Monitoring Insect and Disease Impacts on Rangeland Oaks in California[1]

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Abstract: We developed methods to assess the impacts of diseases and arthropods on sapling and mature rangeland oaks, and applied these methods at 18 sample plot locations in northern California. The impact of arthropod damage was generally rated as minor. Leafy mistletoe (*Phoradendron villosum*) was found on 5 percent of the rated trees. There was a slight correlation between mistletoe infestation levels and dieback ratings. Characteristic canker rot symptoms were seen in 9 percent of the trees surveyed, and 16 percent of the trees had at least 20 percent of the bole volume decayed by fungi. In *Quercus douglasii,* the percentage of trees showing more than 20 percent wood decay in the bole differed significantly between locations, ranging from 0 to almost 43 percent. Canker rot fungi and other wood decay fungi were the most significant agents affecting health and survival of rangeland oaks.

Significant insect and disease impacts were noted in some of the earliest treatises on oaks in California (Sudworth 1908, Jepson 1910), and have been reviewed by Brown (1980) and Raabe (1980). More recently, we completed an extensive review of the published literature and unpublished collection records on diseases and arthropods reported to attack oaks in California (Swiecki and others 1990). Data on the geographic distribution, characteristics, and taxonomy of the agents, symptomatology of the oak-agent interaction, and bibliographic information on the source of each report has been compiled into a computerized database, the California Oak Disease and Arthropod (CODA) Host Index. This database presently contains information on 780 arthropods, 200 disease agents, and over 200 saprophytic fungi known to occur on oaks in California (Swiecki and others 1990).

Even though information on the occurrence of diseases and arthropods is extensive, little information has been compiled on the relative importance and overall impacts of diseases and arthropods on rangeland oaks. Since California oaks have generally not been considered commercial timber species, most of the existing information on the diseases and arthropods that affect California oaks is based on trees in landscape settings.

The purpose of this study was to provide baseline data on the levels of damage and mortality associated with diseases and arthropods in undeveloped oak woodlands and savannahs. It is essential to have such baseline data to monitor changes in the condition of oak resources that occur over time as the result of either natural conditions or cultural practices. We developed, adapted, and tested sampling and rating methods to assess the impacts of diseases and arthropods on rangeland oak stands containing blue oak (*Quercus douglasii* Hook. & Am.).

METHODS

Two series of plots, located in northern California, were surveyed in this study. One series of plots were permanent inventory plots established by the Forest Inventory and Analysis (FIA) Research Work Unit of the USDA Forest Service Pacific Northwest Research Station (Bolsinger 1988, McKay 1987). In 1989 we surveyed eight of these plots, which were selected for the presence of blue oak.

In addition to the above plots, nine plots were surveyed at locations where we had established seedling study plots (Swiecki and others, these proceedings). These plot locations were selected for the presence of blue oak seedlings, without consideration of the tree overstory. Therefore, while not a truly random sample, these plots constitute a relatively unbiased sample with respect to overstory tree condition. One additional plot (2001001) in Alameda county was specifically selected to document the very poor condition of the stand in the area. Data from this plot have been excluded from certain analyses as noted. Locations of all plots are shown in figure 1.

To ensure compatibility with existing survey data, the layout of all new plots was based on the methods used by the FIA. Each field plot consists of five subplots distributed across 2 ha. We normally collected complete tree data on at least two 16 m (0.08 ha) fixed-radius subplots for each plot. Complete tree ratings were usually limited to the first 20 trees in each subplot, and only mortality was rated for the remainder of the subplot. Trees in the remaining three subplots in each plot were rated only for mistletoe and dieback. Data on key site characteristics were collected following FIA methods with some minor modifications and additions, or compiled from published sources (Swiecki and others 1990).

Data on tree characteristics, condition, and injury factors were collected on standardized data sheets. Characteristics noted for each tree included species, age class (mature or sapling), form class (seedling or sprout origin), canopy class, and diameter at 1.37 m height (diameter at breast height, DBH) for mature trees or basal diameter for saplings. Oaks with basal diameters of at least 1 cm and DBH of 1 cm or less were assigned

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to the sapling age class. Canopy classes were the same as those described in the FIA methods. In order of increased shading by other trees, the canopy classes used were: open grown, dominant, codominant, intermediate, and overtopped. Dead trees within each plot were also tallied, and were categorized by visual estimate as having died within the past 10 years or not.

