could not be identified, but that looked as if they could belong to the *Prunus* or *Malus* genera. "Unidentified A" and "Unidentified B" refer to small woody individuals that occurred only once and could not be identified; we considered these individuals to be shrubs because vegetative characteristics did not match any tree species known to occur in PRNS.

Exotic plants

Exotic species were conclusively identified in only two plots: one healthy redwood plot, and one healthy Douglas-fir plot. In both cases, the exotic species was English ivy (*Hedera helix*). However, it is worth noting that we were unable to identify some small and/or young individuals which were represented by limited populations, including some grass species. As such, it is possible that other exotics are present in our study plots, although any such species do not appear to have established sizable populations at this time. As an example, four plots contained very small woody seedlings (approximately 1 or 2 individuals per plot) that looked as if they could be *Prunus* or *Malus* species, but were clearly not *Prunus illicifolia*, which is native to PRNS. Possible candidate species include *Prunus cerasifera* and *Malus sylvestris*, both of which are exotic and known to occur at PRNS, as well as *Malus fusca*, which is native to coastal California, but has a more northern distribution (Hickman, 1996) and is not listed on official species lists for PRNS. These "*Prunus/Malus*" individuals occurred in three healthy redwood plots and one diseased redwood plot. *Hedera helix* and "*Prunus/Malus*" were not included in native species richness tallies (Figures 2.9 and 2.10), but several other unidentified plants (all of which were very small) were included in native richness tallies because we had no reason to assume such species were exotic.

Fuels

Mean total fuel loading (1, 10, 100 and 1000 hour fuels, litter and duff) for all transects was 62.79 tons per acre (TPA) (range 11.82-148.12), when calculated with PNRS species-specific fuels coefficients (Appendix I). Mean surface fuel loading (1, 10, 100, and 1000 hour fuels only) for all transects was 14.64 TPA (range 1.45 – 50.84). Most of the variation in surface fuel weights between transects was in 1000 hour fuels. Fuel loading for 1, 10, and 100 hour fuels only (the primary fuels that carry surface fire) ranged from 0.64 to 17.74 TPA, with a mean of 4.39 TPA. 1000 hour fuels, both sound and rotten, averaged 10.25 TPA. Distributions of surface fuel loading were generally skewed right. Ground fuel measurements yielded mean litter fuel loading of 12.65 TPA, and mean duff fuel loading of 35.50 TPA.

When comparing strata, mean surface fuel loading (1-1000 hour fuels) in diseased redwood plots was significantly higher ($p < 0.05$) than healthy redwood plots. Healthy redwood plots were not significantly different from healthy Douglas-fir plots. Healthy Douglas-fir and diseased Douglas-fir plots were also not significantly different from each other (Figure 2.11, appendix). Higher surface fuel loads in diseased redwood plots can be accounted for primarily by presence of 1000 hour fuels, as loadings of 100-hour fuels and smaller were not significantly different between strata (Figure 2.11, appendix). Litter fuel loads were not significantly different between strata. Duff fuel loads in healthy Douglas-fir plots were significantly higher than in both diseased Douglas-fir plots and healthy redwood plots. Examining total fuel loads (1-1000 hr fuels + litter + duff), diseased redwood plots were significantly higher than healthy redwood plots, while healthy Douglas-fir plots were significantly higher than diseased Douglas-fir plots. This latter finding can primarily be accounted for by high duff fuel loads in healthy Douglas-fir plots. Healthy redwood and healthy Douglas-fir plots were not significantly different from each other in their total fuel loads.

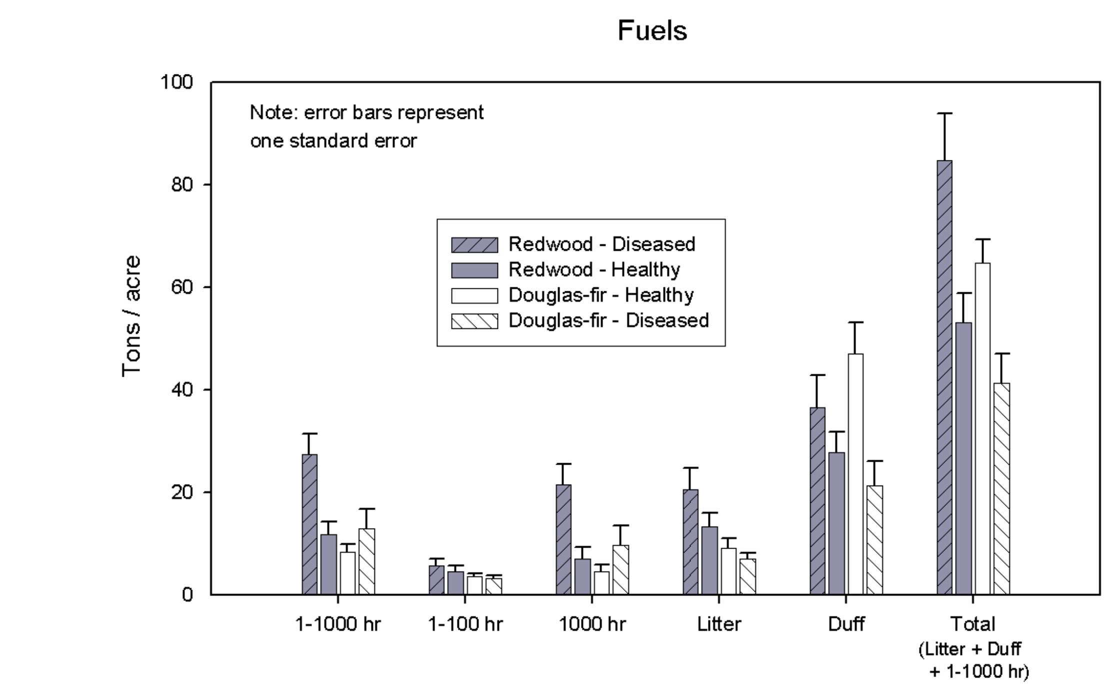

Figure 2.11: Fuel loading by forest type and disease status.

DISCUSSION

Of the coniferous forest types of PRNS, redwood forests appear to be experiencing the greatest impacts from SOD-induced tanoak mortality, with respect to proportional species richness, functional diversity (i.e. broadleaf and coniferous trees), and basal area contribution. However, inferences drawn from this study cannot apply to all redwood or Douglas-fir dominated areas within PRNS, but only to areas containing at least the specified minimum of tanoak basal area (0.92 square meters per 0.05 hectare). We do not have rigorous quantitative data comparing the relative abundance of tanoak in redwood vs. Douglas-fir forests, but our field observations suggest a much greater abundance of tanoak in redwood forests. Also, our rapid assessment phase found that redwood forests contained the highest cover of tanoak of the three forest types studied. Other coniferous forest types, such as those dominated by Bishop pine (*Pinus muricata*) do not exhibit significant numbers of SOD host species, and as such, they are unlikely to be seriously impacted.

Tanoak mortality and disease progression

Mortality of tanoak is greater than 95% of basal area in several of our redwood and Douglas-fir plots, and in some cases only 2% of basal area is still asymptomatic. Figure 2.5 shows that redwood forests, with the specified minimum tanoak component, consist almost entirely of redwood and tanoak, while Douglas-fir forests exhibit significant basal area of other tree species (primarily California bay). This finding suggests that the impacts of SOD-induced tanoak mortality, at least in the short-term, will reduce the diversity of redwood forests more than Douglas-fir forests. At the same time, the average percent of total basal area accounted for by tanoak is indistinguishable between forest types (see Figure 2.4), and as such, the impact of tanoak decline as measured by proportion of total basal area is equivalent for redwood and Douglas-fir forests. If all tanoak trees in our plots eventually succumb to SOD, approximately 35% of total basal area will be lost. The average tanoak basal area in redwood plots (healthy and diseased combined) is approximately 2.14 m^2 (23 ft^2) per 0.05 hectare, and the average tanoak basal area in Douglas-fir plots (healthy and diseased combined) is approximately 1.49 m^2 (16 ft^2) per 0.05 hectare. However, it is important to note that tanoak abundance is not necessarily consistent throughout redwood or Douglas-fir forests, and thus it may be misleading to extrapolate these values to larger areas.

