Giant Sequoia Insect, Disease, and Ecosystem Interactions[1]

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Abstract: Individual trees of giant sequoia *(Sequoia gigantea [Lindl.]* Decne.) have demonstrated a capacity to attain both a long life and very large size. It is not uncommon to find old-growth giant sequoia trees in their native range that are 1,500 years old and over 15 feet in diameter at breast height. The ability of individual giant sequoia trees to survive over such long periods of time has often been attributed to the species high resistance to disease, insect, and fire damage. Such a statement, however, is a gross oversimplification, given broader ecosystem and temporal interactions. For example, why isn't there a greater representation of young-growth giant sequoia trees throughout the mixed-conifer belt of the Sierra Nevadas? What other factors, in addition to physical site characteristics, limit giant sequoia to its present range and grove boundaries? How does fire and fire frequency affect disease and insect interrelationships in the giant sequoia/mixed-conifer ecosystem? Are current forest management strategies (e.g., fire suppression, prescribed burning programs) affecting these interactions? Giant sequoia trees are subject to the same natural forces (e.g., insect and disease organisms) as other tree species. An attempt is made in this paper to discuss some of the more common insect and disease associates of giant sequoia and their significance in relation to the more complex temporal (e.g., succession, aging and other time related events) and ecosystem interrelationships at work in the giant sequoia/mixed-conifer ecosystem.

Giant sequoia *(Sequoia gigantea* [Lindl.] Decne.)[3] may be considered a long-lived species because of its high resistance to damage and mortality by insects, disease, and fire. Various attributes such as thick, fibrous bark, scalelike leaves, heartwood phenolic and tannin extractive content, general lack of resinous extractives in bark and wood, and rapid growth rates of young trees may be partly responsible for enabling individual giant sequoia trees to become very large and long-lived. We know very little, however, about what happens to giant sequoia throughout its lifetime. And, virtually nothing is known about predisposing growth-loss and mortality agents of young-growth giant sequoia in its native range.

Many people assume that once giant sequoia seeds germinate, they will live a very long time and become very large trees. It is not hard to understand why people still believe this, since the older literature is replete with statements that giant sequoia has relatively few insect and disease pests. For example, the statement by John Muir (1894) illustrates this misconception: "I never saw a Bigtree [giant sequoia] that had died a natural death; barring accidents they seem to be immortal, being exempt from all diseases that afflict and kill other trees." Similarly Hartesveldt (1962) concurred that "Sequoia's longevity and great size have been attributed by nearly all writers, popular and scientific, to its few insect and fungus parasites and the remarkable resistance of the older trees to damage or death by fire. There is no record of an individual sequoia living in its natural range as having been killed by either fungus or insect attack." Even as recently as 1991 Harlow and others (1991) stated: "Insects and fungi cause but minor damage, and no large Bigtree killed by them has ever been found."

It is finally being recognized that giant sequoia is subject to the same natural forces as other tree species (Bega 1964, Harvey and others 1980, Parmeter 1987, Piirto 1977, 1984b, Piirto and others 1974, 1977, 1984a, Weatherspoon 1990). Weatherspoon (1990) has reported that "Although diseases are less troublesome for giant sequoia in its natural range than for most other trees, the species is not immune to disease as once assumed." Scientists have been recording disease associations with giant sequoia for some time (Seymour 1929, Bega 1964, Hepting 1971). But the significance, ecological role, and influences that affect these organisms is not well understood.

