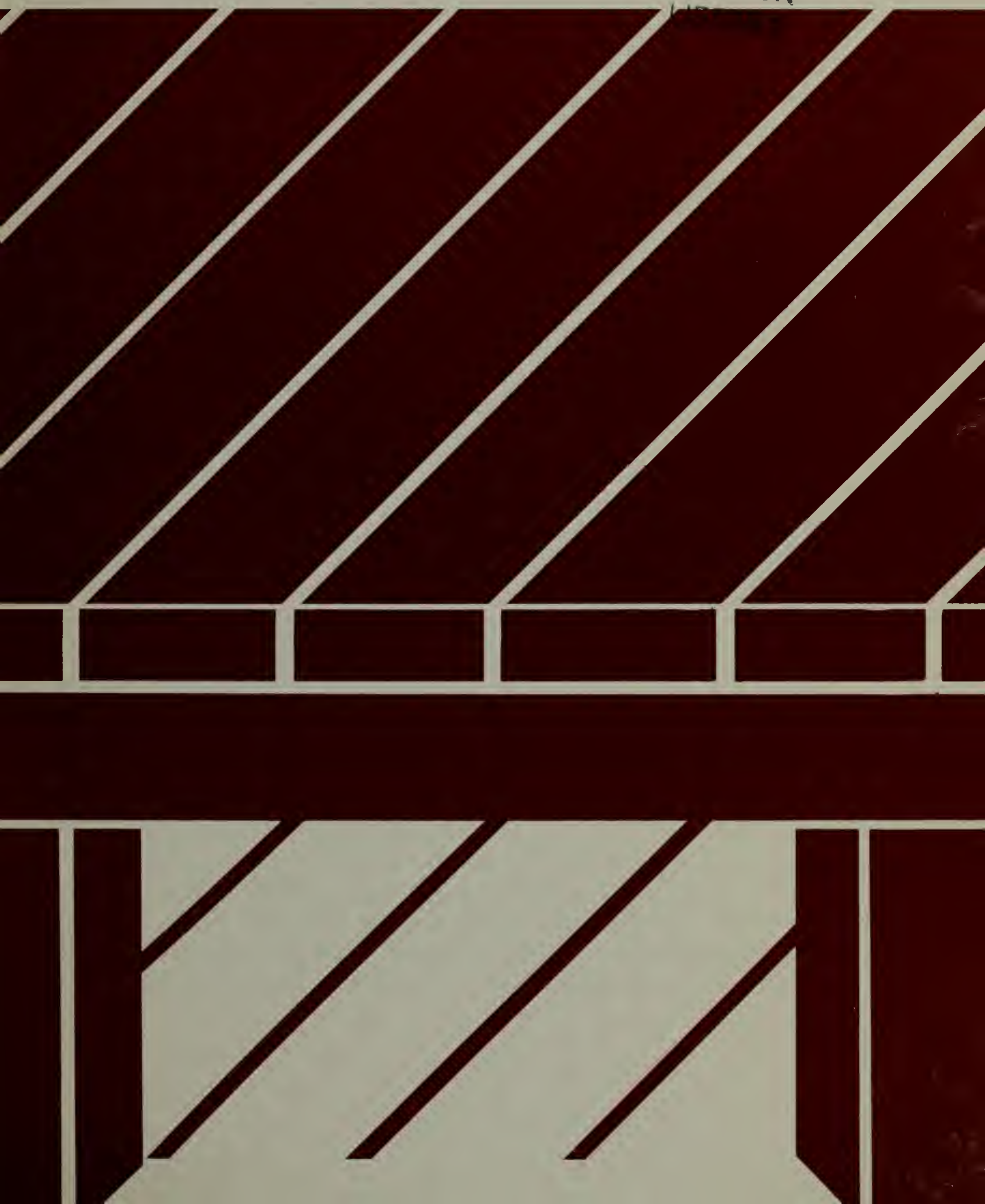
Wooden Walkway Study

Effects of Pentachlorophenol on Alpine Fir



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R. GARY BEAVER
Eastern Montana College
Billings, Montana