Disease progression seems to be more advanced in our redwood plots (which are all located on Bolinas Ridge) than in our Douglas-fir plots (most of which are located on Inverness Ridge). Diseased Douglas-fir plots exhibit a greater basal area of standing dead trees with 50% or more of dead leaves still clinging to the tree ("Standing, E"), while diseased redwood plots exhibit a greater basal area for all subsequent categories of deterioration (see Figure 2.3). This finding corresponds with records from the OakMapper online web GIS application that indicate *P. ramorum* presence in at least one location on Bolinas Ridge by 2004, but not on Inverness Ridge until 2006. Additionally, PRNS staff confirm that SOD became established in the redwood forests of Bolinas Ridge prior to its establishment on Inverness Ridge (Forrestel, 2007). Finally, an aerial survey of tree mortality conducted in 2005 (also available through OakMapper) shows a much greater extent of mortality on Bolinas Ridge than on Inverness Ridge. However, this aerial survey data cannot prove the observed mortality is SOD, and even if we assume that most mortality has resulted from SOD, this aerial survey data still does not clarify whether differences in mortality have resulted from differences in SOD host abundance or from different stages of disease progression. Both of these factors are probably relevant.

Despite differences in disease progression, it is interesting to note that the total percentage of tanoak that is dead is indistinguishable between diseased redwood and diseased Douglas-fir plots (see Figure 2.4). Furthermore, it appears that similar percentages of asymptomatic and living symptomatic tanoak basal area also occur across diseased redwood and diseased Douglas-fir plots (see Figure 2.2). Does this indicate that some tanoak individuals in the redwood forests of Bolinas Ridge are resistant to SOD? Probably not, as our plot selection criteria was designed to maintain consistency between plots and thus we required that diseased redwood plots contain at least 2 square feet of dead tanoak basal area that was still standing; plots where all dead tanoak was broken/fallen were excluded. Therefore, our results reflect a systematic exclusion of the most extremely impacted areas. In other words, the findings of this study do not provide clear evidence of whether or not some tanoaks are likely to survive in SOD-infested areas. Genetic resistance trials have yet to identify any tanoak genotypes with complete resistance to SOD (Hayden 2007), and thus it is possible that tanoak will be completely eliminated from the lands managed by PRNS.

Our field observations suggest that there is a substantial amount of coast live oak, another species susceptible to SOD, within Douglas-fir forests, including on the west side of Inverness Ridge. Our rapid assessment of pathogen distribution did not find any *P. ramorum* west of the ridge crest, but if the pathogen does eventually establish on the west side, it is possible that Douglas-fir forests could be impacted by considerable coast live oak mortality. However, there is also a notable amount of coast live oak in Douglas-fir forests currently experiencing substantial tanoak decline, and we did not observe nearly as much mortality of coast live oak. This observation is in agreement with research that has identified tanoak to be the most susceptible species (Rizzo et al. 2005).

Cover classes of major vegetation and substrate categories

Many of the differences in cover classes for major vegetation and substrate categories are difficult to interpret, with the exception of the reduced canopy cover in diseased redwood plots as compared to all other strata. This difference is clearly a result of the considerable tanoak mortality that has occurred in this stratum. As is shown in Figures 2.2 and 2.3, much of the tanoak in our diseased redwood plots has died and begun to deteriorate, thus diminishing the canopy and allowing more light to reach the forest floor. Visual estimates of canopy cover ("Canopy") are less than spherical densiometer measurements ("Can – S.D.") for two reasons: a) in several cases large shrubs or small trees occurred at plot center, obscuring much of the sky when measured with the spherical densiometer, and b) the concavity of the spherical densiometer resulted in an area larger than the size of our plots being sampled, and this extra-plot area was not necessarily suffering tanoak mortality. In contrast to redwood plots, canopy cover is indistinguishable between healthy Douglas-fir plots and diseased Douglas-fir plots. This discrepancy in SOD-induced canopy cover reductions between vegetation types is not an inherent quality of the vegetation type, but instead results from the lesser disease severity in Douglas-fir plots. It is likely that as SOD progresses in diseased Douglas-fir plots, canopy cover reductions will parallel those currently exhibited in redwood plots. Other cover classes with significant differences (e.g. shrub, bare soil) are inconsistent across forest type and health condition, and we will not venture to interpret these results at this time.

Regeneration

Our regeneration data suggests that as tanoak declines in SOD-infested areas, it will be replaced primarily by redwood in redwood forests, and primarily by California bay in Douglas-fir forests. However, we believe that insufficient time has passed to observe a full regenerative response. Recruitment of Douglas-fir and other relatively shade intolerant tree species may increase considerably as SOD-induced tanoak mortality progresses and light levels rise. Although Douglas-fir regeneration is proportionally negligible in all plots at the present time, mature individuals are dominant throughout the Douglas-fir strata, and Douglas-fir seedlings, saplings, and/or small trees are present in nearly half of all redwood plots. If Douglas-fir recruits prove to be superior competitors, and/or recruitment increases considerably as light levels increase, it is possible that tanoak could be replaced by Douglas-fir in many areas. Additionally, other uncommon tree species (see Figure 2.8) may respond more slowly to the changing competitive environment, ultimately taking advantage of the space and resources made available by the decline of tanoak.

Regeneration by tanoak is currently dwarfing regeneration by all other species, but it is unlikely that tanoak will successfully grow to maturity in SOD-infested forests for the following reasons: a) all ages of tanoak are susceptible to SOD, b) genetic resistance trials have detected no tanoak genotypes with complete resistance, and c) *P. ramorum* persists as a sub-lethal foliar pathogen on dozens of native species (and is therefore likely to have become a permanent resident of PRNS) (Rizzo et al. 2005, Hayden 2007). However, we should not entirely discount the possibility that tanoak will persist, perhaps in a stunted form, in SOD-impacted areas. Large masses of shrub-like tanoak stump sprouts, arising from the root systems of boles girdled by SOD, have been known to survive for at least a few years in some areas heavily impacted by SOD (e.g. Muir Woods) (Forrestel, 2007). At this point, it is not known if tanoak root systems will necessarily die, and even if all tanoak root systems do eventually die, transient but robust sprout clumps may inhibit recruitment and slow forest regeneration.

Species richness and composition

Tanoak represents a considerable proportion of tree species richness and total woody species richness in both redwood and Douglas-fir forests. In redwood forests, which are especially species poor, average tree species richness is 3.2 and average shrub species richness is 2.0 within our study plots. In our Douglas-fir plots, average tree species richness is 4.1 and average shrub species richness is 4.9. As such, the loss of tanoak will represent a greater proportional reduction of total woody species richness in redwood forests.

We found species richness of native broadleaf trees to be lower in redwood plots (healthy and diseased) than in Douglas-fir plots (healthy and diseased) (see Figure 2.9). The opposite trend, greater richness in redwood plots, occurs with respect to conifer regeneration, but the relationship is not as pronounced. These results provide additional support for the prediction that redwood forests will move towards increasing conifer dominance as tanoak declines, while Douglas-fir forests may retain a more balanced mixture of coniferous and broadleaved trees.