For symptoms that could be rated on the basis of the percentage of the tree which was affected, the following 0 - 6 pretransformed percentage scale (Little and Hills 1978) was used:

Rating:	Percentage interval	Interval midpoint (pct)
0	None visible	0
1	Trace to 2.5	0.6
2	>2.5 to 20	9.5
3	>20 to 50	34.5
4	>50 to 80	65.5
5	>80 to 97.5	90.5
6	>97.5	99.4

For some characteristics that could not be readily estimated on a percentage basis, we used the following scale to rate the probability that symptoms would have a significant negative impact on tree health or survival:

Rating:	Probability of significant negative impact
0	no apparent impact
1	low probability
2	moderate probability
3	high probability

In plots where complete tree ratings were taken, symptoms rated and scales used were as follows:

Characteristic rated:	Rating scale	Location within tree
Mistletoe density	0-6	Canopy
Live and dead mistletoes clumps	count	Canopy
Density of epicormic branches	0--none 1= infrequent 2= numerous	Canopy, trunk
Canopy thinning	0=no, 2=yes	Canopy
Overall dieback	0-6	Canopy
Branch flagging (current season)	0=none, 1=present	Canopy
Impact of cankers	0-3	Canopy, trunk
Wood decay	0-6	Canopy, trunk
Impact of wounds	0-3	Canopy, trunk
Foliar arthropod damage	0-6	Canopy
Impact of other arthropods	0-3	Canopy, trunk
Twig and stem gall density	0-6	Canopy
Impact of woody galls	0-3	Trunk

The identity of causal agents associated with damage was coded when known. Trunk data was not collected for oaks in the sapling age class.

For purposes of data analysis, a composite injury index variable was calculated for each individual tree as the sum of all of the above ratings except the number of mistletoe plants. The injury index was not calculated if data from any of the included ratings were missing.

For categorical data, we used Fisher's exact test or the chi-square statistic to test the significance of differences in contingency tables. General linear model analysis of variance (SAS Institute, Inc. 1988) was used to test for differences between oak species, plot locations, age classes and crown classes for pretransformed ratings and the composite injury index. Regression analysis was also used to test for correlations between selected variables. Unless otherwise noted, significant differences and effects are significant at $P < 0.05$.

RESULTS

Approximately 75 percent of the trees rated were *Q. douglasii,* including a small percentage (2.1 percent) of suspected hybrids with other white oaks. Approximately 20 percent of the oaks rated were in the black oak subgenus, the majority of which were interior live oak (*Q. wislizenii* A. DC.) and coast live oak (*Q. agrifolia* Née). Basal area varied significantly with canopy class, and was greatest in dominant and open grown trees, and smallest in overtopped trees. Saplings comprised 12.9 percent of the sampled trees. The live oaks were more commonly scored as being of sprout origin (46 percent for *Q. wislizenii,* 18 percent for *Q. agrifolia*) than was *Q. douglasii* (5 percent). Approximately half of the 1035 trees sampled received complete ratings, while the other half were scored for mistletoe and dieback only.

Visible fungal sporulation was relatively uncommon on sampled trees, but species of *Stereum, Inonotus,* and *Hypoxylon* were occasionally identified within plots. Foliar damage caused by insects and/or mites was present on virtually every tree examined, and symptoms included chewing, window feeding, stippling, blotch and serpentine mines, and galls caused by cynipid wasps and eriophyid mites. Insect groups directly observed on rated trees were primarily Homoptera, including aphids, whiteflies, and pit scales, although Tussock moth pupae and lepidopterous larvae were occasionally observed. However, the percentage of leaf area affected by foliar feeding insects was normally quite low, and was usually rated as less than 2.5 percent. Levels of foliar damage did not differ significantly between saplings and mature trees.

Twig galls, usually caused by cynipid wasps, were also commonly observed but very seldom involved enough of the canopy to have a significant impact on tree health. Wood boring by buprestid and cerambycid beetle larvae and other insects was common, but was usually restricted to dead or dying branches in the canopy. Arthropod damage to the trunk was primarily due to wood borers and termites. These insects most commonly invaded through wounds or cankers, and were often associated with decayed wood. In most cases, their impact was rated as minor (fig. 2A) but occasionally their activities were sufficient

