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Incidence and Effects of Endemic Populations of Forest Pests in Young Mixed-Conifer Forests of the Sierra Nevada

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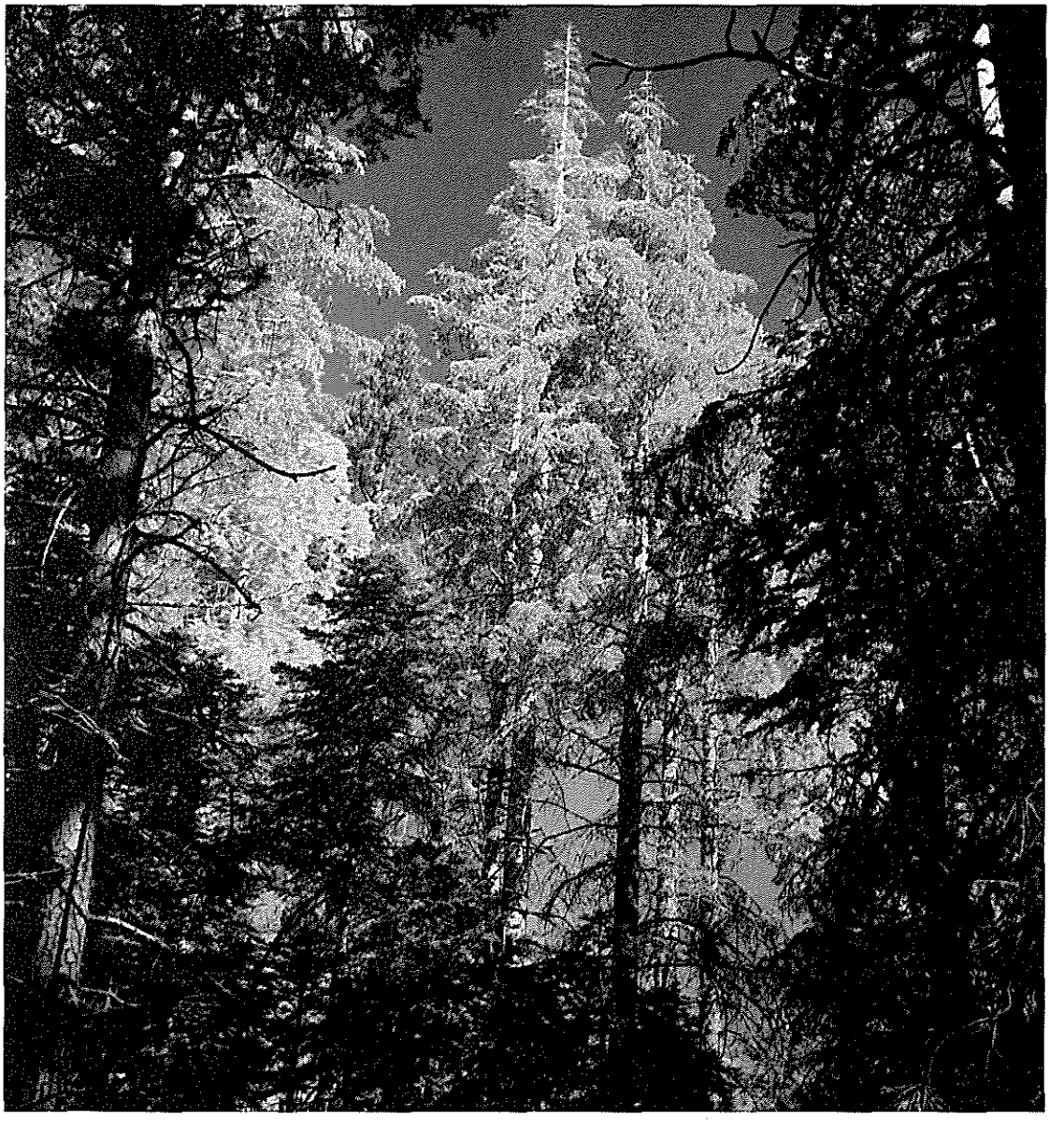

Williams, Carroll B.; Azuma, David L.; Ferrell, George T. 1992. **Incidence and effects of endemic populations of forest pests in young mixed-conifer forests of the Sierra Nevada.** Res. Paper PSW-RP-212. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 8 p.

Approximately 3,200 trees in young mixed-conifer stands were examined for pest activity and human-caused or mechanical injuries, and approximately 25 percent of these trees were randomly selected for stem analyses. The examination of trees felled for stem analyses showed that 409 (47 percent) were free of pests and 466 (53 percent) had one or more pest categories. Incense-cedar contained the fewest number of pests with 133 out of 193 trees (69 percent) free of pests, and 60 trees or 31 percent with one or more pests. White fir and ponderosa pine trees had the highest percentage of pests and mechanical injuries: 64 percent (252 trees out of 395), and 62 percent (93 trees out of 151), respectively. Top injury and disease were the two most frequent pest/damage categories recorded among all tree species. White fir seemed most susceptible to a large number of diseases, particularly wetwood and leafy and dwarf mistletoes. White pine blister rust and cedar rust were the most frequent diseases recorded on sugar pine and incense-cedar, respectively. Most diseases were in the early stages of their infections. Bark beetles were an important pest category for white fir, ponderosa pine, and incense-cedars. Mechanical or human-caused injuries ranged from 6 to 11 percent of the damage records among all mixed-conifer species. Nevertheless, pest damage on most trees was relatively minor throughout the young mixed-conifer stands and seemed to have little effect on height and basal area increment. Tree mortality averaged a little over 3 percent. The data indicate the potential problems for older mixed-conifer stands, and they identify white fir as the tree species particularly susceptible to pests and human-caused damage.

Retrieval Terms: Pest Damage Inventory, mixed-conifers, white fir, ponderosa pine, incense-cedar, sugar pine, Douglas-fir, forest insects, forest pathogens, top injury, mechanical injuries

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Cover—White fir poles killed by *Scolytus ventralis*.

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In Brief . . .