Unidentified "*Prunus/Malus*" seedlings occur in 29% of all redwood plots, but are never represented by more than a few individuals. Throughout all of our travels within the natural areas of PRNS, we were unable to locate any mature trees or shrubs that looked as if they could be the species in question. These observations suggest that "*Prunus/Malus*" is not able to successfully establish in the area, despite the apparent lack of dispersal or germination limitations. However, several qualifications must be amended to the above statement. First, it is possible that this species – which may be native or exotic – is in the process of a range expansion that is unrelated to SOD, implying that simply not enough time has passed for the growth of mature individuals. Second, there is the potential that the loss of tanoak will alter the competitive environment such that "*Prunus/Malus*" will be able to thrive in tanoak's former niche.

The sharp spike in herb species richness in diseased Douglas-fir plots is somewhat puzzling given the relatively early stage of disease progression in these plots. Perhaps a rich soil seed bank is present in the Douglas-fir forests of PRNS, and some trigger (e.g. slightly higher light levels resulting from tanoak canopy decline) has instigated germination of species that tend to remain dormant in darker forest understories (e.g. where tanoak canopies are full and green). Unfortunately, our data do not clearly indicate the particular herbaceous species accounting for the elevated richness in diseased Douglas-fir plots. Many of the observed species were very small and not flowering, and therefore could not be conclusively identified; however, we carefully compared similar individuals within each plot, ensuring that a single species was not accidentally counted as two or more species. As a result, we are confident that our plot-level richness numbers are accurate, despite our inability to identify all species. We suggest that subsequent monitoring be conducted at another time of the year (e.g. spring) to increase the probability of observing flowers.

Exotic plant invasion

Although we did not find conclusive evidence that SOD is increasing the invasibility of redwood or Douglas-fir forests, it would be irresponsible to dismiss this threat entirely. It is possible that simply not enough time has passed for exotic plant propagules to disperse to tanoak mortality gaps. Additionally, because we were unable to identify some small and/or young individuals, other exotic species may already be present. As an example, several plots contained grasses that could be *Ehrharta* sp., but for which conclusive identification was not made. However, all unidentified species were represented by very small populations that covered less than 1% of our plots, and thus any current invasions are limited in severity. Furthermore, we did not detect any patterns relating to disease status. For instance, unidentified grasses occurred in roughly 40% of plots, but were evenly distributed between healthy and diseased plots, and both plots containing

English ivy were in healthy strata. Nonetheless, there is still potential for the decline or elimination of tanoak to alter the competitive environment such that uncommon species, native or exotic, will be able to establish and persist in redwood and/or Douglas-fir forests. In conclusion, more time must pass before the threat of invasion can be adequately assessed.

Fuels

Our hypothesis that there would be no difference in fuel loading between Douglas-fir and redwood plots was confirmed when comparing healthy plots from the two forest types to each other. This helps us to establish a baseline for effective comparison of fuels between forest types. As mentioned previously, we did not compare diseased Douglas-fir and diseased redwood plots to each other due to differences in our initial plot selection criteria. We also hypothesized that fuel loads in healthy plots would be lower than in diseased plots of the same species. This was true for redwood plots but not true of Douglas-fir plots, which helps to confirm our observations that redwood plots are farther along in disease progression than Douglas-fir plots (Figure 2.2). In fact, healthy Douglas-fir plots had higher total fuel loads (litter, duff, and 1-1000 hr. fuels) than diseased Douglas-fir plots, primarily due to higher duff loads. This remains unexplained, but long-term monitoring may further reveal trajectories of fuel loading in diseased versus healthy plots, and we expect that as diseased plots continue to deteriorate we will see an increase in ground fuels in these plots as well.

It appears that as SOD infected tanoaks die and structurally degrade, 1000 hour fuels accumulate through stem breakage and treefall, at least in redwood-tanoak forests. Litter fuels showed similar results, with mean litter fuel loading highest in diseased redwood plots, though this difference was not significant. Duff fuel loading was also highest in diseased redwood plots. SOD infection thus has the potential in redwood-tanoak forests to increase surface and ground fuel loads drastically in forested areas with tanoak components similar to those studied here. However, because this potential increase appears to be primarily in 1000 hour fuels and duff, it may not change potential fire behavior at the flaming front significantly. The primary fuels that carry fire at the flaming front are 1, 10, and 100 hour fuels, and forest floor litter. These fuels respond to atmospheric moisture changes much more quickly than either 1000 hour fuels or duff fuels which typically burn in smoldering or post-frontal combustion. Increases in 1000 hour fuels or ground fuels are important ecologically however, since they may increase total heat output and residence time of fires, which can have consequences for plant survival, seed banks, soils, and many other ecosystem elements. Increased input of large woody debris and organic matter (duff) may also have effects on ecosystem function and elements, such as nutrient cycling and insects. Because Douglas-fir forests appear to be earlier in disease progression, long term-monitoring will help determine if the same holds true for these areas.

CHAPTER 3

Conclusions and Management Implications

The Rapid Assessment (Phase 1 of this project) provided us with valuable information on the current location and extent of *P. ramorum* infection. It also provided us with a starting point for more detailed study and long-term monitoring of SOD (Phase 2 of this project). The following are the major findings of Phase 1.

- Of the 74 different foliar sample locations, 29 (39%) tested positive for *P. ramorum*. The pathogen was found in all three major vegetation types sampled. Results were consistent with prior opportunistic testing done by the NPS and park volunteers. Centers of infection appear to be Bolinas Ridge, Bear Valley/Limantour Road, and Five Brooks areas.
- If we infer from the proportions of our randomly located plots that tested positive for infection, as much as 63% of RDW forests, 45% of CLO forests, and 24% of DGF forests may be infected with *P. ramorum*.
- In terms of susceptible species, 15 plots (31%) had some component of tanoak, while 17 plots (35%) contained some coast live oak.
- Positive tests for *P. ramorum* did not appear to be correlated with slope, aspect, elevation or broad cover classes of vegetation. We were able to predict infection with some accuracy using a five-point "likelihood of infection" rating.
- Baiting of perennial streams west of the crest of Inverness Ridge all resulted in negative tests for *P. ramorum* infection. Results may have been influenced by a relatively dry preceding winter and spring.
- Patchiness of the disease was on the order of tens to hundreds of meters in forests with a tanoak component, suggesting the use of "paired" plots for Phase 2. Proportions of tanoak (by basal area) varied as well, suggesting the use of maxima and minima of tanoak basal area for Phase 2, in order to effectively compare plots.

Continued testing for the pathogen *P. ramorum* throughout PRNS is highly recommended. It appears that some areas of the Seashore (Bolinas Ridge) have been affected for longer than others (Inverness Ridge), and that the disease is already having impacts in terms of regeneration, fuel loading, canopy cover, and diversity. Thus it is important to track how and where the disease is spreading. Additional foliar testing of random locations throughout the range of host vegetation within the seashore would provide finer scale tracking of disease progression. This may be accomplished with volunteers, as training for this type of sampling is minimal. Most of the effort in this type of sampling will be in travel to remote locations off trail. Further testing may also be beneficial in the California bay-coast live oak forests in the northeastern portion of the seashore, as this area has not been sampled as densely. Foliar sampling efforts should focus on areas east of the crest of Inverness ridge, since SOD susceptible species are far rarer on the western side. Continued stream baiting on the western side of Inverness ridge, however, would be a relatively quick way to assess whether the pathogen is present or spreading there. This may also be accomplished with volunteers and minimal effort. If the pathogen is detected by stream baiting, subsequent foliar sampling would provide finer scale resolution on location of infection.