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Introduction

In the spring of 1972 needles of sub-alpine fir (*Abies lasiocarpa*) were observed to be brown and necrotic on trees adjacent to the newly established wooden walkway located on the Hidden Lake Trail at Logan Pass, Glacier National Park (Figs. 1B, 2A, 3). Preliminary investigation suggested that a volatile material emitted from the wooden walkway was the cause. All the lumber used in construction of the walkway had been treated with pentachlorophenol (PCP) as a preservative. A heavy petroleum solvent, Certrex 50-C, was used as a carrier for PCP. The lumber was pressure treated by the empty cell process in accordance with the American Wood Preservers Association's Standard C-1 and C-2 to a net retention of 0.05 pounds PCP (5% solution by weight).

Pentachlorophenol has been commonly used as a wood preservative since 1948 to protect against wood rotting fungi and boring insects. Lumber treated with PCP has generally been used in situations where soil contact or burial occurs, primarily in association with industrial and agricultural construction.

Literature describing the environmental impact of PCP is limited and has caused little concern primarily because of the nature of its use. Treated material buried in the soil seldom displays any visible effect on adjacent vegetation. Common usage and its ease of application make PCP a "standard" wood treatment.

FIGURE 1. (A) Normal healthy spring growth on *Abies lasiocarpa*, Logan Pass. (B) Severely affected *A. lasiocarpa* near wooden walkway showing defoliation and chlorosis of new spring growth. (C) Normal spring growth and necrotic previous seasons growth on *A. lasiocarpa* near wooden walkway in area where treated lumber had been replaced with non-treated lumber.