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Forest pest managers need to assess growth losses and tree mortality caused by forest pests under non-outbreak conditions. A Pest Damage Inventory (PDI) system, developed by forest entomologists and pathologists of the Pacific Southwest Region of the USDA Forest Service, was used to code insect pests and disease-causing agents and rate the severity of pest-caused and human-caused injuries to forest trees in young mixed-conifer stands occupying the mid-elevations on the west slope of the Sierra Nevada. Approximately 3,200 mature trees, generally less than 80 years of age, were examined and 877 of these trees were randomly selected for stem analyses. Information on pest and various injuries recorded on the trees after they were felled for stem analyses showed a substantial increase in the number of pests and injuries compared to that recorded on the same trees before felling. Forty-seven percent of the felled trees were free of pests, whereas 53 percent had exhibited one or more pest categories. Obviously, the felled trees allowed a much closer examination of the tree stems which revealed pests and injuries that were either missed on standing trees or could not be seen, e.g., heart rot and wetwood. Since the felled trees provided the most accurate information, the bulk of the data analyses focused on these trees.

White fir and ponderosa pine trees exhibited the highest percentage of pests and mechanical injuries: 64 percent and 62 percent, respectively, of these trees had one or more pests. Field crews recorded a total of 414 instances of pest damage on 252 white fir trees with pests; 120 trees had two pests, 34 trees had three pests, and six trees had four pests. The most frequent damage observed on white fir were top injuries (96 records), wetwood (96 records), and attacks by the fir engraver (*Scolytus ventralis* Le C.) (69 records). The most frequent pest combinations on white fir were fir engraver and wetwood (29 records) and fir engraver and top injuries (16 records).

The examination of 93 ponderosa pines with pests yielded 120 records of pest presence/damage or pest categories. Twenty-three trees had 32 pest categories, and four trees had three pest categories. Top injuries (49 records) was the most frequent damage observed on ponderosa pine followed by some moderate defoliation caused by sawflies (11 records). Bark beetles (9 records), mechanical injuries (8 records), and smog (7 records) also damaged pines. Bark beetles and top injury was the most frequent pest combination with four records.

Incense-cedars contained the fewest number of pests or pest categories, with 69 percent of incense-cedar trees free of pests and 31 percent with one or more pests. A total of 72 pest records were compiled on the 60 incense-cedar trees with pests. Eleven trees had two pest categories and one tree had three pest categories. The most frequent damage was caused by flatheaded borers (18 records), followed by cedar rust (16 records), top injury (eight records), and mechanical injuries (eight records). Forty-five pest records were listed for 27 sugar pine pest-damaged trees. Fourteen trees had two pest categories, and three trees had three pest categories. Top injury (13 records) and blister rust (12 records) were the most frequent damage observed on sugar pines. Twenty pest records were made on 16 Jeffrey pine trees with visible damage. Four trees had two pest categories, and top injury was the most frequent type of damage observed. Twenty-three pest records were catalogued on 18 Douglas-fir trees with visible damage. Four trees had two pest categories, and one tree had three pest categories. An unknown canker, top injury, and mechanical injuries were the most frequent types of damage recorded on Douglas-fir trees.

In general, top injury was the most frequent pest category recorded among all tree species, and was particularly noticeable for ponderosa and Jeffrey pines. Disease was the second most frequent pest category recorded in the study; however, most diseases seemed to be in the early stages of their infection. White fir seemed most susceptible to a large number of diseases, particularly wetwood and leafy and dwarf mistletoes. White pine blister rust and cedar rust were the most frequent diseases recorded on sugar pine and incense-cedar, respectively. However, no bole infections were seen on any of the sugar pines. Insects, primarily bark beetles, was an important pest category for white fir, ponderosa pine, and incense-cedars.

Height increment for the past 20 years was measured on all stem analysis trees and was the dependent variable used to test variability in pest classifications. No significant variations were detected in height growth rates and total height among the various pest classifications. Comparisons of the last 10 years of basal area increment among trees placed in various pest classes indicated no significant variation for Douglas-fir, white fir, sugar pine, and Jeffrey pine. There was significant variation in basal area increment among the pest classes for incense-cedars and ponderosa pines. Nevertheless, pest damage on most trees was minor throughout the study stands, and

we doubt that pest incidence and damage had a real impact on basal area increment. Tree mortality averaged 3.16 percent for young mixed-conifer stands. Bark beetles and root diseases were the pests most frequently associated with the mortality on white fir and ponderosa pine.

The low incidence of tree mortality and the relatively minor effect of endemic pest activities on tree growth recorded in these studies are not surprising given the fact that the studies were limited to young-growth mixed conifer stands whose basal areas were largely composed of trees 80 years old or younger at breast height. The trees were able to repel the bark beetle attacks and many of the important disease pests in these young stands were in the early stages of their infections, and would not be expected to have much current impact on tree health and growth. Nevertheless, the data indicate the potential problems for older mixed-conifer stands. They identify white fir as the tree species particularly susceptible to pest- and human-caused injuries.

Introduction

Outbreaks of forest pests, including bark beetles, defoliating insects, dwarf mistletoes and root diseases, can reduce tree growth and cause widespread tree mortality. However, little is known about the effects of non-outbreak or endemic levels of these pests on trees and forest stands. Forest pest managers have long understood the need for assessing growth losses and mortality caused by forest pests under non-outbreak conditions in forest stands. But they have found the task impossible without: (1) a system of identifying various pests and agents that cause damage to trees and rating the severity of the damage, and (2) knowledge of the growth potential of forest stands on various sites.

Forest entomologists and pathologists of the Pacific Southwest Region of the USDA Forest Service have developed the Pest Damage Inventory (PDI) system to identify, measure, and evaluate pest-caused damage (Byler 1975, 1978). The PDI provides a system of coding insect and disease-causing pests, injuries and abiotic diseases, and guidelines to rate the severity of their damage. A well-trained observer is needed to identify the pests, as well as abiotic diseases and types of injuries, on the basis of various symptoms, some of which are very subtle. The PDI system has been used to measure tree mortality caused by all pests (pest complex) on major tree species, and to determine the incidence of pests and the severity of their damage to tree growth (Byler 1975, 1978).