The experimental design employed in Phase 2 of this study has allowed us to infer short-term impacts and to predict some long-term impacts of SOD with only one year of data, while simultaneously enabling the collection of baseline data for long-term monitoring plots. Our first year data has provided an initial understanding of how two different ecosystems are being affected by and will likely respond to SOD. This research serves as a starting point for answering the following important questions and illuminating the processes by which the outcomes arise. Will tanoak be replaced by other hardwood species in conifer-dominated ecosystems? Or will SOD permanently and severely reduce the hardwood component? Will the abundance of fuels created by dead and dying tanoak trees create different fire risks in different ecosystems? When will these risks be greatest? Is SOD increasing the risk of exotic plant invasion? The major findings of Phase 2, our preliminary answers to these questions, are as follows. These findings do not apply to all redwood and Douglas-fir forests within PRNS, but rather only to areas with a considerable tanoak component.

- Tanoak comprises an average of one third of total basal area within our redwood and Douglas-fir plots. If all tanoak trees eventually succumb to SOD, a substantial proportion of total basal area will be lost.
- In several plots, tanoak mortality is greater than 95% by basal area. Our protocol systematically excluded the most severely impacted areas of the park and thus it is entirely possible that tanoak mortality has reached 100% in some locales.
- Disease progression appears to be more advanced in the redwood forests of Bolinas Ridge than in the Douglas-fir forests of Inverness Ridge.
- Total canopy cover is reduced in our diseased redwood plots, as compared to healthy redwood plots, and a regenerative response is evident. Such relationships are not yet apparent in our Douglas-fir plots.
- Our data suggest that as tanoak declines in SOD-infested areas, it will be replaced primarily by redwood in redwood forests, and primarily by California bay in Douglas-fir forests. However, because a full regenerative response has not yet occurred, this finding should be regarded as preliminary.
- Tanoak regeneration is currently dwarfing regeneration by all other species in both healthy and diseased plots. However, research by others suggests that tanoak is unlikely to survive to maturity in areas infested with SOD.
- Tanoak represents a substantial proportion of tree species richness and total woody species richness in both redwood and Douglas-fir forests. In our redwood plots, which are species-poor in comparison to our Douglas-fir plots, tanoak accounts for an average of one third of tree species richness and one fifth of total woody species richness. If tanoak is eventually eliminated by SOD, the species richness of redwood forests will be severely reduced.
- Douglas-fir plots exhibit, on average, a greater number of broadleaf tree species than redwood plots. As such, the loss of tanoak will impact the functional diversity of redwood forests more than that of Douglas-fir forests.
- We have not found evidence that SOD-induced tanoak mortality has increased the threat of exotic plant invasion. However, as disease progression continues, opportunities for invasion may increase and therefore we do not recommend dismissing this threat.
- Mean total fuel loading (1, 10, 100, and 1000 hour fuels, litter and duff) for all transects was not different between healthy redwood and healthy Douglas-fir plots. It was greater in diseased redwood plots than in healthy redwood plots. Total fuel loading was greater

in healthy Douglas fir plots than in diseased Douglas-fir plots. Much of the variation in fuel weights can be accounted for by variation in 1000 hour fuels and duff. In terms of fire hazard, SOD may be impacting redwood-tanoak forests by increasing 1000 hour fuels.

It is likely that many of the impacts of SOD-induced tanoak mortality have yet to become apparent, especially in the Douglas-fir forests of the Inverness Ridge, and thus monitoring in subsequent years will provide much more accurate answers to the above questions. We have found that nearly every stand of tanoak within PRNS is already impacted by SOD, and thus we believe that emphasis should be placed on understanding the effects of this disease, and considering restorative and/or ameliorative management actions. Some disease effects are being considered here (fuels, plant composition and structure, regeneration, invasive species), but many other impacts are possible. Tanoak acorns are large, abundant, and highly nutritious, and serve as a valuable food source to many animals (including deer and several rodent and bird species) (Tappeiner et al. 1990). Therefore, the loss of tanoak may result in serious cascading impacts, the severity of which will be largely determined by the wildlife value and relative abundance of the species replacing tanoak. Changes in soils resulting from large woody debris, disruption of mycorrhizal networks, changes in abundance of opportunistic decay fungi and insects are among other potential impacts that have been suggested (Rizzo et al., 2005).

Re-measurement of study plots over the next several years will improve predictive ability and provide critical clues as to the trajectory of redwood and Douglas-fir forests within PRNS. Early detection of undesirable trends (e.g. drastic reduction of hardwoods within redwood forests) will be essential for management decisions and prioritization of restoration needs (e.g. planting of tree seedlings or more active protection of specific locations). Mechanistic studies aimed at identifying the factors limiting the establishment of uncommon tree species (e.g. dispersal limitation, competition with redwood and/or tanoak) would help to inform the feasibility of strategic interventions. Expansion of this study to include California bay-coast live oak forests would provide crucial information about the third forest type within PRNS with potential for serious impacts from sudden oak death.

Recommended monitoring schedule

Re-measurement of existing plots in other SOD research and monitoring projects has ranged from sub-annual to multi-annual in frequency, depending on the purpose of the study and variables being measured (e.g. Swiecki and Bernhardt, 2005; Swiecki and Bernhardt 2006, McPherson et al., 2005). Because this study has two distinct goals (detection and monitoring of pathogen location and spread, and monitoring of disease progression and ecosystem change), we propose two different monitoring schedules. The following are our proposed dates and frequencies for continued testing and monitoring of *P. ramorum* and sudden oak death in PRNS.

- Randomly located foliar testing for *P. ramorum* – annually during spring.
- Stream baiting of the western side of Inverness Ridge – annually during spring.
- Re-measurement of long-term monitoring plots in Douglas-fir and redwood forests – 2009 and bi-annually thereafter in spring/early summer.
- Establishment and monitoring of long-term monitoring plots in California bay-coast live oak forests – 2008 and bi-annually thereafter in spring/early summer.

Continuing to sample for *P. ramorum* presence on an annual scale will be important for tracking disease spread within PRNS, and for prediction of potential impacts. Because *P. ramorum* sporulates most prolifically in wet conditions, foliar sampling and stream baiting should occur in spring or early summer at the latest. For long-term monitoring, the primary focus should be on changes to ecosystem elements such as vegetation composition and structure, regeneration, fuel loading, and exotic plants. Bi-annual re-measurement should be sufficient to assess trajectories of these types of variables. For purposes of plant identification, we recommend that long-term monitoring also occur in spring or early summer.

Other potential management actions

Management actions taken for SOD within PRNS will certainly be guided by overall management goals of the Seashore and the National Park Service. Some potential actions may be in conflict with these goals and mandates. In addition to continued ground-based monitoring of pathogen spread and disease impacts, other actions (Rizzo et al., 2005) that may be considered include:

- Aerial surveys. Aerial surveys may provide for early detection of infection.
- Proper sanitation practices. Park staff, researchers and volunteers working in known areas of infestation should be vigilant about sanitation. Proper sanitation protocols should be followed to avoid inadvertent transmission of the pathogen from infected areas to uninfected areas. See the California Oak Mortality Task Force website for good examples of protocols (www.cnr.berkeley.edu/comtf).
- Seasonal closures. Short-term closure of infected areas of the Seashore during periods of potentially high pathogen sporulation (rainy season) may be a way to reduce the chances of pathogen spread.
- Prescribed fire. Recent work suggests a possible link between SOD and fire (Moritz and Odion, 2005), but this relationship is most likely complex and is currently not well understood. Prescribed fire for fuel load reduction may be a consideration, but should take into account other ecosystem impacts of fire.
- Stand manipulation. Stand-level treatments such as mechanical removal of infected plants may be effective in reducing pathogen levels or retarding spread, but may have other consequences as well.
- Restoration/Amelioration. Planting and re-vegetation of impacted or treated areas should be considered in the context of management goals and desired future conditions. Early efforts to direct ecological trajectories may be able to efficiently alter characteristics such as species composition and stand structure. For instance, planting of native hardwood trees in redwood forests may help to reduce cascading impacts to wildlife, but such actions may only be feasible while growing space is still available (i.e. prior to a full regenerative response).
- Fungicides. Certain chemical applications have been shown to be effective at preventing infection of individual trees.