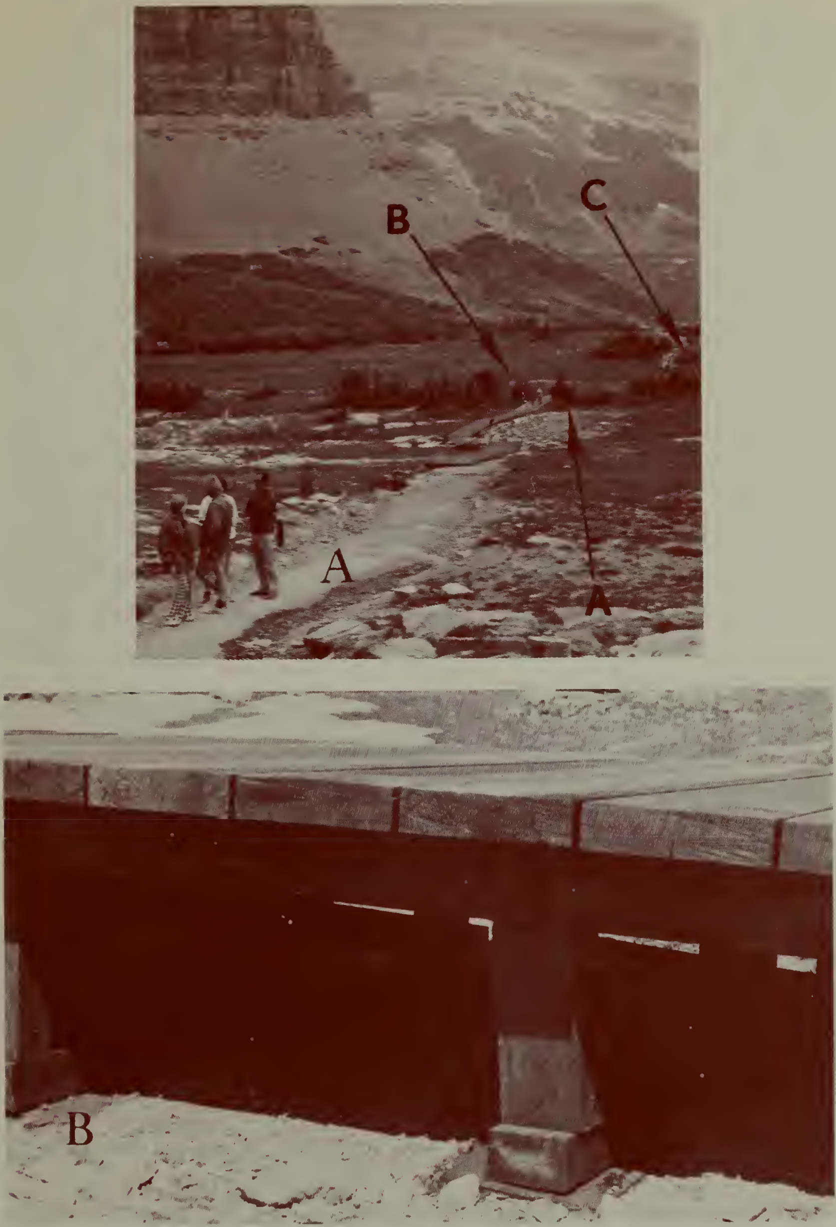

FIGURE 2. (A) Study area along wooden walkway, Logan Pass, Glacier National Park, showing: a. affected area south of walkway, b. affected area north of walkway, c. unaffected control area. (B) Construction details of wooden walkway showing dark colored, heavily treated lumber.