A 1977 inventory of pest damage on the Barton Flats Compartment on the San Bernardino National Forest provided substantial evidence that pests such as dwarf mistletoes, root diseases, and specific insects have profound long-term effects on tree growth. At 167 study points, the 10-year cubic volume growth for sites that had insect and disease problems (74 sites) was 68 percent of that for sites with no problems (93 sites) (Anon. 1977, Byler 1978). For the individual trees with pests, the growth rate was 56 percent of that for healthy trees. Furthermore, the growth of healthy trees on sites that had pests was only 89 percent of that for healthy trees on non-pest sites, indicating a site difference as well (Anon. 1977).

Studies to develop equations that predict tree growth in mixed-conifer stands in the Sierra Nevada provided an opportunity to assess the chronic or low-level effects of forest pests and pest complexes on tree growth and mortality in the same stands (Dolph and Amidon 1979). These equations describe the relationship of variables which have a significant effect on an individual tree's height and diameter growth (Dolph 1988a, Dolph 1988b).

This paper reports the results of an effort to identify the forest pests endemic to mixed-conifer stands in the Sierra Nevada and to assess their effects on tree growth and mortality.

Methods

Study Area

The study area occupied the mid-elevations on the west slope of the Sierra Nevada, extending approximately 350 miles north to south from 40°00' to 35°25' N. latitude (Dolph and Amidon 1979). Data were collected within the boundaries of six National Forests extending from the northern boundary of the Plumas National Forest southward to the southern boundary of the Sequoia National Forest, and included the Tahoe, Stanislaus, and Sierra National Forests. The elevational limits of the mixed-conifer type vary with changes in latitude and aspect within these National Forests. Most of the type is found between 3000 and 7000 ft (900 and 2130 m) elevation, below the red fir (*Abies magnifica* A. Murr.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) types and above the drier foothill types. It reaches its best development on sites along the west side of the Sierra Nevada with abundant winter precipitation followed by long, warm growing seasons.

The tree species which comprise the mixed-conifer type are California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), incense-cedar (*Libocedrus decurrens* Torr.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*), and sugar pine (*Pinus lambertiana* Dougl.). Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) is an associate at upper elevations and replaces ponderosa pine on serpentine soils. Hardwood associates are California black oak (*Quercus kelloggii* Newb.), Pacific madrone (*Arbutus menziesii* Pursh), tanoak (*Lithocarpus densiflorus* [Hook. and Arn.] Rehd.), and Pacific dogwood (*Cornus nuttallii* Audubon) (Helms 1980). Mixed-conifer stands occur as variable mixtures of species or as small groups of single species.

Plot Selection

Young-growth natural stands which fit the definition of Sierra Nevada Mixed-Conifer Type (Tappeiner 1980) were randomly sampled throughout the western slopes of the Sierra Nevada. Starting with a randomly selected point, plot locations were established using the Pacific Southwest Region's five-plot cluster arrangement (U.S. Dept. of Agriculture, Forest Service 1986). Each sample location consisted of five plots arranged in an L-shape with plot centers 132 feet apart along north and east compass lines. Each plot was evaluated for study suitability by the following criteria:

1. Young-growth—No more than 25 percent of the trees tallied were older than 80 years at breast height.

2. Mixed-conifer type—No more than 20 percent of the trees tallied were conifer species other than those characteristic of the mixed-conifer type. Evidence of white fir regeneration in the stand or surrounding area was required also.

3. Homogeneous site—No more than one distinct soil type, slope percentage, or aspect was present on a 0.2-acre circular plot around the plot center (radius 52.7 ft).

4. Untreated stand—No evidence of silvicultural treatment during the 10 years before measurement. A cluster was retained as a suitable sample point if two or more plots met the above criteria.

Stand and Tree Measurements and Evaluations of Damage

Basal area per acre was determined from each plot center by counting all "in" trees with a wedge prism. The Basal Area Factor (BAF) of prism selection procedure followed that described in the Pacific Southwest Region forest inventory handbook and is based on the number of trees counted with a BAF 20 prism (U.S. Dept. Agriculture, Forest Service 1986). Using the selected prism all tally trees 1.0 inch (2.5 cm) d.b.h. and larger were listed on a tally sheet, and the following characteristics and measurements were recorded for each.

1. Species.
2. Diameter at breast height (d.b.h.) (outside bark) in inches.
3. Position, damage, defect, and tree class.
4. Age at breast height.
5. Total height from base to tip of tree, in feet.
6. Height to base of live crown, in feet.
7. Type and extent of insect and disease symptoms using the California Pest Damage Inventory (PDI) system (Byler 1975, 1978).

One increment core was used to measure radial growth on trees 3.0 to 5.9 inches (7.6 to 15.0 cm) d.b.h. and at least 10 years old at breast height (4.5 ft [1.4 m] above the ground on the uphill side of the tree). Two cores taken at right angles were used to measure radial growth for trees greater than 6 inches (15.2 cm) d.b.h.

An average of two trees per plot, selected at random from the prism tree tally sheet, were felled, and the additional following data were recorded:

1. Total stem length in feet, excluding the current season's growth.
2. Height growth in feet during the last two 10-year growth periods.
3. Bark thicknesses in inches along the stem.
4. Type and extent of insect and disease symptoms using the PDI system. The pest information was recorded separately for the same tree, once before it was felled and again after it was felled.

Analysis of Data

All tree records were collated by species, National Forests, and numbers and identities of pests and other injuries as defined by the PDI system. Additionally, all tree records separated by species were divided into quartiles according to their diameter measurements, resulting in four diameter classes. For example, diameter class 1 for white fir consisted of the quartile of the white fir population with the smallest diameter measurements, and diameter class 4 comprised the quartile with the largest diameters. In a similar manner tree heights and height increment data from the stem analyses records were used to produce four height classes and determine site indices.

General Linear Models of the Statistical Analysis System (SAS) (the SAS Institute Inc., Box 8000, Cary, NC 27511-8000) were used to examine the variability of tree basal area and height increments by pest classification, diameter classes, height classes, and site classes, National Forests, and their various interactions. The natural log of 10-year basal area growth was the dependent variable.

