California FORESTRY Note

P.O. Box 944246 Sacramento, CA. 94244-2460 Phone (916) 653 - 9476

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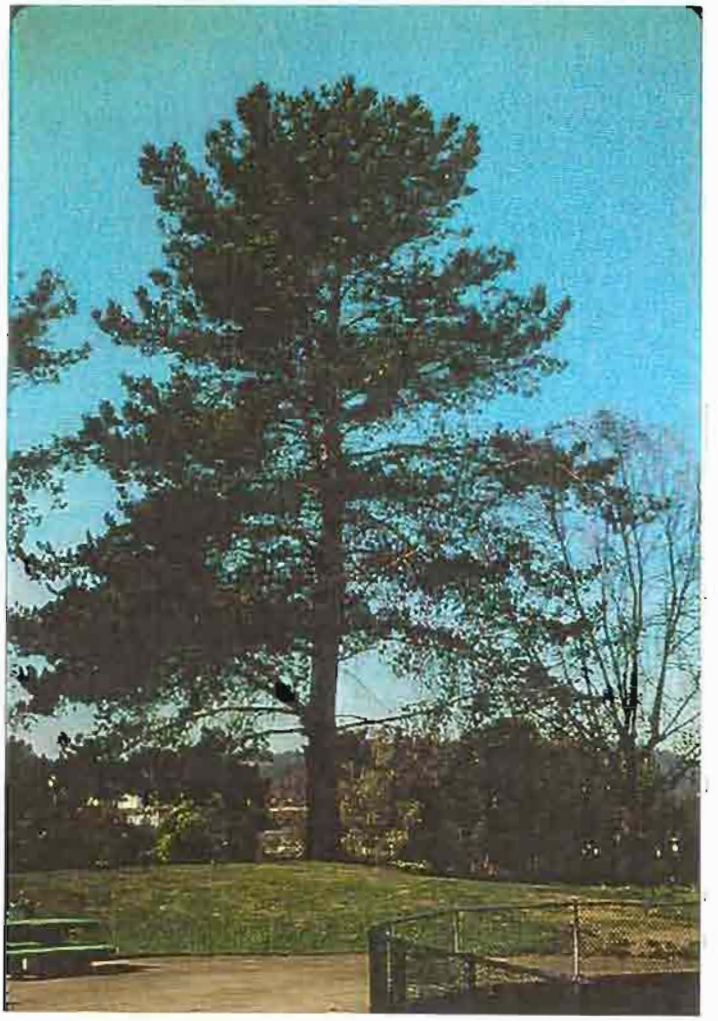
Pitch Canker in California

Andrew J. Storer, Thomas R. Gordon, David L. Wood and Paul L. Dallara[1]



1. Dept. Environmental Science, Policy and Management, University of California at Berkeley, Berkeley, CA 94720

Richard A. Wilson, Director
California Department of Forestry and Fire Protection

Douglas P. Wheeler, Secretary for Resources
The Resources Agency

Pete Wilson, Governor
State of California

Introduction

Since 1961, it has been known that the fungus which causes pitch canker, *Fusarium subglutinans* (Wollenweb. & Reinking) P.E. Nelson, T.A. Toussoun & Marasas f. sp. *pini*, is pathogenic to Monterey pine (*Pinus radiata* D. Don) (Hepting, 1961). Natural infections of Monterey pine in California were not seen until 1986 when the pathogen was isolated from symptomatic tissue in Santa Cruz County (McCain *et al.*, 1987). The disease occurs on Monterey pine and other conifers planted along road rights-of-way, and in landscape settings in the central coast of California, and has become severe in many locations. The pathogen also occurs in native stands of Monterey and Bishop (*P. muricata* D. Don) pine (Storer *et al.*, 1994b; Dallara *et al.*, 1995).

The disease was first reported in North Carolina in 1946 (Hepting and Roth, 1946) and is considered to be endemic in the southeastern United States. It occurs north to Virginia, south to Florida, and west to Texas (Dwinell *et al.*, 1985). Losses from tree mortality, reduced lumber quality because of stem deformation, reduced growth, seed contamination in seed orchards, and seedling mortality in nurseries have been extensive (Barnard and Blakeslee, 1980; Barrows-Broaddus and Dwinell, 1985; Dwinell *et al.*, 1985; Schmidt and Underhill, 1974). The disease mostly affects slash pine, *P. elliottii* Engelm. (Dwinell and Phelps, 1977), and in loblolly pine, *P. taeda* L., wounds provide infection courts for airborne and rain splash carried spores of the fungus (Kuhlman *et al.*, 1982). The disease is occasionally coincident with the deodar weevil (or eastern pine weevil), *Pissodes nemorensis* Germar, which may act as a wounding agent in Florida (Blakeslee *et al.*, 1978). However, other insects, possibly acting both as vectors and as wounding agents, apparently contribute to disease spread (Schmidt and Underhill, 1974; Schmidt *et al.*, 1976).