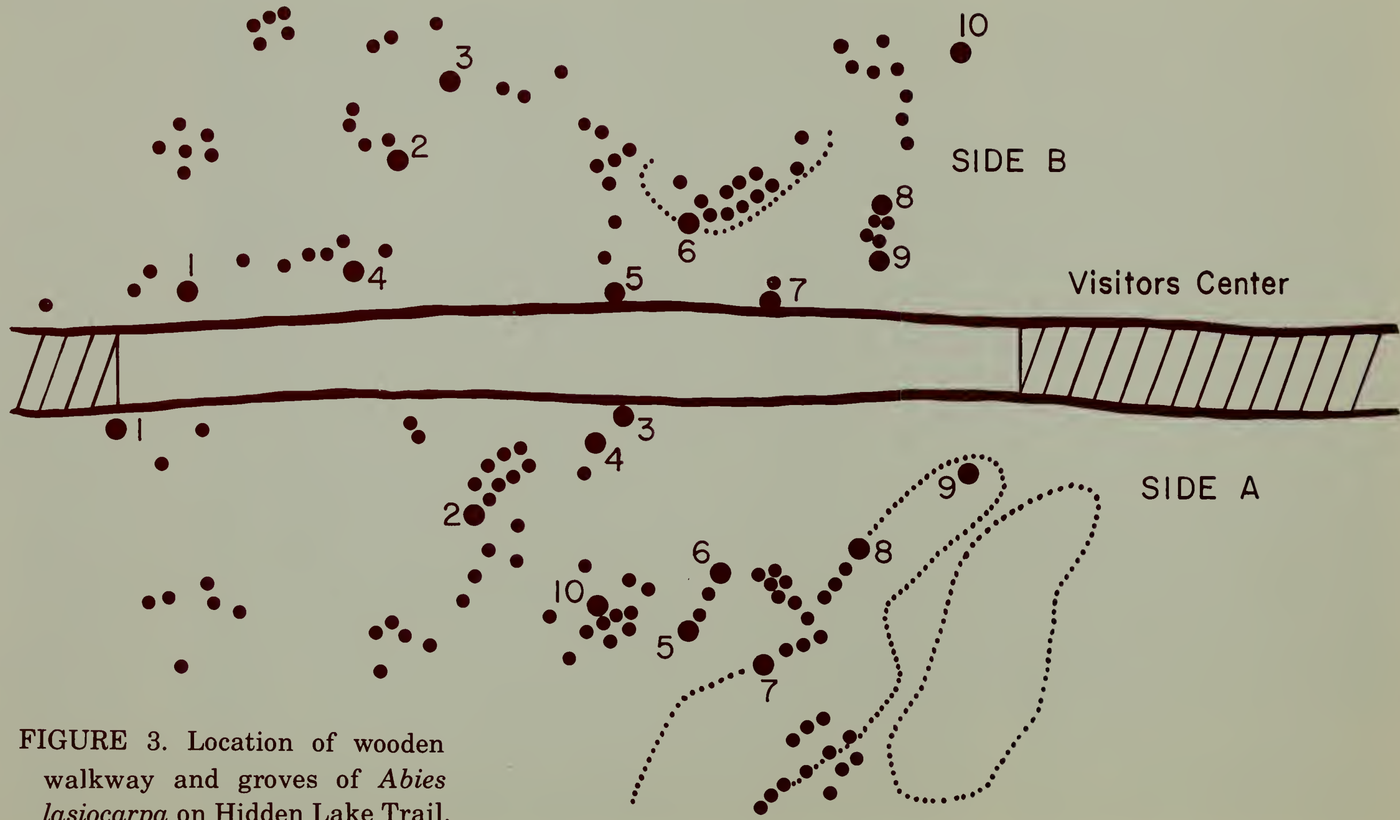

FIGURE 3. Location of wooden walkway and groves of *Abies lasiocarpa* on Hidden Lake Trail,

Because it is considerably toxic for lower organisms, such as bacteria and fungi, as well as for certain plants and insects, PCP has found ever increasing application as a versatile pesticide. In addition to being a wood treatment, PCP is used as a soil disinfectant, a general herbicide, an algicide in heat transfer systems, and a fungicide for preserving many compounds and materials. It is used either free or as a salt of a metal or an amine. A survey of its properties and applications is given by Carswell and Nason (1938).

As might be expected, PCP exerts a toxic effect on mammals, as well as on lower organisms (Table 1). When absorbed in sufficient quantity into the tissues of dogs, rabbits, rats, and guinea pigs, PCP produces an acute toxic state which ultimately results in death (Patly 1962). The LD_{50} for rats was 27 mg/kg 0.5% PCP in fuel oil given orally (Deichmann et al. 1942). Human death has been recorded on several occasions either during manufacture or application. Concentrations as high as 150 ppm were found in the urine of humans in lethal cases. In several instances, individuals who had treated

TABLE 1. Acute toxicity of pentachlorophenol and its sodium salt in experimental animals[271-273] (From Patly 1962).

Species	Route	Solvent	Dose killing approx. 50% of animals, mg/kg	Ref.
Rabbit	Cut.	11% in olive oil	(450 was not fatal)	271
		5% in Stanolex fuel oil	60	272
		5% in Shell fuel oil	130	272
		1.8% in pine oil	40	272
	Subcut.	5% in olive oil	70	271
	Oral	5% in Stanolex fuel oil	70	271
		11% in olive oil	100	271
Rat	Oral	0.5% in Stanolex fuel oil	27	271
		1% in olive oil	78	271
		Sodium pentachlorophenate (in terms of pentachlorophenol)		
Rabbit	Cut.	10% aqueous	250	271
	Subcut.	10% aqueous	100	271
	Oral	2% aqueous	275	273
	Intraven.	1% aqueous	22	271
Rat	Subcut.	2% aqueous	66	271
	Oral	2% aqueous	210	271
		2, 25% aqueous	125-200	
		Copper pentachlorophenate		
Rat	Oral	2 to 20% suspension in Tween 20	600	

[271] W. B. Deichmann, W. Machle, K. V. Kitzmiller, and G. Thomas, *J. Pharmacol, Exptl. Therap.*, 76, 104 (1942).
[272] R. A. Kehoe, W. B. Deichmann, and K. V. Kitzmiller, *J. Ind. Hyg. Toxicol.*, 21, 160 (1939).
[273] W. Machle, W. B. Deichmann, and G. Thomas, *J. Ind. Hyg. Toxicol.*, 25,192 (1943).

lumber with only rubber gloves became ill and died after as little as 3 days on the job (Menon 1958).

The physical properties of PCP in regard to solubility are of particular interest since this compound is generally applied in solution (Table 2). Water solubility presents a special problem where there is any contamination by surface or subsurface runoff. Goodnight (1942) reports that the substance is accumulated by fish and that survival times are about 1 hour at 1 ppm, depending on species, pH, and water temperature. Less well known is the effect of PCP at a level sublethal for fish but lethal for lower members of the food chain. The vapor pressure of PCP is 0.00019 mm Hg at 25°C and 0.019 mm Hg at 75°C. Atmospheric concentrations as high as 2.4 mg/m^3 have been reported (Am. Ind. Hyg. Assoc. 1970).

This study was therefore undertaken to locate and identify the cause of damage to the subalpine fir and to determine to what extent the subalpine environment has been affected. Possible future problems were evaluated.