Results and Discussion

Pest Incidence on Standing Trees

Approximately 3,200 plot trees were examined in six National Forests for signs of pest activity and human-caused or mechanical injuries, and rated by the codes of the PDI system. The PDI code, as used in this report, identifies pests as pest categories and frequency of pest occurrence as pest records. A pest category refers to a particular species or species group of insects/diseases, or to an abiotic disease or type of injury. A pest category such as insects will contain a number of recorded instances of an insect's presence or activity (pest records) for a particular tree species. There may be more than one species of insects recorded in the insect pest category.

We use the term "Pest Classes" to refer to the number of pests or pest categories a tree may have. Trees in this study were rarely found to be affected by more than three pest categories, so we established four pest classes which ranged from "0" (free of pests) to "3" (three or more pest categories). Using this nomenclature, the "0" Pest Class is synonymous with "0" Pest Category, whereas Pest Class "3" would contain three or more pest categories. Of the 3,200 plot trees, 1,980 trees (62 percent)were recorded as free of pests and injuries ("0" Pest Category). Trees free of pests grouped by species ranged from 68 and 70 percent for incense-cedar and Douglas-fir, respectively, down to 52 and 53 percent for white fir and sugar pine, respectively *(table 1)*.

Of these plot trees 877 were randomly selected for stem analyses. Pest information was recorded twice for trees selected for stem analyses, once before felling, and again after felling *(table 1)*. In the examination for signs of pest activities and human-caused and mechanical injuries before the trees were felled, 633 (72 percent) were recorded as free of pests and other injuries; 244 (28 percent) were rated as having one or more pests

and injuries *(table 1)*. Trees rated as free of pests and injuries ("0" Pest Category/Class) ranged from 82 percent for standing incense-cedar to 68 percent for white fir. Conversely, the percent of trees with one or more pests ranged from 32 percent for white fir to 18 percent for incense-cedar.

Pest inventory records of the trees selected for stem analyses before they were felled are samples of the records for all plot trees and generally are expected to be representative of the larger data set. Yet, a comparison of two sets of records shows that only the numbers of pest categories for Douglas-fir trees were similar *(table 1)*. There seemed to be differences among the two data sets for other tree species—ponderosa pine, Jeffrey pine, sugar pine, white fir, and incense-cedar. Generally the standing trees selected for stem analysis exhibited much lower incidence of pest and mechanical injuries than did the larger set of standing plot trees. These data suggest either some bias towards pest-free trees or a flawed procedure in the selection of stem analysis trees.

The question of whether trees selected for stem analysis belong to the same population as trees not selected for stem analysis was examined by comparing the latest 10-year basal area increments of trees selected for stem analysis with those of trees not selected for stem analysis. Data describing the average of the latest 10-year basal area increment for all trees, standing plot trees, and felled stem-analysis trees were summarized by plot and cluster. The 95 percent confidence interval for the difference between the means of the logarithm (base 10) of the basal area increment for all species of stem-analysis vs. the standing trees was (-.026, .247). Because this interval contains zero, a difference in the basal area increment is not detectable at the .05 level. A similar comparison was done on each species. White fir was the only species to show a significant difference. The 95 percent confidence interval for the difference between stem-analysis and standing white fir trees was (.06, .34), which indicates that the stem-analysis trees on the average had a larger basal area increment than did the standing trees. There may have been some bias in the sampling procedure on white fir stem-analysis trees. White fir also had the largest sample size between the individual species for the stem-analysis trees. The possibility of a sampling bias on the white fir stem-analysis trees was not incorporated in further analysis.

Pest Incidence on Felled Trees

Information on pest and various injuries recorded on 875 trees[1] after they were felled showed a large increase in the number of pests and injuries compared to those recorded before felling *(table 1)*. The felled trees allowed a much closer examination of the tree stems and showed that many signs of pest activities and various injuries were missed on the standing trees. Some of the differences are due to pests or injuries that cannot be

[1]Two tree records were lost.

Table 1—*Comparisons of trees in pest and no-pest categories among all study trees*

Tree species	Trees with no pests		Trees with pests		Number of pest categories	Number of trees with 1 or more pest categories				Total pests
	no.	*pct*	*no.*	*pct*		1	2	3	4	
Douglas-fir										
Standing[1]	30	71	12	29	8	12	0	0	0	12
Felled[1]	24	57	18	43	9	13	4	1	0	24
All trees[2]	101	70	44	30	—	—	—	—	—	
Ponderosa pine										
Standing	108	72	43	28	12	37	6	0	0	55
Felled	58	38	93	62	24	66	23	4	0	124
All trees	333	58	232	42	—	—	—	—	—	
Jeffrey pine										
Standing	24	77	7	23	6	7	0	0	0	7
Felled	15	48	16	52	9	12	4	0	0	20
All trees	75	55	61	45	—	—	—	—	—	
Sugar pine										
Standing	44	70	19	30	9	18	2	0	0	22
Felled	36	57	27	43	13	10	14	3	0	47
All trees	112	53	100	47	—	—	—	—	—	
White fir										
Standing	270	68	125	32	22	106	18	1	0	164
Felled	143	36	252	64	30	92	120	34	6	458
All trees	907	52	848	48	—	—	—	—	—	
Incense-cedar										
Standing	157	82	35	18	6	34	1	0	0	36
Felled	133	69	60	31	14	48	11	1	0	73
All Trees	452	68	213	32	—	—	—	—	—	

[1]Trees selected for stem analyses.
[2]Analyses of pest categories were not made for all trees since the felled trees provided the most accurate information.

seen on standing trees (e.g., heart rot and wetwood) or are difficult to see on standing trees (e.g., top injuries).

The examination of felled trees showed that 409 (47 percent) were free of pests and 466 (53 percent) had one or more pest categories *(table 1)*. Incense-cedar contained the fewest number of pests or pest categories with 133 out of 193 trees (69 percent) free of pests, and 60 trees (31 percent) with one or more pests. White fir and ponderosa pine trees had the highest percentage of pest and mechanical injuries: 64 percent (252 trees out of 395), and 62 percent (93 trees out of 151), respectively *(table 1)*.