Finally, support for continuing research on sudden oak death in PRNS will be vital in understanding the effects of the disease both locally and regionally.

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<u>APPENDIX I: FUELS DATA</u>

	N	Mean	St. Dev.	S.E.Mean	Max	Min	Median
Total (L+D+1-1000)							
all plots	58	62.79	29.52	3.88	148.12	11.82	55.15
Douglas-fir healthy	20	64.77	20.46	4.58	137.87	38.15	63.70
Douglas-fir diseased	10	41.44	17.99	5.69	68.52	11.82	38.57
redwood healthy	14	53.21	21.49	5.74	92.55	19.46	50.16
redwood diseased	14	84.79	34.57	9.24	148.12	36.95	88.60
1-1000							
all plots	58	14.64	12.77	1.68	50.84	1.45	9.82
Douglas-fir healthy	20	8.47	6.84	1.53	28.42	1.45	5.94
Douglas-fir diseased	10	12.99	11.94	3.78	43.00	1.60	9.66
redwood healthy	14	11.82	9.13	2.44	33.75	1.74	8.84
redwood diseased	14	27.44	14.82	3.96	50.84	2.85	24.61
1-100							
all plots	58	4.39	3.53	0.46	17.74	0.64	3.28
Douglas-fir healthy	20	3.79	2.12	0.47	7.26	0.76	3.46
Douglas-fir diseased	10	3.25	2.24	0.71	8.14	0.64	2.75
redwood healthy	14	4.65	4.18	1.12	13.90	0.91	3.04
redwood diseased	14	5.82	4.83	1.29	17.74	1.63	4.82
1000							
all plots	58	10.25	12.05	1.58	46.37	0.00	4.71
Douglas-fir healthy	20	4.68	5.97	1.33	21.40	0.00	2.60
Douglas-fir diseased	10	9.74	12.26	3.88	39.97	0.00	3.89
redwood healthy	14	7.18	8.25	2.20	32.39	0.00	4.71
redwood diseased	14	21.62	14.67	3.92	46.37	0.00	20.65
Litter							
all plots	58	12.65	11.54	1.52	54.72	2.24	9.05
Douglas-fir healthy	20	9.16	9.15	2.05	43.44	2.90	5.71
Douglas-fir diseased	10	7.06	3.98	1.26	14.14	2.24	6.09
redwood healthy	14	13.51	9.78	2.61	34.59	2.82	10.47
redwood diseased	14	20.74	15.52	4.15	54.72	4.97	15.88
Duff							
all plots	58	35.50	23.52	3.09	119.64	3.19	33.51
Douglas-fir healthy	20	47.13	27.11	6.06	119.64	9.39	42.48
Douglas-fir diseased	10	21.39	15.07	4.77	50.56	5.17	19.04
redwood healthy	14	27.87	14.82	3.96	52.11	8.13	25.35
redwood diseased	14	36.61	23.44	6.27	76.47	3.19	34.36

Summary of fuel loading (tons per acre) for long-term monitoring plots in PRNS. Values were calculated using fuel coefficients developed by the National Park Service, and weighted by species - basal area proportion.

APPENDIX II: FIELD FORMS

Point Reyes Sudden Oak Death Project
Rapid Assessment

Plot # ____________

Date		Veg Type	
Names		Slope %	Aspect
Coords	N E	Photo #s	N E
Accuracy	+/-		S W
Elevation			
Tree tag#	Species	Dbh(cm)	Canopy Posn (D,C,I,S)

Location of plot center relative to tagged tree (dist & az) ____________

Ocular estimates
Braun Blanquet: r: rare, insig. t: <1% **1**: 1-5% **2**: 5-25% 3: 25-50% **4**: 50-75% **5**: 75-100%

Total canopy cover ____________ Shrub cover ____________ Herb cover ____________

Woody species

Species	Cover class	Species	Cover class

Other species of note: ____________

Sudden Oak Death / Ramorum Blight Symptoms
Radius 1: 12.62 m (0.05ha plot) **Radius 2**: 28.21m (.25ha plot)

Radius	Species	Symptoms	Notes/Photo#

Overall Likelihood of Infection

Highly likely Likely Possible Unlikely Highly unlikely

SOD Severity Index

0 1 2 3 4 5 6 7 8 9 10

Notes ____________

Samples

Sample #	Radius	Species	Notes

Notes

Watershed / Stream:			
Coords: N	E		Elevation:
Notes:			
Samples In	Date:	Water Temp:	# of Bags:
Notes:			
Samples Out	Date:	Water Temp:	
Notes:			
Sample #:	Notes:		

Watershed / Stream:			
Coords: N	E		Elevation:
Notes:			
Samples In	Date:	Water Temp:	# of Bags:
Notes:			
Samples Out	Date:	Water Temp:	
Notes:			
Sample #:	Notes:		

Watershed / Stream:			
Coords: N	E		Elevation:
Notes:			
Samples In	Date:	Water Temp:	# of Bags:
Notes:			
Samples Out	Date:	Water Temp:	
Notes:			
Sample #:	Notes:		

Point Reyes Sudden Oak Death Project
Long-term Monitoring

Plot # ________ H / D ________ Tag #: ________

Date ____________________ Veg Type ____________________
Field Researchers ____________________ Slope % ________ Aspect ________
Coords E ________ N ________ Photo #s N ________ E ________
+/- ________ Elev ________ S ________ W ________
Tree tag# ________ Species ________ DBH(cm) ________ D/C/I/S: ________ plt cntr = ________ m @ ________ °
Tree tag# ________ Species ________ DBH(cm) ________ D/C/I/S: ________ plt cntr = ________ m @ ________ °
Tree tag# ________ Species ________ DBH(cm) ________ D/C/I/S: ________ plt cntr = ________ m @ ________ °

Ocular estimates of cover classes (CC)
Braun-Blanquet CC (%): **r**: rare (<0.5) **t**: <1 **1**: 1-5 **2**: 5-25 **3**: 25-50 **4**: 50-75 **5**: 75-95 **6**: 95-100

Total Cover: Canopy______ Shrub______ Herb______ Litter/Duff______ Bare Soil______ Rock______

Tree Species*	S/S/S, TR	CC	Shrub Species	AVG. HT. (m)	CC	Species	CC

?a = ______________________________ photo #s:__________
?b = ______________________________ photo #s:__________
?c = ______________________________ photo #s:__________

Canopy = foliage ≥ 2m high Shrub = all woody non-tree species Herb = all non-woody species
* for tree species, distinguish between seedlings/sprouts/saplings (S/S/S) [< 3 cm DBH], and trees (TR) [≥ 3 cm DBH]

Sample #	Radius	Species	Notes

Located from _____PPO or _____Paired Plot?
Distance to PPO or previous paired plot = ________ m
PPO ____acceptable or ____ unacceptable because:

PPO #: ________ _____RA or _____supp?
E ________ N ________ +/- ________
[_____see paired plot data sheet for PPO coords]