TABLE 2. Solubility of pentachlorophenol and its sodium salt

Solvent	Solubility at 20°C., % (w/v)
Pentachlorophenol	
Organic solvents	
Methanol	57.0
Ethanol	53.0
Ethanol (95%)	47.5
Diethylene glycol	27.5
Acetone	21.5
Xylene	14.0
Benzene	11.0
Ethylene glycol	6.0
Carbon tetrachloride	2.0
Oils of vegetable origin	
Pine oil	32.0
Corn oil	14.8
Linseed oil (raw)	13.9
Tung oil	11.2
Turpentine	3.0
Water	14[a]
Sodium pentachlorophenate	
Water[b]	15.0 at 4°C. 20.0 at 9.5°C.

[a]Parts per million.
[b]Higher concentrations tend to cause formation of hydrates having lower solubility.

Materials and Methods

Greenhouse Bioassay

Eight- to 14-inch potted seedlings of alpine fir (*Abies lasiocarpa*) and grand fir (*A. grandis*) were grown under greenhouse conditions. Four sets of eight dormant seedlings each (four *A. lasiocarpa* and four *A. grandis*) were forced and exposed to samples of PCP-treated lumber, Mobil oil carrier, commercial PCP, and purified PCP. In addition to the fir seedlings, tomato, sunflower, various other broadleaf weed species, wheat, and Bromus grass seedlings were tested.

All plants were isolated under 18 × 18 × 24-inch polyethylene hoods during testing. Greenhouse temperatures did not exceed 25°C, and the soil was kept moist at all times. All treatments were exposed for 1 month, then examined for the development of symptoms. Other individual trees were exposed for varying periods of time and then removed from the influence of the treatments.

In addition to the bioassay, dormant shoots of 25 exposed and 25 nonexposed subalpine fir from Glacier Park were rooted in a rooting bench under a mist spray. The young developing foliage was examined after the needles were fully expanded from the bud.

Gas Chromatograph and UV Spectroscopy

Samples of five 1-mg commercial and five reagent grade PCP were dissolved in 100 ml toluene. A 30 μl sample was injected into a Varian 920 gas chromatograph, using a 5 ft, 0.25 inch stainless steel column containing 10% UV-1 on a chromosorb W, 60/80 mesh. The gas flow was set at 20 ml per minute with the injection block temperature set at 360°C and oven at 310. The detector was set at 360°C.

The same 10 ppm toluene solution of PCP was used in the UV spectrophotometer and was scanned over a spectrum of 240-360 nm.

Extraction of Samples

Two 1-cm^3 samples of material used in construction of the wooden walkway were shredded and prepared for extraction by the method of Stark (1969). These samples were then analyzed with the aid of the gas chromatograph, as described above.

Environmental Impact

Field studies were conducted by visual means to determine what effect exposure to PCP had on the subalpine vegetation adjacent to the wooden walkway. Growth increment for the past 2 years was measured on subalpine fir adjacent to the wooden walkway and at locations further away from direct PCP exposure. In addition, notes were made on types and numbers of other plants adjacent to the walkway which were affected.

Samples of runoff water were taken for lab analysis for the presence of PCP.

Results

The data from replicated bioassay tests of PCP and the oil carrier on subalpine fir, grand fir, broadleaf seedlings, and grasses carried out in the greenhouse are given in Table 3.

Conifers

In every test where PCP was included, typical herbicide damage was visible. Chlorotic foliage of subalpine fir and grand fir regreened when the plants were removed from the source of PCP (Table 4). Once the necrosis had begun at the tips of the leaves, however, it progressed even after the PCP was removed, resulting in final loss of the needles from the trees.

Cuttings made from branches of healthy and affected subalpine fir broke dormancy with normal bud growth. The emerging leaves were normally light green, later darkening in both the normal and the exposed cuttings. No symptoms of damage were noticed on any new growth of cuttings.

Broadleaf Species

Broadleaf species showed symptoms of chlorosis, epinasty of leaves, and curling of the shoot apex within 24 hours after the initial exposure. The plants subjected to 30-day exposure were all dead by the end of 14 days with all treatments except the oil carrier without PCP. Broadleaf species exposed to shorter periods were severely deformed and stunted but remained alive after the PCP source was removed.