A comparison of the pest data recorded on the trees selected for stem analyses before and after they were felled shows that the number of trees identified as having pests increased substantially after felling, and that the total number of recorded pests doubled *(table 1)*. It was much easier to see and identify pest activities and other injuries, particularly multiple pests and pest associations, after the trees were felled *(table 1)*. Records taken on standing trees revealed few pest-damaged trees with multiple pests, whereas the records for felled trees showed that 61 percent of the pest-injured white fir trees, 63 percent of the sugar pine, and 29 percent of the ponderosa pine had two or more pests/injuries *(table 1)*. Only 20 percent of the pest-damaged incense-cedars had two or more pests/injuries.

The overall incidence of pests by tree species was similar for both sets of records. Before felling, 22 different pest categories were identified on white fir, followed by 12 for ponderosa pine. Jeffrey pine and incense-cedar had the fewest number of pests (6). After the trees were felled, we were able to see and identify 30 kinds of pests on white fir and 24 on ponderosa pine. The number of pest categories recorded on incense-cedar increased from 6 to 14. Douglas-fir and Jeffrey pine had the fewest pest categories (9). This may be due to the smaller number of trees for these species. However, it is clear that the pest inventory records for the felled trees provide the most accurate information on the incidence of pests and various injuries in young forests of mixed conifers.

There is evidence of substantial variability among trees free of pests and those with pests between National Forests. For example, the percent of white fir in the "0" Pest Category averages 26 percent of all pest categories over the six National Forests. But white firs in the "0" Pest Category averaged only 16 and 18 percent of all pest categories in the Plumas and Stanislaus National Forests, respectively, and 46 percent of all pest categories on the Sequoia National Forest *(table 2)*. In contrast, incense-cedar in the "0" Pest Category averaged 65 percent of all pest categories for the six National Forests. Trees in this category ranged from 65 to 79 percent of all classifications of the Eldorado, Sequoia, and Sierra National Forests, and was 44 percent on the Plumas National Forest. The four tree records for the Tahoe National Forest were too few to merit consideration *(table 2)*.

Of all the tree species, white fir appeared most susceptible to damage from insect and disease pests and human-caused and mechanical injuries. Field crews recorded 30 pest categories with a total of 414 instances of pest damage on 252 white fir trees; 120 trees had two pests, 34 trees had three pests, and six

Table 2—*Pest summary by tree species and forest*

Pest category	Forest code[1]							
	3	11	12	15	16	17	Sum	Pct
	Number							
Douglas-fir								
No pests	11	7	0	0	0	6	24	51
Top injury	0	4	0	0	0	1	5	11
Other injuries[2]	3	1	0	0	0	1	5	11
Insects	0	0	0	0	0	1	1	2
Diseases[3]	2	9	0	0	0	1	12	26
Unknown damage	0	0	0	0	0	0	0	
Total							47	
Ponderosa pine								
No pests	16	10	2	5	11	4	58	33
Top injury	10	7	7	18	7	0	49	28
Other injuries	6	2	0	1	1	0	10	6
Insects	8	1	2	2	12	0	25	14
Diseases	11	4	0	5	4	1	25	14
Unknown damage	4	7	0	0	0	0	11	6
Total							178	
Jeffrey pine								
No pests	2	0	13	0	0	0	15	43
Top injury	2	0	9	0	0	0	11	31
Other injuries	0	0	2	0	0	0	2	6
Insects	1	0	0	1	2	0	4	11
Diseases	1	0	1	0	1	0	3	9
Unknown damage	0	0	0	0	0	0	0	
Total							35	
Sugar pine								
No pests	10	5	2	12	4	3	36	44
Top injury	2	2	1	5	3	0	13	16
Other injuries	4	0	1	2	1	0	8	10
Insects	0	0	0	2	1	0	3	4
Diseases[4]	4	11	0	1	1	3	20	24
Unknown damage	1	0	0	0	1	0	2	2
Total							82	
White fir								
No pests	59	15	25	16	11	17	143	26
Top injury	39	11	7	19	14	11	101	18
Other injuries[5]	20	2	5	2	3	0	32	6
Insects[6]	36	13	5	9	4	29	96	17
Diseases	33	11	7	17	12	2	82	15
Wetwood	12	40	5	0	0	37	96	17
Unknown damage	2	0	0	0	0	0	0	
Total							553	
Incense-cedar								
No pests	67	8	13	27	15	3	133	65
Top injury	3	1	1	1	2	0	8	4
Other injuries	5	2	0	0	1	0	8	4
Insects[7]	15	0	0	0	3	0	18	9
Diseases[8]	13	7	4	6	7	1	38	19
Unknown damage	0	0	0	0	0	0	0	0
Total							205	

[1]Forests: 3 = Eldorado, 11 = Plumas, 12 = Sequoia, 15 = Sierra, 16 = Stanislaus, 17 = Tahoe.

[2]Mechanical and human-caused injuries (4 of 5).

[3]Unknown canker comprised 9 of the 12 disease pests.

[4]Blister rust comprised 12 of 20 records of diseases.

[5]Largely human-caused injuries and frost cracks.

[6]Largely fir engraver.

[7]Flatheaded borers.

[8]Cedar rust comprised 16 of the 38 records of diseases.

trees had four pests. Those pest categories or pests with five or more records of the pest's presence/damage were top injury, 96 records; wetwood, 96 records; fir engraver (*Scolytus ventralis* Le C.), 69 records; leafy mistletoe (*Phoradendron bolleanum*), 20 records; frost cracks, 17 records; human-caused and mechanical injuries, 12 records; root disease (*Heterobasidion annosum*), 11 records; dwarf mistletoe (*Arceuthobium abietinum*), 11 records; bole canker, seven records; needle miners, seven records; unknown defoliator, seven records; branch flagging, six records; *Cytospora abietis*, six records; Douglas-fir tussock moth (*Orgyia pseudotsugata*), five records; unknown canker, five records. The most frequent pest combinations observed on white fir were fir engraver and wetwood, 29 records; fir engraver and top injury, 16 records; and top injury and wetwood, 15 records.