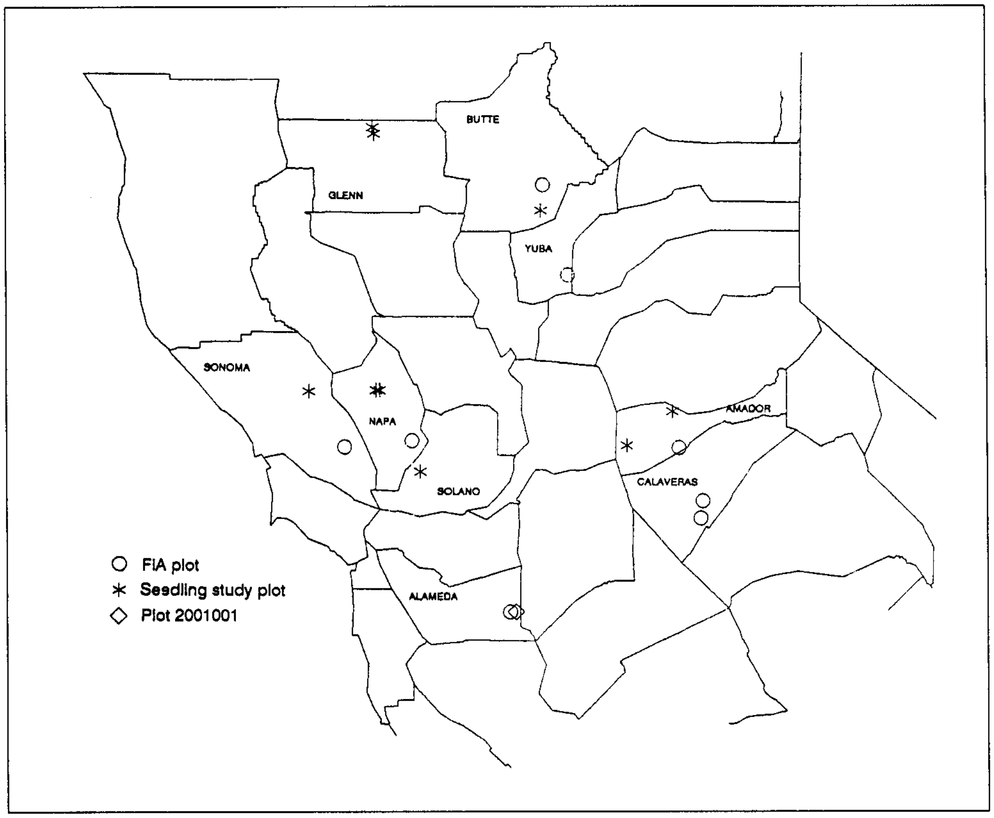

Figure 1—Locations of surveyed plots by type.

to cause significant structural weakening of affected trees. Significant levels of insect damage to the trunk were more common in the live oaks than in blue oak (fig. 2A).

Leafy mistletoe (*Phoradendron villosum* [Nutt.] Nutt.) occurred in the vicinity of 14 out of 18 plots surveyed, but was found in only 5 percent of over 1000 trees rated. It was not found in any of the 107 saplings rated. Mistletoe did not occur in any of the 50 *Q. agrifolia* trees we sampled, but was found at similar frequencies in *Q. douglasii* (4.6 percent, n=777) and *Q. wislizenii* (7.3 percent, n=138). More than one mistletoe clump was present in about 75 percent of infected trees, and up to 30 live mistletoe clumps were found in a single tree. Average mistletoe density ratings and numbers of mistletoe plants were significantly greater (P<.01) in open grown and dominant trees than in codominant, intermediate, or overtopped trees. Among mistletoe-infested trees, there was a slight positive correlation between mistletoe density rating and dieback rating (r^2=.105, P=.039), and heavy mistletoe infections were frequently associated with dieback. Dead mistletoe plants were found in about half of the infected trees.

Dieback rating varied significantly by plot, oak species, and crown class. Among the three oak species best represented in our sample, the average dieback rating was greatest for *Q. wislizenii* (fig. 2B). Unlike many other damage variables, the distribution of dieback ratings approximated a normal distribution. No obvious geographic trends were seen in dieback ratings. Average dieback ratings differed significantly between canopy classes, and were greatest in overtopped trees. Overall, average levels of dieback were significantly higher in the mature tree size class (2.5 ± 1.1) than in the sapling class (2.2 ± 1.5).

Although it was not possible to definitively diagnose the causes of canopy dieback for all trees rated, our field observations do not implicate any single cause overall. Shading in dense stands and overtopped trees appeared to be a major cause of branch decline and dieback in blue oak. Dieback was also common in blue oaks that showed symptoms of water stress, had canker rot symptoms, or were heavily colonized by mistletoe. Fungi and insects that specifically attack twigs or branches did not appear to be the primary cause of branch dieback in most cases, although boring insects and decay fungi were common on dead and declining branches.