This Forestry Note reviews what is known about pitch canker disease in California. It includes information on the epidemiology and management of the pathogen.

Symptoms of Pitch Canker Disease

Infections by *F. s. pini* occur on branches, shoots, cones, exposed roots and boles of pines, which results in the formation of resinous cankers (Figure 1). Removal of bark from the cankers reveals slightly sunken, honey-colored wood that is soaked with resin. The needles distal to branch tip infections wilt, fade from yellow to red, and fall from the tree. Multiple branch tip infections often result in a noticeable dieback in the tree crown. Female cones on infected branches often abort before reaching full size, and typically remain closed. Cankers on the tree bole do not usually appear until branch dieback has occurred. They are flat or slightly sunken, up to approximately 30cm. in diameter, and produce large amounts of resin that often coats the bark several feet below the infection site.

Resinous pitch canker symptoms on Monterey pine Christmas trees usually occur on the root crown. The whole tree rapidly wilts and dies. Occasionally branch infections occur without the rapid death of the tree.

On Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), resin exudation does not seem to be associated with pitch canker infections, and callous tissue forms over the infection site (Storer *et al.*, 1994b). Extensive branch tip dieback has been observed on Douglas-fir, but bole cankers have not yet appeared.

Geographic and Host Range

Geographic range

Branch tips with symptoms of pitch canker infection were collected from tree canopies using pole pruners. Isolations of the pathogen from infected tissue were made in the field, and/or in the laboratory. Samples of resin soaked phloem and xylem tissue were removed using a flame sterilized scalpel, and placed on an agar medium selective for *Fusarium* spp. (Correll *et al.*, 1991). Plates of this medium were incubated at room temperature under a 12:12 lighting regime for five days. Fungal colonies were observed under a dissecting microscope, and positive identification of *F. subglutinans* was often possible at this stage. Other colonies suspected of being the pitch canker pathogen were reisolated onto carnation leaf agar prior to making positive identifications. The pathogenicity of a sample of isolates recovered from plant material was confirmed by inoculating Monterey pine in the greenhouse and noting the development of resin soaked lesions 3-4 weeks later.

The geographic range of pitch canker is shown in Figure 2. The isolated locations represent few records, or outbreaks with very limited geographic ranges such as those in Christmas tree plantations in southern California.

The native range of Monterey pine is limited to three sites in mainland California: Año Nuevo Point, the Monterey Peninsula and Cambria. The pitch canker pathogen has been isolated from all of these forests. On the Monterey peninsula, pitch canker was confirmed at the Pebble Beach firehouse in April 1992 on two trees, and by December of 1992, over twenty trees in the immediate area were showing symptoms of the disease. The pathogen has now become widespread on the Monterey peninsula (Storer *et al.*, 1994b). At Año Nuevo Point, symptoms of the disease were first observed on native Monterey pine in December 1992. Since that time, the disease has become widespread in this native stand, and the pathogen was isolated and identified in November 1993 (Storer *et al.*, 1994b). In November 1994 the pathogen was isolated from a native Monterey pine at Cambria (Dallara *et al.*, 1995).

The pitch canker pathogen was isolated from a native Bishop pine stand on the Mendocino coast in November 1992. This was the first record of the pathogen north of San Francisco, and further positive identifications of the pathogen were made in this area in August 1993 (Storer *et al.*, 1994b). It was also isolated from a symptomatic Monterey pine in Ukiah (Mendocino Co.) and from several Monterey pines in Santa Rosa (Sonoma Co.). Infected Monterey pines have been found in several northern Alameda county locations (Berkeley, Oakland, and Alameda), and in the cities of Monterey and Carmel-by-the-Sea, reflecting spread of the pathogen in these areas.

Host range

Although Monterey pine is by far the most commonly infected species, the pathogen has also been isolated from Aleppo pine (*P. halepensis* Mill.), Bishop pine (*P. muricata*), Italian stone pine (*P. pinea* L.), (McCain *et al.*, 1987), Canary Island pine (*P. canariensis* C. Smith) (Correll *et al.*, 1991), Coulter pine (*P. coulteri* D. Don), ponderosa pine(*P. ponderosa* Laws.) (Fox *et al.*, 1991), Digger (=gray) pine (*P. sabiniana* Dougl.), knobcone pine (*P. attenuata* Lemm.), shore pine (*P. contorta contorta* Dougl.), Torrey pine (*P. torreyana* Parry), and

Douglas-fir (*Pseudotsuga menziesii*) (Storer and Dallara, 1992; Storer *et al.*, 1994b) (Table 1). Moreover, all pines native to California which were tested as seedlings in the greenhouse were found to be susceptible to this fungus (McCain *et al.*, 1987).