A large number of pest categories and injuries were also recorded on ponderosa pine: 24 pest categories and 120 records of pest presence/damage on 93 trees. Twenty-three trees had two pest categories, and four trees had three pest categories. Pest categories or pests with five or more records were top injury, 49 records; sawflies, 11 records (all on the Stanislaus National Forest); human-caused and mechanical injuries, eight records; smog damage, seven records (all on the Plumas National Forest); white scale, five records. Bark beetles (*Dendroctonus brevicomis, D. ponderosae* and *D. valens*) were on nine records. *D. brevicomis* and top injury were the most frequent pest combination (four records).

Field crews compiled 14 pest categories and 72 pest records on 60 incense-cedar trees. Two pest categories were found on 11 trees, and one tree had three pest categories. Pest categories with five or more records were: insects (flatheaded borers), 18 records; cedar rust (*Gymnosporangium libocedrus*), 16 records; top injury, eight records; human-caused and mechanical injuries, eight records; and heart rot, five records.

Thirteen pest categories with 45 pest presence/damage records were listed for 27 sugar pine trees. Fourteen trees had two pest categories, and three trees had three pest categories. Pest categories with five or more records were top injury, 13 records; blister rust (*Cronartium ribicola*), 12 records; human-caused and mechanical injuries, seven records. The most frequent pest combinations were: top injury and mechanical injury, three records; *D. ponderosae* and top injury, three records; and top injury and blister rust, with two records.

Nine pest categories with 20 instances of pest presence/damage were recorded on 16 Jeffrey pine trees. Four trees had two pest categories. Top injury contained 11 pest records and was the only pest category with more than two records. Nine pest categories with 23 pest records were also cataloged on 18 Douglas-fir trees. Four trees had two pest categories and one tree had three pest categories. Pest categories with five or more records were: unknown canker, nine records; top injury, five records; human-caused and mechanical injuries, five records. The most frequent pest combination was the unknown canker and top injury on two of the records.

In general, top injury was the most frequent pest category recorded among all tree species, and was particularly noticeable for ponderosa and Jeffrey pine (*table 2*). A top-injury rating included any form of top injury that occurred at any time of the tree's development, and includes spike tops, broken tops, multiple tops, and regrown tops. However, for stem-analysis trees, this category was restricted mainly to regrown tops, because trees with multiple, spike, or broken tops were dismissed as being unsuitable for stem analysis. It is practically impossible to determine the cause of an old top injury, but possible causes are damage by wind, snow, and from falling trees, or branches of other trees. Western spruce budworm and Douglas-fir tussock moth can cause substantial top injury, including stem dieback, to white fir and Douglas-fir trees that is usually clearly seen. In contrast, the western pine shoot borer (*Eucosma sonomana*) injures the terminals of ponderosa and Jeffrey pines, substantially reducing height growth, but the top injury is more subtle and not seen as clearly as that caused by other insects. Imperfections in the PDI rating system may not allow for the impact of top injury on growth to be determined. Nevertheless, there should be an effect on height growth of the tree.

Disease was the second most frequent pest category recorded on mixed-conifer tree species (*table 2*). Of all the tree species, white fir seemed most susceptible to a large number of diseases, including wetwood and leafy and dwarf mistletoes. Wetwood was so extensive among the trees that some field crews stopped recording it, so the incidence of wetwood was much greater than the 96 records suggest. The mistletoe infections were generally light, and occurred mostly in the upper crown at the base of branches next to the bole. Because of their locations in the inner parts of the crown, these infections were difficult to spot from the ground. Douglas-fir was particularly susceptible to cankers. The most common were small limb cankers and were classified as unknown. These were usually very old, and the causes were not determined. White pine blister rust and cedar rust were the most frequent diseases recorded on sugar pine and incense-cedar, respectively (*table 2*). These infections were considered minor. Most of the sugar pines infected with blister rust had spindle-shaped limb cankers some distance from the bole. On some trees, infections between 4 and 24 inches from the bole were observed. No bole infections were seen on any of the trees.

Insects, primarily bark beetles, were an important pest category of white fir, ponderosa pine, and incense-cedars. Attacks by fir engravers, top injuries, and diseases were the most frequent pest categories for white fir. Sixty-nine of the 96 insect records were unsuccessful attacks by fir engravers, usually in the form of strip kills. Attacks by fir engravers were frequently associated with wetwood (29 records) and top injury (16 records) in white firs. All the insect records on incense-cedar were for flatheaded borers (*Buprestidae*). These were on trees growing very slowly in stagnated groups. Unsuccessful attacks by the western pine beetle (*Dendroctonus brevicomis*), mountain pine beetle (*D. ponderosae*), and red turpentine beetle (*D. valens*) comprised nine of the 25 insect records for ponderosa pine. Sawflies (*Neodiprion* sp.) and white scale comprised 11 and five of the remaining insect records, respectively, on ponderosa pine. Logging and mechanical injuries ranged from six to 11 percent of the damage records among mixed-conifer species.

Height Growth and Site Index Values

Stem analyses of felled trees allowed the calculation of site index values for each tree species (Dolph 1988a) and comparisons of height growth rates and total heights among trees with various pest classifications (Dolph 1988b). Descriptive statistics for the site index values show that ponderosa pine, white fir, Douglas-fir, and sugar pine trees comprised the dominant forest canopies across all site classes of mixed-conifer forests *(table 3)* (Dolph 1988a, 1988b). Douglas-fir exhibited the best height growth rates on the poorest sites (site class 4) with a range of height of 39 to 65 feet at age 50 years. White firs exhibited a range of heights of 28 to 59 feet and ponderosa pine a range in heights of 22 to 59 feet at age 50 on these sites *(table 3)*. Incense-cedars showed the poorest growth on site class 4, with a range of heights of 12 to 38 at age 50 years. Ponderosa pine and white fir trees showed the highest height growth rates on the best sites (site class 1) with ranges in heights of 97.5 to 127 feet and 90 to 134 feet, respectively, at age 50 years. Douglas-fir and sugar pine trees ranged in heights from 90 to 111 feet and 88 to 109 feet, respectively, at age 50 on these sites. Incense-cedars and Jeffrey pines showed the poorest relative growth on these sites and ranged in heights from 63 to 94 feet and 58.7 to 95 feet, respectively, at age 50 on site class 1 *(table 3)*.