Further, recent research on insects associated with giant sequoia has set aside many long-standing misleading generalizations about insect relationships in giant sequoia (David and others 1976, David and Wood 1980, DeLeon 1952, Stecker 1980a,b, Tilles 1984, Tilles and Wood 1982, 1986). Stecker (1980a) in this regard reports that "In summary, the giant sequoia, the largest living organism past or present, and one of the oldest, is unusual in having relatively small insects comprising a relatively small insect fauna." These research findings have caused some people still to conclude that insect depredations are not seriously harming giant sequoias. Yet carpenter ants have been directly reported as being associated with old-growth giant sequoia trees (David and others 1976, David and Wood 1980, Piirto 1976, 1977, Piirto and others 1984, Stecker 1980a, Tilles 1984, Tilles and Wood 1982, 1986). Carpenter ants, bark beetles, wood borers, and a variety of other insects are commonly found in basal fire scars of old-growth giant sequoia. The role of these insects in predisposing a giant sequoia tree to failure or possibly in vectoring disease organisms is not completely understood (David and others 1976, Piirto 1976, 1977, Piirto and others 1984). And, even though the insect fauna seems to be smaller for giant sequoia based on present reports (Stecker 1980a), it is inconclusive that insects are not a problem to giant sequoia. The objectives, then, of this paper are to: briefly review some of the more common disease and insect organisms associated with giant sequoia; and discuss both temporal and ecosystem disease and insect interrelationships at work in the giant sequoia/mixed-conifer ecosystem.

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[3]The correct scientific name for giant sequoia is currently a subject for disagreement. The common name, giant sequoia, and the scientific name *Sequoia gigantea, will* be used in this paper. Justification for this is detailed in Davidson (1972) and in Piirto (1977). The common name, coast redwood, will refer to *Sequoia sempervirens.*

Insect Relationships

The scientific study by Stecker (1980a) is the most complete work to date on insects associated with giant sequoia. Limited entomological research involving giant sequoia occurred prior to 1974 (DeLeon 1952, Fry and White 1930, Hopkins 1903, Keen 1952, Person 1933). DeLeon (1952) was one of the first entomologists to dispute the claim that coast redwood and giant sequoia have few insect enemies. DeLeon (1952) listed twenty insects which may use giant sequoia during all or part of their life cycles, including: bark and ambrosia beetles; flatheaded, roundheaded and other borers; leaf feeders; termites; carpenter bees; and carpenter ants.

Stecker (1980a,b) conducted detailed investigations on the invertebrates associated with giant sequoia seedlings, living trees and fallen trees. Stecker's sample sites included Redwood Canyon, Redwood Mountain, Whitaker's Forest, Converse Basin, and Mountain Home State Forest. Stecker (1980a) found that:

> Of the 143 species of insects encountered in this study, 4 species were found on seedlings (3 of which were also in older trees). Thirty-two insects were found in different stages of downed and dead limbs of standing giant sequoias, while 3 of these were also observed in standing dead wood of the living host. One hundred and fourteen insect species were found only in the canopy of the living tree.

Stecker (1980a) explains the results of his scientific investigations as follows:

> The insect fauna of the giant sequoia is small when compared to that of other conifers of the same region. It differs considerably from that treated by Southwood (1961) in the hypothesis that insect species associated with a tree are a reflection of the cumulative abundance of that tree throughout recent geologic history. Insect faunas of historically newer trees are considerably larger than those of the much older giant sequoia. The insect faunas of pines and firs are usually two to three times greater than the presently known fauna from the giant sequoia.

Several of the insects listed in his study such as termites, defoliators, various bark beetles (ambrosia beetle *Gnathotrichus sulcatus* LeConte and *Phloesinus punctatus* LeConte), wood borers *(Semanotus ligneus amplus* Casey and *Trachykele opulenta)* and carpenter ants *(Camponotus modoc)* can be very destructive to young- and old-growth giant sequoia. *T. opulenta* larvae mine in the wood around fire scars and apparently can also develop wholly in the bark (Fumiss and Carolin 1977). In addition, prominent insects associated with seedling damage and mortality include the camel cricket (*Pristocauthophilus pacificus*), two geometrids *(Sabuloides caberata* and *Pero behresarius),* and cutworms *(Noctuidae* spp.*)* (Parmeter 1987, Harvey 1980, Stecker 1980b, Metcalf 1948).