Excluding data from the biased plot 2001001, 8.9 percent of the oaks receiving complete ratings showed characteristic canker rot symptoms, and an additional 2 percent had other cankers that may have been caused by canker rot fungi. The incidence of canker rot symptoms varied significantly between plots, ranging from 0 to 44.6 percent. Symptoms and fruiting bodies of canker rot fungi were also found in the vicinity of several plots where no canker rot was tallied within the plots. Excluding plot 2001001, canker impact was rated as moderate to high in 12.9 percent of tree canopies and 13.4 percent of tree trunks. Among live trees, average dieback rating was significantly higher (P<.001) in oaks with canker rot symptoms (2.8 ± 1.0) than in those without canker rot symptoms (2.3 ±.9).

Excluding data from plot 2001001, approximately 26 percent of the oaks rated had trunk decay ratings of at least 2, and

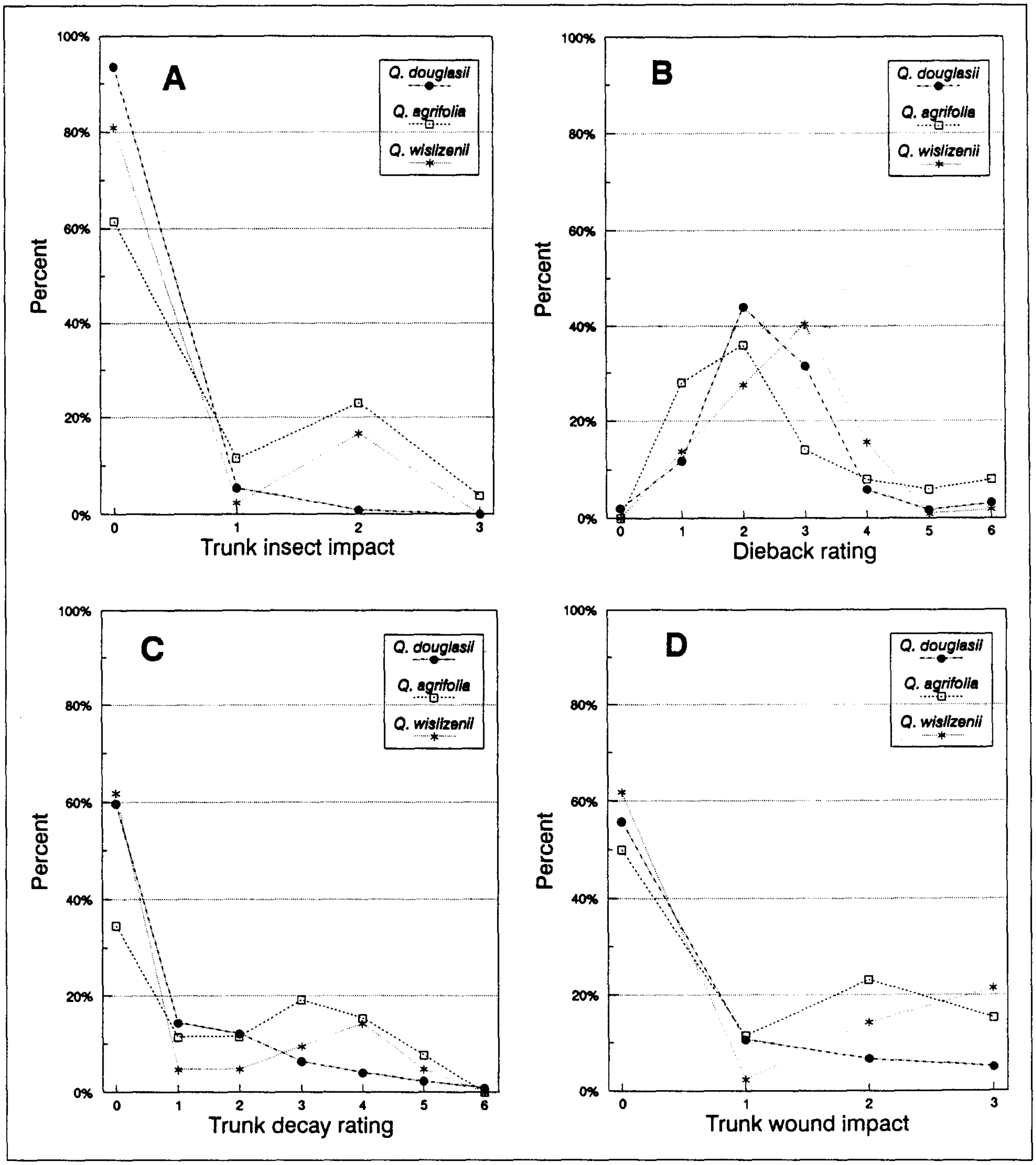

Figure 2—Frequency distributions of damage variables by oak species. A, Trunk insect impact rating. B, Dieback rating. C, Trunk decay rating. D, Trunk wound impact rating.

16 percent had trunk decay ratings of at least 3. Average trunk decay ratings were significantly greater in *Q. agrifolia* than in *Q. wislizenii* and *Q. douglasii,* but the live oaks *Q. agrifolia* and *Q. wislizenii* showed similar bimodal distributions of decay levels (fig. 2C). Trunk decay was associated with wounds in 40.7 percent of all trees rated, and the incidence of severe trunk wounds was also greater in *Q. agrifolia* and *Q. wislizenii* (fig. 2D). In *Q. douglasii,* trunk decay ratings differed significantly between plots and by canopy class, with the greatest levels of trunk decay occurring in dominant trees. The incidence of *Q. douglasii* trees with at least 20 percent of the trunk decayed ranged from 0 to almost 43 percent in the plots we surveyed. More than 1 out of 5 blue oaks had at least 20 percent trunk decay in 5 of the plots we rated.

Even though plot 2001001 was selected for rating because it showed severe disease impacts, most disease levels in this plot were within the range of the 17 randomly selected plots. Average ratings for mistletoe density, dieback, and condition, as well as the incidences of canker rot and trunk decay ratings greater than 2, were all near the maximum levels observed among the other plots.

Ten-year mortality rates were estimated for each plot based on the number of trees that were judged to have died within the previous 10 years. Estimated mortality rates per decade ranged from 0 in seven of the 18 plots, to a high of 12.5 percent at plot 2001001. These estimated rates are likely to underestimate actual mortality in areas where dead trees are removed for firewood or are consumed in ground fires and cannot be tallied. Estimated 10-year plot mortality rates showed low correlations with canker rot incidence in live trees (r^2=.039) or average trunk decay ratings (r^2=.044).