The most recent new host records of the pathogen are all from planted trees in Santa Cruz County: shore pine at Sunset State Beach, Torrey pine at Seacliff State Beach, Digger pine in central Santa Cruz Co., and knobcone pine and Douglas-fir in southern Santa Cruz Co. The pathogen has also been isolated from Aleppo pine Christmas trees in San Diego Co., which is the first record of pitch canker in southern California on a tree species other than Monterey pine.

Table 1: Tree species found infected with the pitch canker fungus in the field, and species susceptible to the pathogen in laboratory tests. (from McCain *et al.*, 1987; Storer and Dallara 1992; Storer *et al.*, 1994b)

Tree species		Native to CA?
Naturally infected species		
Aleppo pine	*Pinus halepensis*	No
Bishop pine	*P. muricata*	Yes
Canary Island pine	*P. canariensis*	No
Coulter pine	*P. coulteri*	Yes
Digger (gray) pine	*P. sabiniana*	Yes
Italian stone pine	*P. pinea*	No
Knobcone pine	*P. attenuata*	Yes
Monterey pine	*P. radiata*	Yes
Monterey x knobcone pine	*P. radiata x attenuata*	Yes
Ponderosa pine	*P. ponderosa*	Yes
Shore pine	*P. contorta contorta*	Yes
Torrey pine	*P. torreyana*	Yes
Douglas-fir	*Pseudotsuga menziesii*	Yes
Other species susceptible in laboratory tests		
Eldarica pine	*P. eldarica*	No
Jeffrey pine	*P. jeffreyi*	Yes
Scots pine	*P. sylvestris*	No
Sugar pine	*P. lambertiana*	Yes

The Genetics of the Pitch Canker Fungus in California

All isolates of *F. subglutinans* recovered from diseased pine tissue, insects and air samples in California were virulent on Monterey pine in greenhouse pathogenicity tests, as were pine isolates of *F. subglutinans* from Florida (Correll *et al.*, 1991; 1992, and unpublished). It has been proposed that the pitch canker pathogen be recognized as a special form, to be designated *F. subglutinans* f. sp. *pini* (hereafter designated *F. s. pini*), because: 1) all isolates of *F. subglutinans* from plant hosts other than pine were avirulent on Monterey pine (Correll *et al.*, 1991), 2) mitochondrial DNA

was invariant among pine isolates of *F. subglutinans*., and 3) pine isolates of *F. subglutinans* could be differentiated from non-pine isolates of this species based on restriction fragment length polymorphisms in mitochondrial DNA (Correll *et al.*, 1992).

Variability in *F. s. pini* populations in California and Florida was surveyed by vegetative compatibility tests among pathogen strains and variability in mitochondrial DNA (Correll *et al.*, 1992). The vegetative compatibility tests revealed considerable diversity. In California, five vegetative compatibility groups (VCGs) were identified among 209 isolates of *F. s. pini*, whereas in Florida 45 VCGs were identified among 117 isolates examined. One VCG represented 70% of all samples from the California population. None of the Californian VCGs were identified among the isolates from Florida. Within a single stand in Florida, there was greater VCG diversity than in the entire California population of the pitch canker pathogen. Thus, by comparison to the Florida population, the limited diversity found in the California population of *F. s. pini* is consistent with a recent introduction to California, though not necessarily from the southeastern United States. The population structure in California also indicates a strictly asexual mode of reproduction. Furthermore, all sexual crosses attempted among *F. s. pini* strains failed to yield viable progeny (Correll *et al.*, 1992).

Epidemiology

Associations between the pitch canker pathogen and insects

Insects collected from the tree parts were identified, killed by freezing, and plated onto agar medium selective for *Fusarium* spp.. Pathogenicity of some isolates recovered from insects was confirmed by inoculating Monterey pine in the greenhouse and noting the development of resin soaked lesions 3-4 weeks later. The pathogen has been isolated from many insect species (Table 2). Some of these are implicated as vectors, and some are of unknown importance in the epidemiology of the disease.

Cone beetles, Twig beetles and Anobiids.

Two species of beetles, *Conophthorus radiatae* Hopkins and *Ernobius punctulatus* Fall, infest cones of Monterey pine and appear to be important vectors of pitch canker in California. In samples of cones collected in Snata Cruz County and reared in the laboratory, 25 to 30% of emerged adult beetles carried propagules of *F. s. pini*. For those cases where the two species were found together (26%), the percentage of cones containing contaminated *C. radiatae* was greater when *E. punctulatus* progeny were also contaminated than when *E. punctulatus* was not. These results indicate interspecific transmission of the fungus (Hoover *et al.*, 1995). In sticky traps, 12% of *E. punctulatus* and 14% of *Pityophthorus* spp. were contaminated with the pitch canker fungus (Hoover 1992, Hoover *et al.*, unpublished).