Very little scientific entomological research has been done to determine the ecological importance of some of the insects listed by Stecker and others (1980a,b). Stecker (1980b) determined that *Phymatodes nitidus* is very important in the continual release of seeds and subsequent reproduction of giant sequoia. Researchers at the University of California at Berkeley found carpenter ants *(Camponotus modoc),* which excavate nests in giant sequoia to rear their young, feeding on dead arthropods and honeydew from attended aphids (David and others 1976, David and Wood 1980, Tilles 1984, Tilles and Wood 1982, 1986). The attended aphid colonies were found in the upper crowns of nearby white fir trees *(Abies concolor* [Gord. and Glend.] Lindl. ex. Hildebr.). This research finding has some very interesting implications. For example, do the changes in white fir stand density in giant sequoia groves (which have occurred as a result of fire suppression programs) cause associated changes in aphid populations which in turn influence carpenter ant populations found nesting in living giant sequoia trees? Carpenter ants are known to cause excavations that are so extensive as to seriously impair structural stability (Furniss and Carolin 1977, Piirto 1977, Piirto and others 1984b). Piirto and others (1984b) found that:

> Carpenter ants were found in or near the failure zone in 16 [out of 33] study trees: only six of these, however, contained carpenter ant galleries in the immediate failure zone. Microscopic examination of discolored wood associated with carpenter ant galleries revealed an early to moderate stage of decay.

A check of recent research records at Sequoia-Kings Canyon National Park (Esperanza 1992) showed very little entomological research done since 1982 on insect associates of giant sequoia. Piirto and others (1992a,b) identified six orders of insects found in association with giant sequoia fire scars. Thirteen individual insect species were identified, six of which have not been reported previously. Insects identified most frequently were *Ichneumonidae* spp. (Ichneumons), *Camponotus* spp. (carpenter ant), *Curculionidae* spp. (snout beetle), *Ceuthophilus* spp. (cave cricket), and *Blapylis alticolus* and *B. productus* (darkling beetles). On an infrequent basis, seven insects were found associated with giant sequoia fire scars. These insects were identified as *Sphecidae* spp. (thread-waisted wasp), *Pompilidae* spp. (spider wasps), *Dorcasina grossa* (long-horned beetle), *Cantharidae* spp. (soldier beetle), *Anthomyiidae* spp (Anthomyid fly), *Raphidiidae* spp. (snakeflies), and *Coreidae* spp. (leaf-footed bug). More research is needed, however, to determine the full ecological significance of insects associated with giant sequoia both inside and outside its native range.

Disease Relationships

For the purpose of this paper disease is defined as any deviation in the normal functioning of a plant caused by some type of persistent agent (Manion 1991). The abiotic and biotic agents that cause disease are referred to as pathogens. It is important to recognize that diseases which develop in plants and trees are the product of the tree/plant, the pathogen, and the interactions of these with the environment over time. Time is an important factor as it is related to both the rate at which a disease develops within an individual plant or tree and to the spread and increase of the pathogen population within a host population (Manion 1991).

Abiotic agents that can cause disease in forest trees include air pollution, high temperatures, freezing temperatures, phytotoxic gases, pesticides, moisture stress, salt, poor soil aeration, nutritional deficiencies/imbalances, mechanical damage and other abiotic factors. Any one or all of these factors may affect giant sequoia at one time or another during its life cycle. For instance, significant scientific information is becoming available on the impacts of air pollution on Sierra Nevada forests. Studies have been completed and many are underway which have/are evaluating the impacts of air pollution, climate change, acid rain and a number of other abiotic agents which affect these forest ecosystems. Even though it seems apparent that abiotic agents like air pollution are having dramatic impacts on the giant sequoia/mixed-conifer ecosystem, giant sequoia trees are rated as being most resistant to "smog" damage (Miller 1978). It is not known how this resistance varies with age of individual giant sequoia trees. The reader is referred to Manion (1991) for a general discussion of abiotic disease agents.