DISCUSSION

Survey Methods and Ratings

Since no general disease and insect surveys have previously been conducted for rangeland oaks in California, we developed our rating system without prior knowledge of the agents that would be the most significant. Therefore, most of our ratings focused on damage symptoms rather than individual causal agents. We took this approach because tree condition is often affected by a complex of biotic and abiotic factors acting simultaneously or in sequence. The precise effects of individual agents or factors often cannot be partitioned out without a detailed study, which is impractical in an extensive survey. Symptoms such as dieback and flagging are not specific to a single agent, and can be caused by arthropods, pathogens, or abiotic factors. Other symptoms, including thinning and epicormic branching, are indicators of tree vigor which also do not correspond to attack by specific agents. Symptoms such as cankers and wood decay are normally caused by fungal pathogens, but the specific causal agent is not usually known. However, our rating system does allow for coding the identity of specific agents when they can be associated with a particular type of damage. Thus, the rating system allows us to rate tree condition without exact knowledge of each agent involved, yet provides for the capture of additional information on specific agents where possible.

Our rating system emphasizes damage to woody tissues, especially the larger branches and trunk. The integrity of these structural members is critical to the survival of the tree, whereas fine twigs and leaves are more readily replaced. While high levels of foliar damage can have a substantial impact on tree health, the condition of foliage may vary widely from year to year and even month to month. Therefore, it may not be meaningful to compare or summarize foliar damage levels from plots sampled in different months or years. In contrast, the condition of the trunk and larger branches normally changes much more slowly, so that valid comparisons can be made between plots sampled at different times. Moreover, the effects of previous pest, disease, and environmental impacts are integrated to some degree in the condition of the larger woody tissues, so their condition is a reasonable gauge of cumulative impacts.

The methods we developed and tested form the basis for future assessments of disease and arthropod impacts in California oak woodlands. These methods provide a standardized framework for characterizing disease and arthropod levels within oak stands. When used with permanent plots, these evaluation methods also provide a means for monitoring the change in the condition of individual trees over time. This information could be applied to estimate the rate of tree decline.