The felled trees of each National Forest were divided according to height and placed into quartiles (four height classes). Height increment for the past 20 years was measured on all stem-analysis trees and was the dependent variable used to test variability in pest classifications among the height classes for the various tree species and National Forests. We did not detect any significant variation in height growth rates and total height among the various pest classifications. Trees with two or more pests tended to be the larger trees; most likely they were also the older trees.

Basal Area Increment

We calculated the natural log of the last 10 years of basal area increment for all the study trees, and using the Bonferroni "T" tests we compared this 10-year basal area increment for each tree species by diameter, site class and pest classes. As has already been reported, basal area increment differed significantly at the 0.05 percent level among diameters and site classes for all tree species (Dolph 1988a). However, there was no significant variation in basal area increment among trees placed in the various pest classes for Douglas-fir, white fir, sugar pine and Jeffrey pine *(table 4)*. For some reason incense-cedars placed in Pest Classes "1" and "3" grew significantly faster than those in Pest Classes "0" and "2" *(table 4)*. Ponderosa pines placed in Pest Classes "0" and "1" grew significantly faster than those in Pest Class "2" *(table 4)*. Nevertheless, pest damage on all tree species was minor throughout the study stands, and we doubt that pest incidence and damage had a real impact on basal area increment.

Tree Mortality

Out of 3,255 tree records examined among the six National Forests, 103 were dead, resulting in a mortality average of 3.16 percent for young mixed-conifer stands *(table 5)*. According to these tree records, tree mortality ranged from 0.49 percent for the Plumas National Forest to 6.89 percent for the Stanislaus National Forest *(table 5)*. The percent of tree mortality by species also varied greatly among the National Forests *(table 6)*. However, the major species which comprise the mixed-conifer type—white fir, ponderosa pine, and incense-cedar—had 35, 26, and 21 percent, respectively, of the total mortality for the six National Forests *(table 6)*. The largest number of dead trees in the study plots was encountered on the Plumas National Forest; about half were white fir. Bark beetles and root diseases, primarily *Heterobasidion annosum*, were the pests most frequently associated with the mortality on white fir and ponderosa pine.

Table 3—*Descriptive statistics for site index values*[1]

Species	No. of plots	Mean height	SE mean[2]	Min. height[3]	Q_1	Q_2[4]	Q_3	Max. height[3]
		feet		*feet*	*feet*	*feet*	*feet*	*feet*
White fir	316	75.84	1.23	28.00	59.25	74.00	90.00	134.00
Incense-cedar	225	50.96	1.12	12.00	38.00	51.00	63.00	94.00
Ponderosa pine	149	79.38	1.88	22.00	59.00	81.00	97.50	127.00
Sugar pine	94	72.38	2.07	19.00	55.00	71.00	88.25	109.00
Jeffrey pine	36	53.94	2.22	23.00	46.25	52.50	58.75	95.00
Douglas-fir	58	75.60	2.32	39.00	65.00	76.00	90.00	111.00

[1]Height at age 50 years.
[2]Mean Standard Error
[3]Site index values are divided into four classes from MIN to MAX.
i.e.: Site Class 4 = (MIN, Q_1)
Site Class 3 = (Q_1, Q_2)
Site Class 2 = (Q_2, Q_3)
Site Class 1 = (Q_3, MAX)
[4]Median Height

Table 4—*Comparison of log 10-year basal area increments of study trees by species and pest classes*

Tree species	Pest classes	Lower confidence limit	Difference between means	Upper confidence limit	Signif-icance at 0.05 limit
Douglas-fir[1]	1-0[2]	-0.12195	0.17569	0.47333	NS
	1-2	-0.57121	0.46670	1.50461	NS
	1-3	1.28209	2.72680	4.17151	*
	0-2	-0.72446	0.29101	1.30649	NS
	0-3	1.12244	2.55111	3.97979	*
	2-3	0.51947	2.26010	4.00073	*
Ponderosa pine[3]	0-1[4]	-0.10964	0.06944	0.24852	NS
	0-3	-0.36012	0.44140	1.24292	NS
	0-2	0.12625	0.51008	0.89391	*
	1-3	-0.43732	0.37196	1.18123	NS
	1-2	0.04088	0.44064	0.84040	*
	3-2	-0.80892	0.06868	0.94628	NS
Jeffrey pine[5]	3-2[6]	-1.1314	0.1975	1.5265	NS
	3-0	-0.7476	0.3549	1.4573	NS
	3-1	-0.4532	0.6616	1.7765	NS
	2-0	-0.6343	0.1573	0.9490	NS
	2-1	-0.3447	0.4641	1.2729	NS
	0-1	-0.0148	0.3068	0.6283	NS
Sugar pine[7]	2-0[8]	-0.21246	0.35749	0.92743	NS
	2-1	-0.20123	0.38073	0.96269	NS
	2-3	1.86275	3.33082	4.79888	*
	0-1	-0.19524	0.02324	0.24173	NS
	0-3	1.60795	2.97333	4.33872	*
	1-3	1.57964	2.95009	4.32053	*
White fir[9]	3-0[10]	-0.07435	0.21735	0.50906	NS
	3-2	-0.09571	0.22628	0.54826	NS
	3-1	-0.04593	0.25075	0.54742	NS
	0-2	-0.14686	0.00892	0.16471	NS
	0-1	-0.05941	0.03339	0.12619	NS
	2-1	-0.14044	0.02447	0.18938	NS
Incense-cedar[11]	3-1[12]	-0.20223	0.66484	1.53190	NS
	3-0	0.10195	0.95867	1.81540	*
	3-2	0.15060	1.08522	2.01985	*
	1-0	0.12090	0.29384	0.46678	*
	1-2	0.00874	0.42039	0.83204	*
	0-2	-0.26285	0.12655	0.51594	NS

[1]Alpha = 0.05, Confidence = 0.95, DF = 107, MSE = 0.279511; Critical Value of T = 2.68819.