Table 2: Insects from which the pitch canker fungus has been isolated (from Fox *et al.*, 1990 & 1991; Storer and Dallara, 1992; Storer *et al.*, 1995).

Common Name	Latin Name	Family
Engraver beetles		
Monterey pine ips	*I. mexicanus*	Scolytidae
California four-spined ips	*I. plastographus*	Scolytidae
California five-spined ips	*Ips paraconfusus*	Scolytidae
Monterey pine cone beetle	*Conophthorus radiatae*	Scolytidae
Twig beetles	*Pityophthorus carmeli*	Scolytidae
	P. pulchellus tuberculatus	Scolytidae
	P. nitidulus	Scolytidae
	P. setosus	Scolytidae
Red turpentine beetle	*Dendroctonus valens*	Scolytidae
Dry twig and cone beetle	*Ernobius punctulatus*	Anobiidae
Monterey pine weevil	*Pissodes radiatae*	Curculionidae
Sequoia pitch moth	*Synanthedon sequoiae*	Sesiidae

Experimental evidence shows that *C. radiatae* and *E. punctulatus* can transmit the fungus to each other and to their progeny (inter- and intraspecific transmission, respectively) (Hoover, 1992). Fifteen percent of 177 cones observed between August 1990 and May 1991 developed pitch canker symptoms. Of those tagged, attacked cones that developed pitch canker, 52% were infested by *C. radiatae* and 12% by *Pityophthorus* spp. Between June 1990 and January 1991, 28% of 460 observational conelets were infested by *C. radiatae*, *Pityophthorus* spp., and/or *E. punctulatus*. 29% of these insect-infested conelets were positive for *F. s. pini*. *C. radiatae* and *Pityophthorus* spp. did not occur together. *E. punctulatus* occurred with *C. radiatae* but not *Pityophthorus* spp. Mean contamination of these beetles ranged from 34-53% (Hoover, 1992).

When artificially contaminated and confined to their host, *C. radiatae* transmitted the pathogen to healthy cones and their progeny acquired the fungus from their parents (Hoover, 1992). Artificially contaminated *E. punctulatus* transmitted this fungus to cones attacked by uncontaminated *C. radiatae*. Interspecific transmission of inoculum in both directions was suggested under experimental conditions (Hoover, 1992). The frequency of contaminated *C. radiatae* progeny was greater when a contaminated *E. punctulatus* adult was introduced (74%) than when an uncontaminated adult was introduced (26%). The frequency of contaminated *E. punctulatus* progeny increased when a contaminated *C. radiatae* adult was introduced compared to an uncontaminated adult. *E. punctulatus* required an entrance tunnel by *C. radiatae* to enter and infect the cone (Hoover, 1992). Interspecific transmission of inoculum may enhance the potential for *C. radiatae* and *E. punctulatus* to spread the pathogen to California's native pines. *C. radiatae* is host specific to Monterey pine, but *E. punctulatus* also infests Douglas-fir, knobcone pine and ponderosa pine (Furniss and Carolin, 1977).

Pityophthorus spp. occasionally attacked mature Monterey pine cones and frequently infested conelets where over 40% of the adults recovered were contaminated with *F. s. pini* propagules. Prior to this, attack of cones by twig beetles had only been reported from one record in Mexico (Cibrian-Tovar *et al.*, 1986).

Infected branch tips placed in rearing chambers produce large numbers of *Pityophthorus nitidulus* (Mannerheim) and *P. carmeli* Swaine. Both of these species and *P. setosus* Blackman have been shown to carry propagules of the pitch canker pathogen in central, coastal California. The species of twig beetles emerging from rearing varies according to site and time of year (Dallara, 1994). *P. pulchellus tuberculatus* Eichhoff has also been found to carry propagules of the pathogen in southern Californian Monterey pine Christmas trees (Storer and Dallara, 1992). Insect associates of *Pityophthorus* spp. have also been shown to carry propagules of the pitch canker pathogen (Dallara, 1994, Dallara *et al.*, 1995).

Engraver beetles.