By coupling these tree condition assessments with site information, it is possible to examine the relationship between damage caused by diseases and arthropods and environmental factors or cultural practices. We were able to detect significant correlations between tree condition ratings and various site factors even though our sample size is somewhat limited (Swiecki and others 1990). Information on these relationships could have important applications in the development of management models and guidelines for California's oak woodlands.

Disease and Arthropod Impacts

The level of damage caused by arthropods to mature trees was relatively low in the plots we surveyed. Damage caused by foliar-feeding insects was generally low, and oak pit scale (*Asterolecanium* spp.), which is regarded as a significant pest of oaks in urban areas (Koehler and others 1977), was rarely encountered in our plots. Wood boring insects, though common, usually appeared to be acting as secondary pests, attacking weakened or wounded tissues. However, insect population levels can vary greatly between years, locations, and host species. Thus, although insect damage was generally below levels that significantly affected oak health and survival in the areas we sampled, these results should not be extrapolated to imply that insect damage is unimportant in *Q. douglasii* or other native oaks.

Leafy mistletoe was the only agent that was the specific focus of particular rating criteria. It is a conspicuous and readily quantifiable pathogen which has the potential to significantly affect oak health. Our survey methodology was modified specifically to increase the sample size for trees rated for mistletoe. However, mistletoe was detected somewhat inefficiently even with this increased sampling intensity, due to its clumped spatial distribution (Thompson and Mahall 1983) and its relatively low overall frequency.

Significant dieback was only associated with moderately high levels of mistletoe infestation. Therefore, only trees with multiple infections are likely to be adversely affected by mistletoe. As reported by Thompson and Mahall (1983), we observed that among mistletoe infected trees, the incidence of multiple infection was high. We observed the highest levels of mistletoe infection in open grown and dominant trees, which also have the largest trunk diameters. Similarly, Thompson and Mahall

(1983) observed that oaks with larger basal areas were more likely to be infected by mistletoe, although they did not consider canopy class. These results suggest that open grown and dominant oaks are most likely to be impacted by leafy mistletoe. Furthermore, since trees in these crown classes are visually prominent, the incidence and overall importance of mistletoe is likely to be overestimated by casual observations.

The levels of decay we found in blue oak were somewhat higher than those we calculated from the FIA database records (Swiecki and others 1990), but correspond with levels reported in the early literature. Both Jepson (1910) and Sudworth (1908) comment on the high levels of heartwood decay in blue oak in their descriptions of the species. Jepson (1910) notes that in some areas, 33 to 66 percent of the blue oaks were "badly rotted". Based on these historical accounts and our own observations (Swiecki and others 1990), we believe that moderate to high levels of decay are characteristic of mature and overmature blue oak stands. Most of the canker rot and other decay fungi affecting oaks in California are not limited to a single oak species, and wood decay was common in most of the oak species we observed.

As decay progresses, there is an increase in the severity of nonspecific decline symptoms such as canopy dieback and thinning. In addition, failure of large branches in blue oak and other oak species is often due to extensive wood decay, a relationship that was also noted by Jepson (1910). These breaks commonly extend into sound wood, opening new wounds that are subject to infection, furthering disease progress and tree decline.

Due to their high pathogenic potential (Sinclair and others 1987) and relatively high rates of incidence, the canker rot fungi and other wood decay fungi rank as the most important agents affecting oak health and survival in the plots we surveyed. Canker rot and other decay fungi have long been recognized as important pathogens of oaks in the southeastern U.S. (Hepting 1971). However, their role as primary oak pathogens in California has been largely overlooked in spite of or perhaps because of their ubiquity.

Wood-decay fungi are mostly slow-acting pathogens whose progress can be intermittently slowed or halted by host defense reactions including compartmentalization (Sinclair and others 1987). The rate of decay may be accelerated in trees under stress due to environmental or cultural conditions such as drought, severe overgrazing, fire, and changes in the soil water table. Since site conditions can significantly affect the rate of disease progress and tree decline, we were not surprised to find low correlations between estimated mortality rates and decay and canker rot incidence. We believe that although environmental and cultural factors may increase or synchronize oak decline and mortality in an area, canker rots and other wood decay fungi normally play a primary causal role in the decline of mature oaks in California (Swiecki and others 1990). Further information on the factors affecting infection and disease progress will improve our understanding of oak woodland ecology, and may have important implications for the future management of oak stands.

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