Grasses

The Bromus species subjected to the various treatments of PCP and oil carrier showed no symptoms during the entire 30-day exposure and continued to grow normally after removal from the PCP source.

Gas Chromatography and UV Spectroscopy

Extracts were prepared from PCP-treated boardwalk lumber and compared with commercial and reagent grade PCP with the aid

TABLE 3. The effect of PCP vapors on various plant species

	PCP-treated lumber	Commercial PCP	Chemical grade PCP	Oil carrier without PCP
Alpine fir	Chlorosis, necrosis on new foliage, no effect on mature leaves	Chlorosis, necrosis on new foliage, no effect on mature leaves		No visible efects
Grand fir	Chlorosis, necrosis on new foliage, no effect on mature leaves	Chlorosis, necrosis on new foliage, no effect on mature leaves		No visible effects
Sunflower	2, 4-D type action, curling of new growth, and epinasty of leaves	2, 4-D action	2, 4-D action	No visible effects
Tomato	Severe 2, 4-D type action, curling of new growth, and epinasty of leaves	2, 4-D action	2, 4-D action	No visible effects
Bromus	No visible effects	No visible effects	No visible effects	No visible effects
Broadleaf seedlings	2, 4-D	2, 4-D	2, 4-D	No visible effects

of a gas chromatograph. No indication of foreign pesticides was noted in either the PCP extracted from treated lumber or the commercial PCP (Fig. 4). Alpine tissue exposed to PCP vapors and showing chlorosis was also extracted and analyzed for the presence of PCP. With the current extraction procedure, no trace of PCP buildup in either the affected tissue or water samples could be found.

Comparisons of the lumber extract with the commercial and reagent grade solutions using UV spectroscopy supported the gas chromatography data. In both tests possible accidental contamination through manufacture or packaging of the PCP was ruled out.

Environmental Impact

Data derived from studies on the growth rate of subalpine fir are expressed graphically in Figs. 5-10. The data represent conditions on the north and south side of the walkway, as well as conditions in a control area away from the walkway (Figs. 1A, 2). Construction of the wooden walkway (Seibel 1974) (Fig. 1B) permits two large, treated surface areas to be exposed to air currents, allowing maximum volatilization of PCP in lumber. Since the prevailing wind is from the northwest, trees located on the south side of the walkway experience the greatest damage, with damage being inversely proportional to the distance from the walkway. The yearly growth increment of trees subjected to fumigation from the walkway follows this same pattern.

The greatest reduction in growth occurred at the lowest level of branches on the trees nearest the walkway. The intermediate and upper levels of branches showed successively less reduction in growth. This pattern was apparent, as well, on trees further away from the walkway, with the exception of trees on the perimeter of the affected area. Here, the lower levels were more protected from the vapor-laden air currents and only the intermediate or upper levels showed the effects.

Chlorosis of the needles gave the impression that growth might be more severely retarded on the sides of trees nearest the walkway. Analysis of variance at the 5% level of significance, however, showed no significant difference in growth increment on the two sides of the trees.

Natural environmental conditions complicated analysis of the data since exposure of trees to direct wind currents also retarded the growth rate in some instances. Figure 5 shows a decrease in growth increment for control trees as the distance from the walkway increased. Trees used as controls experienced increased wind exposure as their distance from the walkway increased. This hypothesis was supported by the irregular paths of chlorosis and necrosis noted

TABLE 4. Effect of various exposure times to PCP on symptom development and remission of symptoms after removal