____ insufficient total tanoak
____ insufficient healthy tanoak
____ insufficient standing dead
____ insufficient broken/fallen dead
____ too much dead (for a healthy plot)
____ quadrant requirements not met
____ insufficient dominant species (__ R1 BA, __ R2 CC)
____ slope greater than 60%
____ presence of other dominant species:
____ presence of planted species:
____ other:

Notes (e.g. access directions, clarifications, concerns):

1% = 5 m2	**R1** = 12.62 m (1/20 ha; 500 m2)		0.5% = 2.5 m2	**R2** = 28.21 m
1% crc: r = 1.26 m	1% sq: ℓ = 2.24 m	0.5% crc: r = 0.89 m	0.5% sq: ℓ = 1.58 m	(1/4 ha; 2500 m2)

Point Reyes Sudden Oak Death Project
Tree and Canopy Data

Plot # H / D Tag#
Hypsometer Calibration:

Name
Date
Veg Type

Spherical Densiometer Count

N	E	S	W

Tree Data (.05 Ha Plot Radius = 12.62m)
>3cm DBH

Tag#	Species	Status	Sprout?	DBH	HLCB	HCFB*	Position	Distance	AZ
1)									
2)									
3)									
4)									
5)									
6)									
7)									
8)									
9)									
10)									
11)									
12)									
13)									
14)									
15)									
16)									
17)									
18)									
19)									
20)									
21)									
22)									
23)									
24)									
25)									

*Only record HCFB if different from HLCB

Species	Seedling/Sprout Tally*	Sapling Tally**

* Give seedling/sapling counts in groups separated by commas

Fallen Tanoak (Fallen/Broken below DBH)

Tag#	DBH (est)	Dir to top	Distance	AZ
1)				
2)				
3)				
4)				
5)				
6)				
7)				
8)				
9)				
10)				
11)				

Status codes

SOD Susceptible Species:

A - Alive → A - Asymptomatic; S - Symptomatic → B - Bole, C - Canopy, T - Tree → E - Early (<50% leaves dead), A - Advanced (>50% leaves dead)

D-Dead → S - Standing → E - Early (>50% leaves on), I - Intermediate (<50% leaves on), A - Advanced (all leaves fallen); B - Broken → 3 - 3 inches, 6 - 6 inches, 12 - 12 inches, 24 - 24 inches

All Other species: A - Alive or D - Dead

HCLB classes
1) 0-1m 2) 1-3m 3) 3-5m 4) 5-10m 5) >10m
1) 0-3.3ft 2) 3.3-9.8ft 3) 9.8-16.4ft 4) 16.4-32.8ft 5) >32.8ft

Position Classes
O - Open Grown, E - Emergent, D - Dominant, C - Codominant, I - Intermediate, S - Suppresseed
R-Reclining

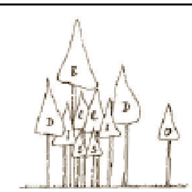
Figure TD-8. Use this illustration of crown classes to help you describe the crown class of the tree you are measuring

Comments

Tree Data (continued)

Tag#	Species	Status	Sprout?	DBH	HLCB	HCFB*	Position	Distance	AZ
26)									
27)									
28)									
29)									
30)									
31)									
32)									
33)									
34)									
35)									
36)									
37)									
38)									
39)									
40)									
41)									
42)									
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Comments

Point Reyes Sudden Oak Death Project
Fuels Data

Names ________________________ Plot # ________ H / D ________ Tag# ________
Date ________________________ Veg Type ________________________

Fuels

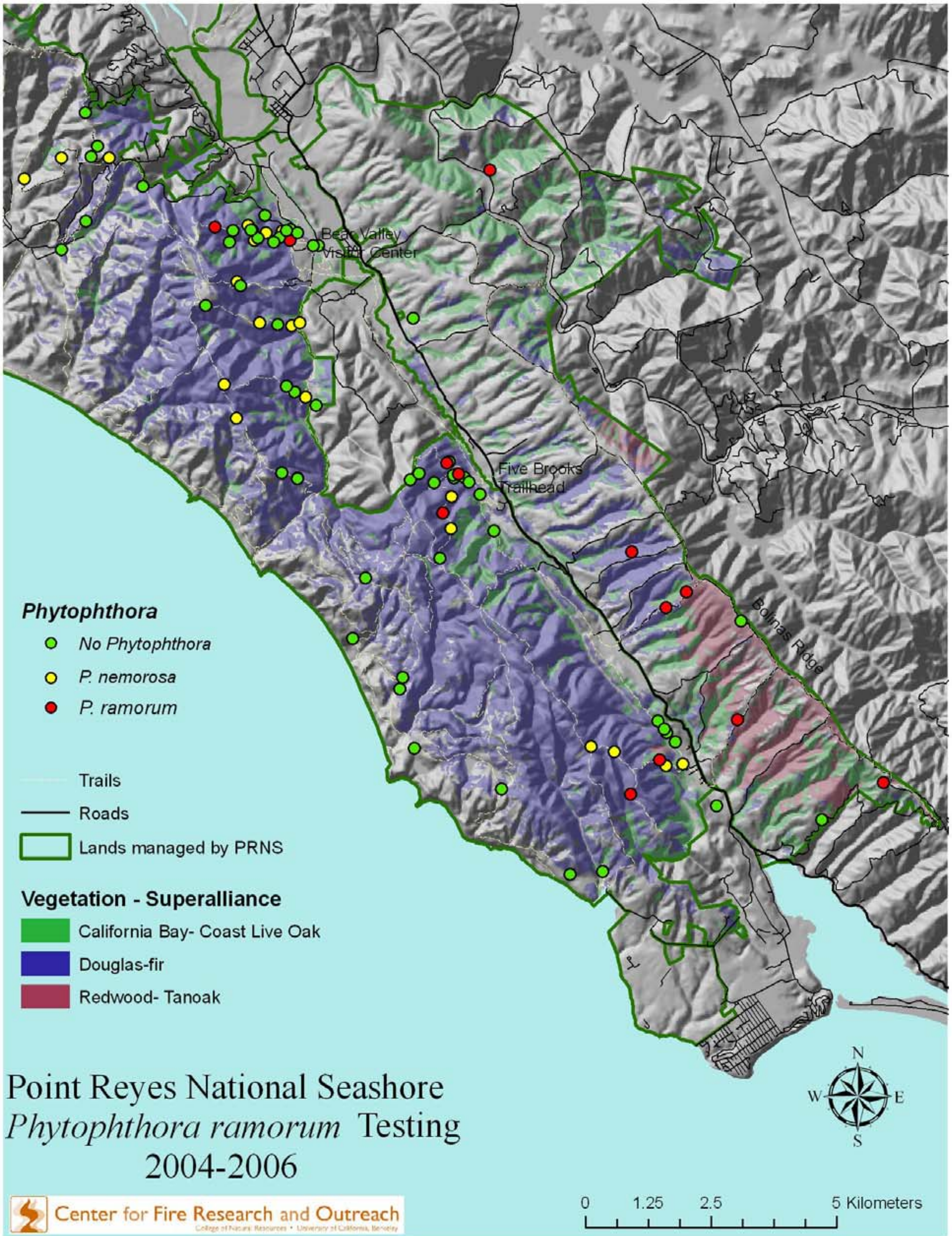
	Transect 1	Transect 2	Transect 3	Transect 4
	AZ:	AZ:	AZ:	AZ:
1 hour (10.5-12.5m)				
10 hour (10.5-12.5m)				
100 hour (8.5-12.5m)				

1000 hour (0-12.5m)	Dia.	Sp.	S/R	Dia.	Sp.	S/R	Dia.	Sp.	S/R	Dia.	Sp.	S/R

	9m	6m	9m	6m	9m	6m	9m	6m
Surf. Fuel Ht. (cm)								
Litter (cm)								
Duff (cm)								