Several species of *Ips* are known to be active in Monterey pine stands in Santa Cruz Co., CA. In all Monterey pine stands examined in Santa Cruz Co., *Ips* spp. had tunneled into healthy branches and boles (Fox *et al.*, 1990). In naturally occurring slash in these off-site Monterey pine stands, *I. mexicanus* (Hopkins) was the most abundant engraver beetle observed, followed by *I. paraconfusus* Lanier; *I. plastographus* (LeConte) was rare (Fox *et al.*, 1990). More recent observations of slash in Santa Cruz Co. suggest that the abundance of *I. plastographus* may be considerably higher at certain times of the year (Storer *et al.*, unpublished). During the winter *I. mexicanus* excavated mass feeding cavities in shade-suppressed branches (Fox *et al.*, 1990). In stands severely affected by pitch canker, canopy top and branch mortality associated with *Ips* spp. attacks were much more frequent than in uninfected stands (Fox *et al.*, 1990).

F. s. pini was recovered from *I. mexicanus*, *I. paraconfusus*, and *I. plastographus* that emerged from pitch canker-infected Monterey pine slash (Fox *et al.*, 1991; Storer *et al.*, unpublished). *Ips paraconfusus* adults experimentally contaminated with propagules of *F. s. pini* transmitted pitch canker to 3- to 4-year-old seedlings and mature pines (Fox *et al.*, 1991). Field transmission was demonstrated when cankers were produced following pheromone-induced *I. paraconfusus* attacks on pines. *Ips* spp. inoculated *F. s. pini* into pine slash, thus creating reservoirs of the pathogen. Larvae, pupae, and young adults acquired the fungus from logs originally inoculated by their parents. *Ips* spp. progeny production and development over one generation were not significantly altered by the fungus. Thus a new association may be developing among native *Ips* spp. and *F. s. pini* (Fox *et al.*, 1991).

Branch and stem infections

In California, the pitch canker fungus is believed to be transmitted to branch tips by twig beetles and to cone whorls by twig beetles and cone beetles. The relative importance of these two groups is still to be determined.

Infections are frequently found associated with cone whorls. In March 1993, asymptomatic branches of Monterey pine trees at three sites in Santa Cruz Co. were tagged Each site was heavily infected with pitch canker. Branches which had cone whorls were selected for comparison with branches which had no cone whorls. Branches with no cone whorls were mostly lateral branches, but some terminal branches without cones were used. All branches with cone whorls were terminal branches. The tagged branches were assessed for pitch canker symptoms after 5 months (Table 3) (Storer *et al.*, 1995).

Table 3: Incidence of pitch canker symptoms in August 1993 on branches with and without cone whorls which were asymptomatic in March 1993 (number symptomatic/number observed in parentheses) (Storer *et al.*, 1995).

Site	% cone terminals symptomatic	% non-cone terminals symptomatic	% non-cone laterals symptomatic
1	14.3 (5/35)a	11.1 (1/9)a	3.8 (1/26)a
2	29.0 (9/31)a	0.0 (0/9)ab	0.0 (0/22)b
3	36.8 (14/38)a	0.0 (0/1)ab	2.7 (1/37)b
Overall	26.9 (28/104)a	5.3 (1/19)b	2.4 (2/85)b

Percentages in the same line which are followed by different letters differ significantly from each other ($P < 0.05$, *z*-test, (Freund, 1967)). When non-cone terminals and laterals are combined, with the exception of site 1, non-cone branches differed significantly from cone branches.

In this study, branches with cones were more likely to show symptoms of pitch canker than were branches without cones. 90.3% (S.E. = 5.3) of branches which became symptomatic between March and August 1993 had cone whorls.

Infections at cone whorls are thought to result from feeding activity of *C. radiatae*, and to a lesser extent *Pityophthorus* spp. which were found carrying propagules of the pathogen (Hoover, 1992; Hoover *et al.*, 1995). *Pityophthorus* spp. may preferentially feed in the bark associated with branches bearing cones. These results suggest that Monterey pine with heavy cone crops may be more prone to infection by *F. s. pini*.

Infections of terminal branches were observed to occur more frequently than were infections of lateral branches. In March 1993, asymptomatic Monterey pine terminal branches without cones, and a lateral on each of these branches, were tagged at two heavily infected sites in Santa Cruz Co. These branch pairs were assessed for pitch canker after 5 months (Storer *et al.*, 1995) and after 1 year (Table 4).

Table 4: Incidence of pitch canker symptoms in August 1993 and March 1994 on terminal and lateral branches without cone whorls which were asymptomatic in March 1993 (number symptomatic/n in parentheses).

	August 1993		March 1994	
Site	% terminal branches symptomatic	% lateral branches symptomatic	% terminal branches symptomatic	% lateral branches symptomatic
1	0.0 (0/25)a	0.0 (0/25)a	16.0 (4/25)a	0.0 (0/25)b
2	17.4 (4/23)a	0.0 (0/23)b	52.9 (9/17)a	5.9 (1/17)b
Overall	8.3 (4/48)a	0.0 (0/48)b	30.9 (13/42)a	2.4 (1/42)b

Means in the same row on the same date followed by different letters differ significantly ($p < 0.05$, *z*-test, (Freund, 1967)).