Plant species	No. of plants tested	Length of treatment	Type of treatment	Symptoms at time of removal	Symptoms 2 weeks after removal
Subalpine fir	4	30 days	PCP-treated lumber	Chlorosis/necrosis expanding needles	Continued development of necrosis in 3 of the 4 specimens
Grand fir	4	30 days	PCP-treated lumber	Chlorosis/necrosis expanding needles	Continued development of necrosis on all plants
Sunflower	6	30 days	PCP-treated lumber	All plants dead	----
Tomato	6	30 days	PCP-treated lumber	All plants dead	----
Bromus sp.	10	30 days	PCP-treated lumber	None	None
Broadleaf seedlings	12	30 days	PCP-treated lumber	All plants dead	----
Subalpine fir	3	14 days	PCP-treated lumber	Chlorosis of emerging needles	Gradual regreening of needles
Grand fir	4	14 days	PCP-treated lumber	Chlorosis of needles	Gradual regreening of needles
Sunflower	6	14 days	PCP-treated lumber	5 plants dead	1 plant severely stunted and deformed. No new growth
Tomato	6	14 days	PCP-treated lumber	All dead	----
Broadleaf seedling	12	14 days	PCP-treated lumber	All plants dead except 1 *Plantamus* sp. and 1 unidentified composite	Both deformed. These two showed no new growth
Subalpine fir	3	7 days	PCP-treated lumber	None	None
Grand fir	2	7 days	PCP-treated lumber	None	None
Sunflower	7	7 days	PCP-treated lumber	Chlorosis and deformation of new growth epinasty	Stunted chlorotic, some new growth
Tomato	6	2 days	PCP-treated lumber	3 dead 3 severely deformed	Stunted, some new growth

TABLE 4. Effect of various exposure times to PCP on symptom development and remission of symptoms after removal (*continued*)

Plant species	No. of plants tested	Length of treatment	Type of treatment	Symptoms at time of removal	Symptoms 2 weeks after removal
Bromus sp.	10	7 days	PCP-treated lumber	None	None
Broadleaf species	12	7 days	PCP-treated lumber	Varying amounts of chlorosis and epinasty	Stunted, new growth, normal but slow

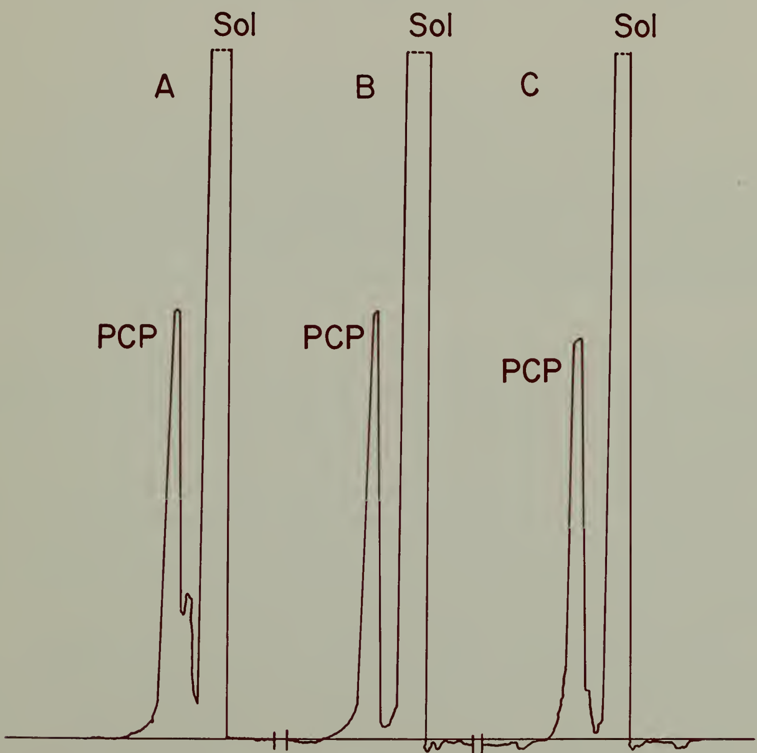

FIGURE 4. Gas chromatographic analysis of three samples of pentachlorophenol showing an absence of any foreign material in any sample. (A) Commercial grade pentachlorophenol extracted from samples of lumber used in construction of wooden walkway. The shoulder at the base of the PCP peak is extraneous material extracted from the wood and was present on controls from non-treated lumber. (B) Commercial grade pentachlorophenol obtained from the manufacturer. (C) Reagent grade pentachlorophenol. (SOL = solvent peak; PCP = pentachlorophenol peak.)