Some of the common biotic agents that cause disease in forest trees include nematodes, viruses, bacteria, fungi, and parasitic flowering plants (e.g., dwarf mistletoes). The symptoms of diseases caused by these biotic agents are usually expressed in disturbed or abnormal physiology of the host plant. Vascular wilt pathogens, for example, reduce the capacity of the vessels in trees to translocate water from the roots to the top of the transpiring tree. These diseases are typically classified into categories that are related to the stage of the host life cycle which the disease affects and/or to the expressed physiological effect seen in the forest tree. Diseases caused by biotic agents include seedling diseases, leaf and needle diseases, root and trunk rots, shoot blights, vascular wilts, or stem diseases. Full lists of these diseases associated with giant sequoia can be found in Seymour (1929), USDA (1960), Bega (1964), Hepting (1971), Davidson (1972), Peterson and Smith (1975), Piirto (1977), Piirto and others (1984a,b), and Parmeter (1987). Additional unpublished lists of disease organisms associated with giant sequoia can also be found in the records maintained by various herbariums (e.g., University of California at Berkeley, USDA Center for Forest Mycology Research at the Forest Products Laboratory in Madison, Wisconsin and the USDA Forest Service Pacific Southwest Research Station in Albany, California). These lists are by no means all encompassing, as much remains to be learned about disease relationships in giant sequoia.

Comparatively little work has been done on the biotic and abiotic agents which damage seeds, seedlings, saplings and young-growth giant sequoia trees. Cone and seed molds, damping off fungi and rootrot fungi are suspected as being major factors in preventing seedling establishment in native giant sequoia stands (Stark 1968a,b; Parmeter 1987). These fungi have been shown to cause reduced seed viability and to prevent seedling establishment in undisturbed duff and litter areas within coast redwood stands (Davidson 1972). The role that these fungi play in native giant sequoia stands is not known. Shellhammer and others (1971) reported that mice *(Microtus* spp.), gophers *(Thomomys* spp.), Cerambycid beetles *(Semanotus ligneus amplus)* and a saprophytic fungus *Hyphloma* spp. possibly *fasciculare* were associated with dead and dying 10- and 11-year-old giant sequoias in the Abbot Creek drainage of the Cherry Gap Grove, a previously logged area near Converse Basin.

There are no known occurrences of any true mistletoe or dwarf mistletoe species on either coast redwood or giant sequoia (Hawksworth 1978, 1992).

Factors Associated With Tree Failure

A number of major findings were reported in a study evaluating causes for tree failure of old-growth giant sequoia trees (Piirto 1977, Piirto and others 1984a,b). Thirty-three tree failures were evaluated in this study. Of the 33 failures listed, 21 percent apparently fell mainly because of poor footing (wet soil, stream undercutting, etc.), 67 percent because of the failure of decayed roots and 12 percent because of stem breaks. All but two trees (both fell because of poor footing) had decay in either the stem or roots. Carpenter ants were found in 16 trees but appeared to contribute to failure of only six. Fire scars were present on 27 trees and 26 fell to the fire-scarred side. This phenomenon of giant sequoia tree failures falling to the scarred side was also reported by Hartesveldt and others (1975).

Fungal Agents Associated With Decay and Tree Failure

Many Basidiomycetes are responsible for the decay observed in giant sequoia trees. *Heterobasidion annosum,* also called *Fomes annosus,* has been frequently observed in both the upper and lower stems of recent tree failures of giant sequoia trees (Piirto 1977, 1984a,b, Piirto and others 1974,). Recent research (Piirto and others 1992a,b) is shedding new light on the hypothesis put forward by Piirto (1977) and Piirto and others (1984b) involving increasing stand density levels of white fir and other associated trees species in giant sequoia groves. White fir is highly susceptible to a variety of forest diseases, particularly *H. annosum.* Otrosina and others (1992) and Piirto and others (1992) reported that both *H. annosum* isolates from white fir and giant sequoia are of the 'S' intersterility Group meaning that they are interfertile. Given the interfertility of isolates collected from giant sequoia and true fir, an increase of white fir density in the absence of natural and prescribed fire may result in the build-up of *H. annosum* inoculum that could affect giant sequoia trees. *H. annosum* may spread along with other means via root contacts from white fir to giant sequoia. In greenhouse seedling inoculation studies, isolates of *H. annosum* collected from true fir and isolates collected on giant sequoia were capable of causing pathogenesis on either species (Piirto and others 1992).