Terminal branches were more likely to become infected with the pitch canker pathogen during this study. All infections which had occurred by August 1993, and 92.9% (S.E. = 6.9) of infections which had occurred by March 1994, were on terminal branches.

Tree decline due to pitch canker

Permanent plots for monitoring pitch canker were established in March 1992, in Santa Cruz, Monterey, Alameda and San Mateo counties. Each plot consisted of a minimum of sixty trees, fifteen of which were selected at random for intensive observation. The two trees closest to each of these fifteen trees were observed less intensively. Plots in which more than 25 out of 45 selected trees had symptoms of the disease were classified as having high levels of infection. Plots with less than 25 infected trees were classified as having low levels of infection.

The status of pitch canker infection in the canopy of sample trees was assessed by viewing from one side only, and counting the number of symptomatic tips up to a maximum of ten for each of three categories (yellow needles, red needles, barren of needles). These trees were also assessed for the number of attacks by the red turpentine beetle, *Dendroctonus valens* LeConte, the sequoia pitch moth, *Synanthedon sequoiae* (Hy. Edwards), and the number of bole cankers (up to a maximum of five). The two trees nearest to the sample tree were viewed from all sides to assess the number of symptomatic tips, up to a maximum of ten, in each of the above categories. The number of bole cankers were recorded. Sites which had high rates of infection at the beginning of this study were assessed every four months, and sites with low or zero rates of infection at the start of the study were assessed every two months. These plots have been repeatedly assessed since March 1992.

In June 1993, preliminary analyses (z-tests) of some of these data were carried out to determine the overall pattern of disease development in plots with high and low infection rates (Table 5) (Storer *et al.*, 1995).

Table 5: Preliminary results of a study to elucidate the patterns of pitch canker spread in permanent assessment plots.

	High plots	Low plots
% trees uninfected in Feb. 1992 which were infected by June 1993 (n)	6.3 (48)a	26.4 (72)b
% trees with <10 infections in Feb. 1992 which had >10 infections in June 1993 (n)	22.3 (139)a	7.3 (82)b
% of trees with no bole cankers in Feb. 1992 with bole cankers by June 1993 (n)	17.7 (277)a	4.8 (126)b

Data in the same row with different letters, differ significantly ($p < 0.05$, *z*-test). n= number of trees examined.

Uninfected trees in plots with low levels of pitch canker infection were more likely to develop symptomatic branches during the course of this study than uninfected trees in plots with high levels of pitch canker infection. Trees with less than 10 branch tip infections at the start of the study were more likely to

have more than 10 infections at the end of the study in high infection plots than in low infection plots. This suggests that disease intensification occurs to a greater extent on trees in plots with high levels of infection. Trees with no bole cankers at the start of the study were more likely to have bole cankers at the end of the study in high infection plots than in low infection plots. Bole cankers appear to be a more advanced symptom of the disease. Only one tree has been observed during this study with a bole canker but with no apparent branch tip symptoms.

These results support the observation that disease development follows the sequence of branch tip dieback, followed by the appearance of bole cankers on the main stem (Storer *et al.*, 1994a, 1995). Mortality of the upper crown of the tree is more likely to occur in areas with than without the pitch canker pathogen (Fox *et al.*, 1990). Since many of the trees in this study are amenity trees, they are frequently removed before top kill or tree mortality occurs. In the case of early infections, each diseased branch tip represents at least one introduction of the pathogen into the tree. Hence, a tree with significant branch tip mortality has been infected numerous times, probably as a result of *Pityophthorus* spp. and *C. radiatae* activity. *Ips paraconfusus* and *I. mexicanus* are capable of vectoring the pathogen to the boles of trees, resulting in bole canker formation (Fox *et al.*, 1991). However, *Ips* spp. are not always present when bole cankers are dissected. It is hypothesized that preliminary feeding by *Ips* spp. during host searching may cause infections even though many hosts are rejected as potential breeding sites (Fox *et al.*, 1991). Top kill of trees appears to be a result of mass attack by *Ips* spp. The species of *Ips* involved varies according to the local abundance of the three species at a particular site.