[2]Number of Douglas-fir trees in Pest Classes 0, 1, 2, and 3 are 95, 30, 2, and 1, respectively.

[3]Alpha = 0.05, Confidence = 0.95, DF = 449, MSE = 0.450443; Critical Value of T = 2.65000.

[4]Number of Ponderosa pine trees in Pest Classes 0, 1, 2, and 3 are 323, 142, 23, and 5, respectively.

[5]Alpha = 0.05, Confidence = 0.95.

[6]Number of Jeffrey pine trees in Pest Classes 0, 1, 2, and 3 are 62, 36, 4, and 2, respectively.

[7]Alpha = 0.05, Confidence = 0.95, DF = 138, MSE = 0.257813; Critical Value of T = 2.67682.

[8]Number of sugar pine trees in Pest Classes 0, 1, 2, and 3 are 109, 60, 6, and 1, respectively.

[9]Alpha = 0.05, Confidence = 0.95, DF = 1438, MSE = 0.365309; Critical Value of T = 2.64191.

[10]Number of white fir trees in Pest Classes 0, 1, 2, and 3 are 897, 442, 119, and 31, respectively.

[11]Alpha = 0.05, Confidence = 0.95, DF = 584, MSE = 0.415485; Critical Value of T = 2.64728.

[12]Number of incense-cedar trees in Pest Classes 0, 1, 2, and 3 are 482, 122, 20, and 4, respectively.

Table 5—*Incidence of mortality in young-mature trees in the mixed-conifer stands of six National Forests*[1]

Item	Forest code[2]						
	3	11	12	15	16	17	Total
Total trees	1346	481	402	509	430	358	3526
Missing trees	80	71	27	39	9	45	271
Total dead	45	2	7	14	29	6	103
Percent dead	3.55	.49	1.87	2.98	6.89	1.92	3.16

[1]Determined by subtracting the number of missing trees from the number of total trees and using the result as the divisor of total dead.

[2]Forests: 3 = Eldorado, 11 = Plumas, 12 = Sequoia, 15 = Sierra, 16 = Stanislaus, 17 = Tahoe.

Table 6—*Incidence of mortality in young-mature mixed-conifer stands by tree species and National Forest*

Tree species	Forest code[1]						
	3	11	12	15	16	17	Total
Douglas-fir							
Number dead	1	0	0	0	1	0	2
Percent of total	2.22				16.67		2
Ponderosa pine							
Number dead	12	1	2	5	7	0	27
Percent of total	16.67	50	28.57	35.71	24.14		26
Jeffrey pine							
Number dead	5	0	2	0	0	0	7
Percent of total	11.11		28.57		7		
Sugar pine							
Number dead	1	0	0	4	5	0	10
Percent of total	2.22			28.57	17.24		10
White fir							
Number dead	22	0	2	1	5	6	36
Percent of total	48.89		28.57	7.14	17.24	100	35
Incense-cedar							
Number dead	4	1	1	4	12	0	22
Percent of total	8.89	50	14.29	28.57	41.38		21
Total dead	45	2	7	14	30	6	104

[1]Forests: 3 = Eldorado, 11 = Plumas, 12 = Sequoia, 15 = Sierra, 16 = Stanislaus, 17 = Tahoe.

Discussion

Pest/Damage inventory records taken on standing trees provide a good approximation of the incidence of pest activities and other injuries in young mixed-conifer forests. However, those records taken from felled trees provide the most accurate information. White fir was the tree species most susceptible to insect, disease and human-caused injuries. Only 26 percent of the white firs on the study plots were free of pests and injuries. The most frequent records were for top injuries, wetwood, and the fir engraver. Approximately 33 percent of the ponderosa pines were free of pests and injuries, and top injury was the most frequent injury recorded. Incense-cedar was the tree species that exhibited the least number of pests and injuries; approximately 65 percent of the trees were free of pests and injuries. Flatheaded borers and cedar rusts were the pests most frequently encountered on incense-cedar in the study plots.

The pests and human-caused injuries seemed to have very little effect on tree growth and mortality in the study stands. The low incidence of tree mortality and the relatively minor effect of endemic pest activities on tree growth recorded in these studies are not surprising given the fact that the studies were limited to young-growth mixed-conifer stands whose basal area is largely composed of trees less than or equal to 80 years old at breast height. The exclusion of older stands resulted in many five-point clusters in the study stands having fewer than five plots, as well as relatively low incidence of pests and tree mortality. However, there were a number of trees much older than 80 years at breast height. Much of the variability in basal area increment among pest classes is largely due to these trees.

Our observations of many of the important disease pests in the study stands showed that they were in the early stages of their infections, and would not be expected to have much current impact on tree health and growth. For example, white pine blister rust infections were located on the branches of sugar pines and had not progressed to the boles where they would have had greater impact on tree growth and mortality. Symptoms of root and stem diseases were not as readily seen in the study stands as they are in much older stands. Root and especially stem diseases are major pests in mature and old-growth stands of coniferous forests, and the cumulative effects of the spread and development of their infections predispose infected trees to attack by bark beetles. There were frequent associations between fir engraver and wetwood and top injury for white fir, western pine beetle and top injury for ponderosa pine, and flatheaded borers and cedar rust for incense-cedars.

Endemic levels of pests require a substantial amount of time for their cumulative effects to have any significant impact on forest trees and stands, and the studies reported here indicate that mixed-conifer stands 80 years of age and younger are too young to show these effects. Nevertheless, the data indicate the potential problems for mature and older mixed-conifer stands. They identify white fir as the tree species particularly susceptible to pests and human-caused injury. Under uneven-aged forest management with frequent stand entries white fir would become the predominant tree species in mixed-conifer forests. The results of this study suggest that a forest in which white fir is the dominant forest tree would be severely affected by pests and mechanical injury and would most likely produce low yields.

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