Other Basidiomycetes of particular note include *Poria albipellucida, Armillaria mellea, Poria incrassata, Stereum hirsutum,* and others (Piirto 1977, Piirto and others 1984a,b). *Armillaria* spp. as receiving increasing attention as being an important pathogen of giant sequoia both within and outside the native range of giant sequoia (Libby 1982). Libby (1992) reports *Armillaria* spp. as being the possible cause of mortality in young-growth giant sequoia trees (up to 20 years of age) planted in the Rhine River area of Germany. Trees older than twenty years of age seemed to be less susceptible to *Armillaria* spp. and hardwoods were known to have occurred in this Rhine River giant sequoia plantation.

Another recent and interesting report from Libby (1992) involves the forty-year old plantation of giant sequoia trees around the Forest Hill Seed Orchard. The study showed that up to forty percent of the planted young giant sequoia trees which are between 30 and 50 feet tall and up to 10 inches in diameter at breast height had thin crowns and bunches of trees were easily pushed over. Preliminary observations by Forest Service pathologists present with Bill Libby at the Forest Hill site indicate that *Armillaria* spp. may be responsible for the mortality that is occurring there. In the Forest Hill situation, stumps of California black oak *(Quercus kelloggii* Newb.) and dead deer brush *(Ceanothus integerrimus* H.&A.) were in the immediate vicinity of the dead giant sequoia trees. It can be inferred from previous research and from the Rhine River and Forest Hill Seed Orchard situations that *1) Armillaria* spp in combination with other organisms may be important pathogens of both young- and old-growth giant sequoia; *2) Armillaria* spp seems to be particularly aggressive in areas where hardwoods and possibly vulnerable species of *Ceanothus* spp. occur; 3) giant sequoia trees planted outside their natural range may be particularly vulnerable to a whole host of disease problems which as of yet are not completely understood.

Bega (1964), Libby (1982), Worral and others (1986) have conducted studies on giant sequoia trees planted outside their native range and found some of them severely damaged by a canker fungus *Botryosphaeria* sp. In addition, giant sequoia seedlings in nurseries were found to be particularly vulnerable to charcoal root disease caused by *Macrophomina phaseoli* and grey mold caused by *Botrytis cinerea* (Peterson and Smith 1975). Understanding the organisms that cause disease and decay in giant sequoia is important, but it is equally important to understand the interactions that occur between organisms and the environment.

Fire/Pathogen Interactions

Research recently completed by Piirto and others (1992a,b) identified 17 new fungi from giant sequoia fire scar wood samples. The fungi most frequently isolated were *Byssochiamys fulva* (a heat resistant fungus), which was isolated from 34 out of 90 fire scars sampled (38 percent); *Acrodontium intermissum* (a preservative detoxifier), isolated from 22 out of 90 fire scars (24 percent); and *Tritirachium* sp. (an entomogenous fungus), which was isolated from 14 out of 90 fire scars (16 percent). Other interesting fungi isolated include *Neosartorya fischeri* (a heat resistant fungus), *Epicoccum nigrum* (a soft rot fungus), *Leptographium* sp. *(L. wageneri* causes black stain root disease), *Hyalorhin-ocladiella* sp. (pentachlorophenol tolerant; see Wang 1989), *Mariannaea elegans* (capable of forming soft rot cavities in European birch and Scots pine wood; Levy 1969), and Basidiomycetes (fungi causing white or brown rots). A positive identification was made of one of the four confirmed Basidiomycete cultures isolated from giant sequoia fire scars. Referred to as *Phlebia subserialis* [(Bourd. et Galzin) Donk] of the Corticiaceae family and known to affect both hardwoods and softwoods this organism is classified as a white rotter which may have potential in biological pulping processes (Dorworth 1992, Burdsall 1992).