Pitch canker as a seed borne disease

The pitch canker pathogen can be isolated from seeds collected from cones on infected branches. Closed cones were collected from infected and uninfected branches at a number of locations. Cones were opened by heat treatment at 40°C and the seeds were then removed and stored at 4°C. Batches of seeds from each cone were treated in each of the following ways: 1) plated onto an agar medium selective for the pitch canker fungus, 2) soaked in 1% sodium hypochlorite for 5 minutes and plated on an agar medium selective for the pitch canker fungus, 3) sown in pasteurized U.C. mix potting soil, and 4) surface treated as in 2, and sown in pasteurized U.C. mix potting soil. In some cases the pathogen appears to be carried on the surface of the seeds, since surface sterilization in 1% sodium hypochlorite solution frequently reduced the incidence of the fungus. In some cases however, all surface sterilized seeds from cones from infected branches yielded colonies of *F. s. pini* when plated onto *Fusarium* selective medium. Seeds germinated more frequently when originating from cones from uninfected branches than when originating from cones from infected branches. Seedlings from infected cones frequently yielded *F. s. pini* when removed from the soil, washed, and plated onto *Fusarium* selective medium (Storer and Gordon, unpublished).

These findings have important implications for the regeneration of native Monterey pine stands. Seeds from heavily infected trees are likely to be carrying propagules of the fungus, and thus natural regeneration to replace dead and dying native trees will be reduced.

Effect of temperature on the pathogen

Based on its present distribution, pitch canker is a disease of coastal California where the climate is mild. Similarly, where the disease occurs in the southeastern U.S., moderate temperatures prevail through most of the year. This geographic pat-

tern may reflect limitations on the activity of the pathogen, as might be imposed by lower temperatures in more inland and higher elevation locations. If so, expansion of pitch canker beyond its present range may be limited by the inability of the pathogen to grow and establish infections at ambient temperatures which prevail away from the coast. In laboratory tests, the pathogen failed to establish infections at 10°C (McDonald, 1994), and hence the development of the pathogen may be limited in some areas.

Economic Importance of Pitch Canker Disease

Timber species

The potential damage which may result from the introduction of the pitch canker pathogen into California goes far beyond the current threat to Monterey pine. All commercially important native pine species in California are susceptible to pitch canker. Pitch canker has been found in ponderosa pine and Douglas-fir in Santa Cruz Co. Both are commercially important timber species in California, and their native ranges extend into Santa Cruz Co., notably in and near Henry Cowell State Park. Both of these species are important components of the Sierra Nevada mixed conifer forest. Jeffrey pine and sugar pine are also susceptible to the disease. If pitch canker spreads to the Sierra Nevada, these commercially important timber species may be at risk from the disease. The incidence of the disease north of San Francisco is expected to increase. The pathogen has been isolated from native Bishop pine and planted Monterey pine in Mendocino Co., and from planted Monterey pine in Sonoma Co. Perhaps the most significant new record of pitch canker is from Douglas-fir, a widespread North American tree species.

There are at least three possible avenues which the disease may take to the commercial timber forests in California. The disease may spread inland using isolated areas of Monterey pine and other suitable hosts such as Digger pine as stepping stones to the Sierra Nevada, or spread north or south to more complete host bridges through the Cascades or southern California mountains. Another likely event is the spread of the pathogen through movement of infected plant material into previously uninfested areas.

Christmas trees and nurseries

Due to the seasonal nature of the Christmas tree market, financial losses cannot be reduced by the immediate marketing of trees showing early signs of infection. In Rosemead, California, 5% of Monterey pine Christmas trees died due to pitch canker in 1992, and by September 1993, losses had already exceeded those for 1992. Because little is known about the epidemiology of pitch canker in Christmas tree plantations, management recommendations cannot be made.

Native stands

Monterey pine is the most widely planted pine in the world (McDonald and Laacke, 1990). It is used as a timber species in New Zealand, Australia, and Chile, and is one of the most important amenity trees in California. Hence the very limited native stands of this species represent a vitally important genetic resource of germplasm for selection and cloning to provide desirable growth characteristics and resistance to insects and disease.

Torrey pine is represented by two small native stands in coastal San Diego Co. Though not an economically important tree species, a number of urban plantings have been undertaken. Off-site plantings of this species are susceptible to the pathogen, and there is concern that pitch canker may become established in native Torrey pine stands, which are less than 50 miles away from heavily infected Monterey pine Christmas tree plantations.

Certain genotypes of other more widely distributed tree species are also threatened by the pitch canker pathogen. For example the limited coastal populations of ponderosa pine, knobcone pine and Douglas-fir in Santa Cruz Co. are at risk due to their close proximity to infected off-site plantings of Monterey pine.

The Urban Forest

The character of areas with planted pines has changed greatly over the past few years. For example, the State Highway 1 corridor through Santa Cruz Co. has been altered by the removal of diseased trees. This type of loss is also evident in many of the state parks in the area. Monterey pines which are hazardous or unsightly are now being removed.