Comments

APPENDIX III: PRIOR SAMPLING



APPENDIX IV: PLOT LOCATIONS

Projection and Datum: UTM Zone 10N, NAD83

Rapid Assessment Plots

PLOTID	EAST	NORTH
PORE-001	521538	4209443
PORE-002	527452	4200782
PORE-003	518519	4211552
PORE-004	526788	4199109
PORE-005	525476	4200877
PORE-006	520754	4213164
PORE-008	521179	4210417
PORE-009	521384	4206271
PORE-010	522064	4206022
PORE-011	521129	4202038
PORE-012	517690	4208395
PORE-013	522524	4203645
PORE-014	516745	4206150
PORE-015	516021	4207186
PORE-016	524316	4203926
PORE-017	523489	4201825
PORE-018	517084	4207990
PORE-019	520489	4203842
PORE-020	520359	4200473
PORE-022	521697	4201980
PORE-023	514906	4208215
PORE-024	514773	4206818
PORE-025	515408	4211530
PORE-027	516325	4205123
PORE-028	522985	4199242
PORE-030	515069	4209085
PORE-031	517866	4205616
PORE-032	525031	4204104
PORE-034	520966	4205245
PORE-035	524986	4210546
PORE-037	523194	4211919
PORE-038	524262	4203177
PORE-040	514474	4210626
PORE-041	521630	4201170
PORE-042	515926	4207966
PORE-043	523671	4206329
PORE-044	519865	4206230
PORE-045	521404	4204335
PORE-046	527486	4201530
PORE-048	526438	4200695
PORE-049	525792	4203160
PORE-051	525284	4203617
PORE-053	523412	4207102
PORE-054	526918	4202368
PORE-055	526486	4202961

PORE-061	524187	4201606
PORE-062	516613	4209327
PORE-063	526169	4200165

Stream Baiting Locations

PORE-SB-001-A	523266	4198316
PORE-SB-001-B	523278	4198219
PORE-SB-002-A	512731	4207954
PORE-SB-002-B	512729	4207936
PORE-SB-003-A	513498	4207616
PORE-SB-003-B	513370	4207551
PORE-SB-004-A	514208	4207125
PORE-SB-004-B	514198	4207085
PORE-SB-005-A	516577	4204693
PORE-SB-005-B	516521	4204642
PORE-SB-006-A	515815	4205607
PORE-SB-006-B	515831	4205571
PORE-SB-007-A	519453	4201001
PORE-SB-007-B	519399	4200932

Long Term Plots

PLOTID	EAST	NORTH
PORE-034H	520914	4205256
PORE-038H	524247	4203197
PORE-038D	524276	4203177
PORE-044H	519970	4206253
PORE-046H	527533	4201631
PORE-046D	527511	4201567
PORE-049H	520800	4203160
PORE-049D	525782	4203223
PORE-051H	525341	4203673
PORE-051D	525450	4203621
PORE-054H	526867	4202377
PORE-054D	526886	4202188
PORE-055H	526535	4202943
PORE-062H	516599	4209327
PORE-100H	527787	4201426
PORE-100D	527933	4201342
PORE-101D	529540	4199861
PORE-103H	525510	4204031
PORE-104D	528148	4200775
PORE-201H	515711	4211642
PORE-210D	515755	4211794
PORE-203H	517015	4209150
PORE-205H	516478	4211442
PORE-205D	516646	4211443
PORE-206H	516711	4210745
PORE-206D	516807	4210694
PORE-211H	519391	4205843
PORE-220H	520648	4205937
PORE-220D	520720	4205888

APPENDIX V: FIELD RATING SCALES

SOD Severity Index (Rapid Assessment)

Within a circular 500 m^2 plot (radius = 12.6 m / 41.5'):

	OVERSTORY				UNDERSTORY		
	Dead*		**Sympt / Dead***		**Dead***		**Sympt / Dead***
0	none	AND	none	AND	none	AND	none
1	none	AND	none	AND	1-2 tr	OR	1-4 tr
2	none	OR	< 5% CC	AND/OR	3-4 tr	OR	5-6 tr
3	< 5% CC	OR	≥ 5% CC	AND/OR	≥ 5 tr	OR	≥ 7 tr
4	≥ 5% CC	OR	≥ 25% CC		<<<<<<<<<<<<< irrelevant >>>>>>>>>>>>>		
5	≥ 25% CC	OR	≥ 50% CC		<<<<<<<<<<<<< irrelevant >>>>>>>>>>>>>		
6	≥ 50% CC	OR	≥ 75% CC		<<<<<<<<<<<<< irrelevant >>>>>>>>>>>>>		
7	≥ 75% CC	OR	≥ 95% CC		<<<<<<<<<<<<< irrelevant >>>>>>>>>>>>>		
8	≥ 95% CC	OR	≥ 95% CC in area ≥ 750 m^2		<<<<<<<<<<<<< irrelevant >>>>>>>>>>>>>		
9	≥ 95% CC in area ≥ 750 m^2	OR	≥ 95% CC in area ≥ 1000 m^2		<<<<<<<<<<<<< irrelevant >>>>>>>>>>>>>		
10	> 95% CC in area ≥ 1000 m^2		<<<< irrelevant >>>>		<<<<<<<<<<<<< irrelevant >>>>>>>>>>>>>		

"Dead" = standing dead or fallen; stump sprouting ignored
"Sympt / Dead" = the total of both dead and symptomatic trees
"tr" = tree(s), defined as woody stems ≥ 1" dbh
"CC" = canopy cover

NOTE: symptoms vary with host plants
NOTE: understory condition is irrelevant for values of 4 or greater

Likelihood of Infection Ratings

Host Presence (tanoak only or tanoak & coast live oak)	Bole Symptoms	Canopy Decline	California Bay	Bay Symptoms	Rating	Notes
Present	Present	Considerable	Present	Symptomatic	5 - Highly Likely	
				Asymptomatic	5 - Highly Likely	rare/unlikely situation
			Absent	NA	5 - Highly Likely	
		Limited	Present	Symptomatic	5 - Highly Likely	
				Asymptomatic	4 - Likely	rare/unlikely situation
			Absent	NA	5 - Highly Likely	
		None	Present	Symptomatic	4 - Likely	
				Asymptomatic	3 - Possible	rare/unlikely situation
			Absent	NA	4 - Likely	
	Absent	Considerable	Present	Symptomatic	5 - Highly Likely	rare/unlikely situation
				Asymptomatic	3 - Possible	rare/unlikely situation
			Absent	NA	4 - Likely	rare/unlikely situation
		Limited	Present	Symptomatic	4 - Likely	
				Asymptomatic	2 - Unlikely	
			Absent	NA	3 - Possible	
		None	Present	Symptomatic	3 - Possible	
				Asymptomatic	1 - Highly Unlikely	
			Absent	NA	2 - Unlikely	
Absent	NA	NA	Present	Symptomatic	3 - Possible	
				Asymptomatic	1 - Highly Unlikely	
			Absent	NA	1 - Highly Unlikely	