The majority of these fungi identified in the Piirto and others study (1992a,b) are microfungi. As described by Wang and Zabel (1990), microfungi are ubiquitous and cosmopolitan. Some are plant pathogens and some are human pathogens, but most are saprobes that derive nourishment from decaying organic matter that occupy all segments of the environment, most commonly the soil. The term microfungi is commonly used to describe fungi belonging to the Subdivision Ascomycotina. These microfungi have been found associated with utility poles made of Douglas fir, southern pine, and western red cedar. Some have shown to cause soft rot and degradation of wood structure. Recent research suggests some of the microfungi can also reduce the fungitoxicity of wood preservative chemicals (Wang and Zabel 1990). Based on previous research, it is possible the microfungi isolated from giant sequoia may play a role in the decay process. An interesting organism for instance, that has been known for some time to be frequently found on exudate of exposed heartwood of coast redwood and giant sequoia fire scars *is Mycocallicium sequoiae* (Bonar 1971, Piirto 1977, Piirto and others 1992a). More research is needed on the variety of microorganisms at work in the giant sequoia/mixed-conifer ecosystem.

Microorganisms and pathogens can be affected in a variety of ways by fire; and while none of these effects has been adequately evaluated for giant sequoia ecosystems, some possible fire effects with important management implications have been described (Parmeter 1977, Parmeter and Uhrenholdt 1975, 1976, Piirto 1977). It has been discussed that if *Heterobasidion annosum* may build up on white firs *(Abies concolor)* and then attack nearby giant sequoias (Piirto 1977), fires may "cauterize" giant sequoia fire scars and thus reduce decay (Christensen and others 1987). While these aspects are recognized and in need of study, it is likely other fire effects on both the host and associated pathogens occur and only research monitoring these fire effects on microorganisms will allow recognition and further evaluation. These fire/pathogen interactions in the giant sequoia/mixed-conifer ecosystem are reported in Piirto and others (1992a,b).

The management implications of how a disease impacts stands of giant sequoias is incomplete (Parmeter 1987). Knowledge of giant sequoia disease is increasing, but specific effects on regeneration, stand development, old-growth and young-growth trees are still relatively unknown.

Wounds As Entrance Courts

Following fire, trees may show reduced growth and vigor, owing mainly to heat injury (Hare 1961) or perhaps to "shock" if stand density is changed. The ecological effects of this damage can result in numerous pathogens and insects adapted to attack the weakened yet surviving plants. The literature is replete with reports noting a strong association of insect, pathogen, and microorganism activity in fire damaged trees. In all of these reports, fire damaged roots and/or above ground basal fire scars served as an infection court for these organisms.

Perhaps the best documented effects of fire on disease involve the creation of infection courts for heart rot fungi (Boyce 1961; Harvey and others 1976; Hepting 1935; Nelson and others 1933; Nordin 1958). Heart rot which frequently develops in fire scars may in turn effect other processes, such as bark beetle activities in burned stands (Geiszler and others 1980a,b). Canker fungi may also be associated with fire scars (Hinds and Krebill 1975). Decay following fire scarring can reduce productivity in timber stands. It can also lead to hazard problems and to the loss of valuable specimen trees in parks and preserves, as may be the case with loss of giant sequoias (Piirto 1977). Gill (1974) reported secondary effects of fire on fire scars often lead to mechanical failure of *Eucalyptus pauciflora.*

Perry and others (1985) report that damage to living jarrah *(Eucalyptus marginata),* Karri (*E. diversicolor),* and maritime or cluster pine *(Pinus pinaster)* in southwestern Australia by fire or mechanical injury during forest operations emerges as a major factor facilitating the entry of fungi and termites that spread and degrade substantial areas of heartwood. Littke and Gara (1986) and Gara and others (1986) report that the extension of decay columns from fire damaged roots up into the boles of lodgepole pine *(Pinus contorta* var. *murrayana)* suggests root damage is their most important source of stem decay. Newly fire-damaged root tissues were infected with imperfect fungi and white rot basidiomycetes. Decayed material from previous fires yielded primarily brown rot basidiomycetes. It is important to know that the amount of microorganism, pathogen and insect activity associated with fire scars is influenced by the tree species and environmental conditions. This has been emphasized by Hepting and Shigo (1972) for oaks in North Carolina and Maine. It is equally important to know that once infection has occurred, survival and damage may continue throughout the life span of a tree. This has been reported for fire-damaged white fir *(Abies concolor)* regeneration (Aho and Filip 1982).