Extensive infections of the pitch canker fungus have been recently found in Monterey pine grown as landscape trees in the city of Carmel-by-the-Sea. In the northwest section of the city, 25% of trees (n=88) were found to have symptoms of pitch canker in March 1994. The incidence of disease in other areas of the city was lower. The northwest section borders on the native stands of Monterey pine at Pebble Beach, where pitch canker infections are widespread. The disease is expected to spread across the city of Carmel-by-the-Sea from the infections which are now established.

Recommendations and Potential for Control of Pitch Canker Disease

Monterey pine in California is at serious risk of infection by the pitch canker fungus. It is therefore not recommended that landscape plantings of Monterey pine be initiated at the present time (Storer *et al.*, 1994b). The planting of other pine species should be undertaken with caution. Planting trees which are known to be susceptible should be avoided in areas with diseased Monterey pine (Gordon and Storer, 1994). Many of the insect species which vector the pitch canker fungus in Monterey pine are also known to breed successfully in other pine species, and may vector the pathogen to new host species. It is further recommended that no pines be planted in close proximity to Torrey Pine State Park, San Diego Co. (Storer *et al.*, 1994b). This will reduce the chance of the pitch canker fungus becoming established in the very limited native stands of this species.

The removal of infected tips and dead tops from trees is not effective in managing the pathogen in heavily affected areas. On trees from which all visible infections were removed, subsequent infections occurred (Schultz and Gordon, unpublished). The presence of nearby infected trees and their associated beetle populations increases the probability that additional infections will occur. If the number of infected tips is very low and the affected tree is relatively isolated from other infected trees, pruning to remove all infections may slow the development of the disease. Cuts must be made well below the visibly affected part of the branch which should be treated as described below. However, recent infections may not yet be symptomatic so additional pruning may be required several weeks or months later.

Destruction of cut and fallen branches and trees reduces the availability of breeding material for beetles which may transmit the fungus. Cut branches, prunings, and fallen trees and branches should be chipped, debarked, or burned to kill beetles breeding under the bark. Tools should be sterilized with Lysol® before and after contacting infected material. No fungicidal or insecticidal treatments are effective in controlling pitch canker (Storer *et al.*, 1994b).

The movement of infected tree tissue should be limited as much as possible. Fresh slash and recently cut logs or windthrown trees are known to act as reservoirs for the pathogen and the insects associated with it (Fox *et al.*, 1991). Movement of infected material, including firewood and chipped infected branches, into areas free of the pathogen greatly increases the chance of introducing it into those areas.

In many areas where pitch canker occurs, individual Monterey pine trees are free of infection, which may reflect genetic resistance of these trees. Tree strains which are resistant to the pathogen are currently being studied, and long term management of this disease may depend on the development of these resistant strains. Work is underway to investigate the possibility of producing genetically resistant varieties of Monterey pine, and if successful, it may be possible to resume ornamental plantings of Monterey pine in the future.

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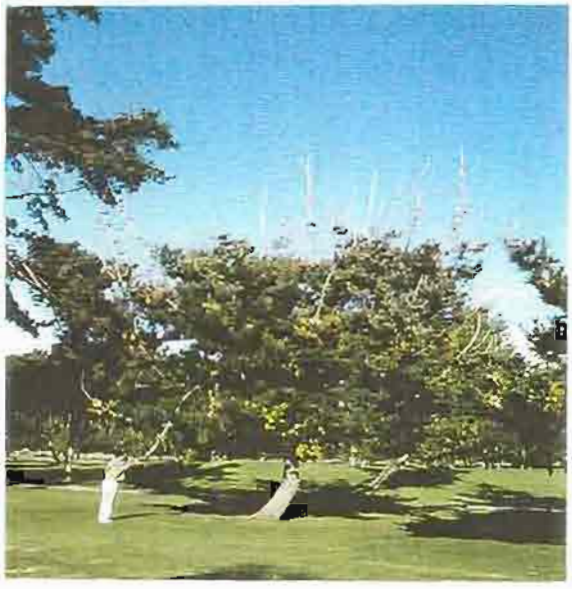
FIGURE 1. Symptoms of pitch canker

ABOVE- Branch tip infections on Monterey pine cause wilting and lime green coloration of the needles.

LEFT- Multiple branch infections produce a noticeable dieback in the crown of the tree, as seen in this Monterey pine.



ABOVE- Monterey pine in an advanced stage of decline due to pitch canker. The top of the tree is dead due to multiple branch tip infections.

ABOVE- A bole canker on the main stem of Monterey pine. Note the resin streaming form the infected area.

ABOVE- Branch tip infections of Douglas-fir cause browning of the foliage in the infected area.

ABOVE- Infected branch tip from ponderosa pine showing resin on the surface of the branch, coming from the point of infection.

FIGURE 2. Distribution map of pitch canker in California (Dallara *et al.*, 1995)