Host Presence (coast live oak only)	Bole Symptoms	Canopy Decline	California Bay	Bay Symptoms	Rating	Notes
Present	Present	Considerable	Present	Symptomatic	5 - Highly Likely	
				Asymptomatic	4 - Likely	rare/unlikely situation
			Absent	NA	4 - Likely	
		Limited	Present	Symptomatic	4 - Likely	
				Asymptomatic	3 - Possible	rare/unlikely situation
			Absent	NA	3 - Possible	
		None	Present	Symptomatic	4 - Likely	
				Asymptomatic	3 - Possible	rare/unlikely situation
			Absent	NA	3 - Possible	
	Absent	Considerable	Present	Symptomatic	3 - Possible	rare/unlikely situation
				Asymptomatic	2 - Unlikely	rare/unlikely situation
			Absent	NA	2 - Unlikely	rare/unlikely situation
		Limited	Present	Symptomatic	3 - Possible	
				Asymptomatic	2 - Unlikely	
			Absent	NA	2 - Unlikely	
		None	Present	Symptomatic	3 - Possible	
				Asymptomatic	1 - Highly Unlikely	
			Absent	NA	1 - Highly Unlikely	
Absent	NA	NA	Present	Symptomatic	3 - Possible	
				Asymptomatic	1 - Highly Unlikely	
			Absent	NA	1 - Highly Unlikely	

* These rating scales apply to general area around plot center, i.e. are not restricted to within 12.62m radius

** Separate scales are necessary for tanoak and coast live oak areas, since coast live oak in PRNS is currently affected by other diseases such as California oak worm

APPENDIX VI: STREAM BAITING

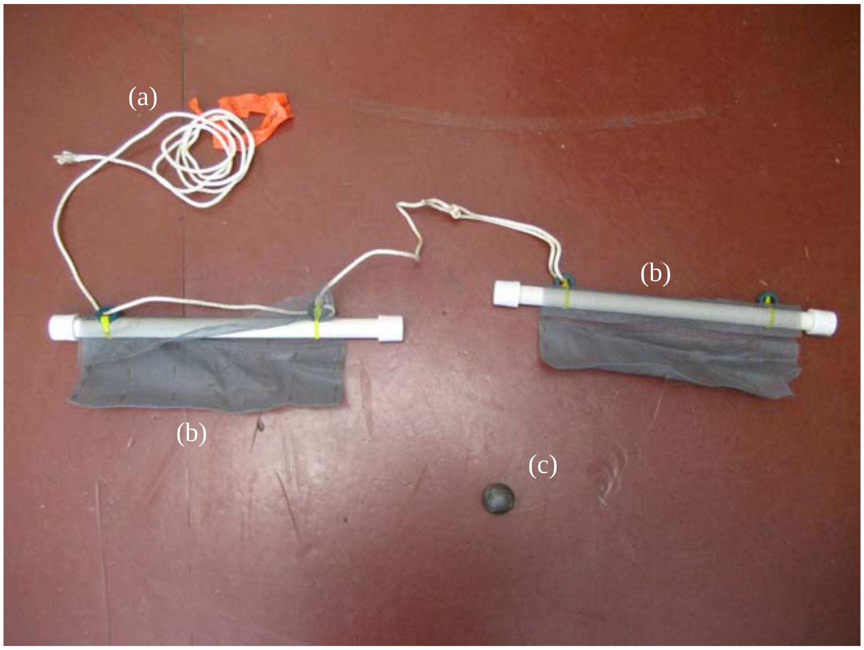


Figure VI.1: Typical stream bait bag setup, with (a) rope to anchor bags to nearby rock or tree, (b) mesh bait bags holding 5 leaves each, and (c) fishing weight attached to one bait bag with fishing line to anchor in stream. Two of these setups were installed in each stream, approximately 50m from each other.

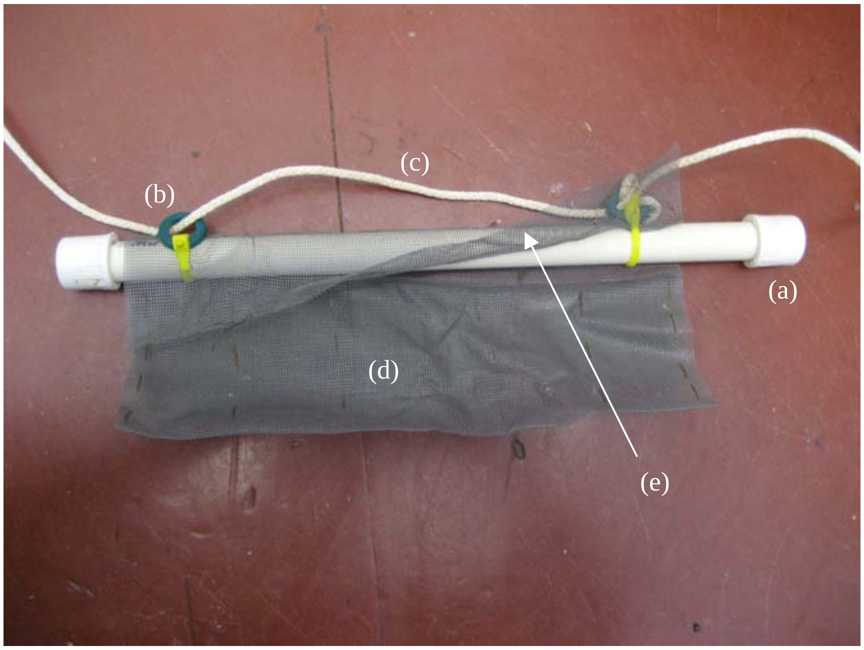


Figure VI.2: Individual mesh bait bag, constructed of (a) pvc piping, (b) zip ties and rubber washers, (c) nylon rope or parachute cord, and (d) mesh screening material, with 5 compartments either sewn or stapled. Mesh flap (e) is closed with light gauge bailing wire when in stream.

Approximate Stream Baiting Times (Murphy, 2007)

Water temperature	Remove leaves after
10-15° C	14 days
15-20° C	10-12 days
> 20° C	7 days maximum

APPENDIX VII: EQUIPMENT LIST

Rapid assessment plots (two person crew)

Digital camera
Clinometer
GPS unit
Compass
Maps and plot coordinates
Loggers tape (or 30m reel tape and diameter tape)
Plant clippers
Disinfectant spray (“Lysol”, or 95% ethanol, or 10% bleach water solution) and brush
Ziploc bags (quart size) – 2-3 per plot
Sharpie
Plant lists and keys (only for rapid id – no need for Jepson)
Clipboard, pencils
Rapid Assessment Field forms
“SOD Severity Index” and “Likelihood of Infection” scale references
Tree tags and nails (one per plot) and small hammer
Temporary plot stake
Roll of flagging
First aid kit

Stream Baiting (one or two person crew)

Bait bags (4 per stream) arranged as in Appendix VI
Bait leaves (20 per stream) kept in refrigerator or cooler until day of baiting
Water thermometer with Celcius scale
Hand sanitizer
GPS unit
Compass
Maps and baiting location coordinates
Digital camera
Disinfectant spray (“Lysol”, or 95% ethanol, or 10% bleach water solution) and brush
Ziploc bags (quart size) – 2-4 per stream (for 2 bait locations and any additional foliar samples)
Clipboard, pencils
Sharpie
Stream Baiting Field Form
Roll of flagging
First aid kit

Long-term monitoring (two or three person crew)

Digital camera
Clinometer
GPS unit
Compass

Maps and plot coordinates
1-2 Loggers tapes or diameter tapes
30m reel tape
Plant clippers
Disinfectant spray ("Lysol", or 95% ethanol, or 10% bleach water solution) and brush
Ziploc bags (quart size) – for *P. ramorum* samples as well as plant ID
Sharpie
Clipboard, pencils
Field forms – plot info/vegetation form, tree/canopy form, fuels form
Spherical densitometer
Tree tags, nails, small hammer
Flagging
Plot stakes (3/8" x 1' rebar) and rebar caps ("mushroom" style, orange)
Plant lists and keys, loupe
Go-nogo gauge (fuel measurement gauge)
Hypsometer and receiver
Pole or tall stake for receiver at plot center
First aid kit