In a recent study conducted by Piirto and others (1992a,b), it was determined, based on a quantitative evaluation of 90 living old-growth giant sequoias, that as much as 70 percent of the circumference (values ranged from 3.3 percent to 69.5 percent with an average of 27.3 percent) and as much as 54 percent of the cross-sectional area (values ranged from 3.2 percent to 53.7 percent with an average of 15.6 percent) were adversely affected by fire scars at groundline. This research work further demonstrated that prescribed burning programs caused damage to callus tissue around existing fire scars 52 percent of the time, with recessional and enlargement damage noted 57 percent and 35 percent of the time respectively.

The role of fire scars on giant sequoia trees as entrance courts for decay and insect attack has been defined on the basis of numerous research studies. As we move forward with the reintroduction of fire in the form of prescribed burns in giant sequoia grove areas, the questions still remain as to what intensity, where, when, and how much should be burned to largely promote the positive values fire provides to the giant sequoia/mixed-conifer ecosystem while minimizing the negative consequences to specimen old-growth giant sequoia trees. The results by Piirto and others (1992a,b) confirm that the valued older trees in the giant-sequoia/mixed-conifer system are damaged, and that fire management strategies should be implemented to minimize these adverse fire impacts.

Summary and Conclusions

It is important to consider several factors when interpreting insect and disease relationships in the giant sequoia/mixed-conifer ecosystem including:

1. No single variable functions alone because insects, disease organisms and the ecosystems operate interdependently.
2. Various microorganisms have beneficial and antagonistic influences on disease evelopment. Hepting (1935) was one of the first forest pathologists to note an association of various microorganisms (e.g., bacteria, *Trichoderma* spp. and *Penicillium* spp.) with decay fungi. These organisms can inhibit or facilitate decay development in forest trees. Many such known and unknown interactions are at work in the giant sequoia/mixed-conifer ecosystem.
3. Fire does influence the type and population levels of a vast variety and number of insects, pathogens and microorganisms found in the giant sequoia/mixed-

conifer ecosystem. These interactions are not well understood. These relationships are further complicated by changing climatic patterns such as drought. For example, a bark beetle like *Phloesinus punctatus* (western cedar bark beetle), which is common in fallen branches of giant sequoia could, in drought periods, become more detrimental (Wood 1992). More research is needed.

4. Further complicating these complex ecosystem interactions is the influence of human activities. Fire suppression, whereas beneficial in many ways, has altered stand development in the giant sequoia/mixed-conifer ecosystem. Changes in stand density and species makeup may be aggravating disease and insect relationships (Piirto 1977). Prescribed burning, on the other hand, has both beneficial and detrimental effects. Wounds caused by fire have unquestionably been associated with both disease and insect attack in forest trees (Manion 1991).
5. Young-growth giant sequoia both in and planted outside its native range are vulnerable to a whole host of insect and disease problems. *Botryosphaeria* spp and *Armillaria* spp appear to be two major pathogens commonly associated with disease problems in young-growth giant sequoia trees. Little is known about the vulnerability of young-growth giant sequoia trees to insect and disease attack both within and outside of its native range.
6. Other time dependent events (e.g., aging) may be influencing susceptibility of giant sequoia to attack by insect and disease organisms; and insect/disease associations currently present may be to some degree affected by the age of the tree.
7. Fire and mechanically damaged roots, stems, limbs and other tree tissues serve as entrance courts to pathogen and insect attack. It is incumbent upon managers of giant sequoia groves to take appropriate protective measures to minimize deleterious effects of forest management practices on the giant sequoia/mixed-conifer ecosystem. At the very least, it is essential that we study these influences as we move forward with deciding which management approaches are appropriate for giant sequoia groves.
8. Much is still unknown about disease and insect relationships in the giant sequoia/mixed-conifer ecosystem.

It is important to remember insects, disease and other microorganisms when evaluating ecological relationships at work in the giant sequoia/mixed-conifer ecosystem.

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