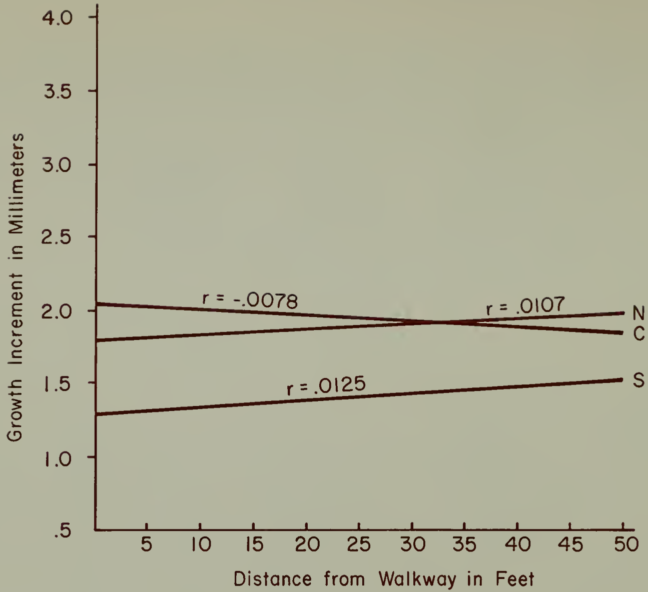

FIGURE 5. Effect of PCP on yearly growth increment as a function of distance from the wooden walkway for *Abies lasiocarpa*, 0-1 m above the soil. (N = north side of walkway; S = south side of walkway; C = unaffected control area.)

within clumps of trees adjacent to the treated wooden walkway. Clumps of trees were located such that wind currents would follow irregular paths through the trees, causing some trees to be affected and others not.

The degree of damage to *A. lasiocarpa* caused by fumigation was moderate to severe depending on position and distance from the wooden walkway. Growth was retarded by as much as 50% (Table 5). Chlorosis and necrosis was most severe nearest the walkway and generally improved as distance increased. (Table 6).

Broadleaf plants adjacent to the walkway were also affected. Plants directly under the walkway were usually killed from vapors or from direct contact with oil/PCP which dripped from the treated lumber on warm days. Vegetation along a 1-m-wide path on either side of the walkway was affected. Species of *Saxifraga* and *Anemone* were most severely affected, showing typical herbicide damage of curling and necrosis. None of the grass species showed any damage but other broadleaf species were reduced in size within the affected area. No visible symptoms were noted on any vegetation other than alpine fir at distances greater than 1 m from the walkway.

The spread of oil/PCP mixture was not limited to areas adjacent to the walkway. Subtoxic amounts were visible as an oil film in runoff water from snowfield (Figs. 11A, B). The source was from the

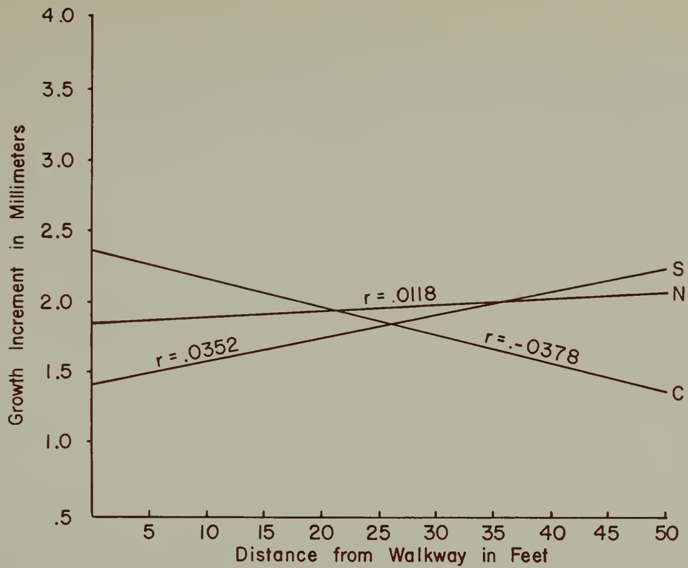

FIGURE 6. Degree of chlorosis/necrosis caused by PCP on *Abies lasiocarpa* as a function of distance from the wooden walkway for foliage 1-2 m above the soil. Range of severity from 1 = total necrosis of needles to 5 = no visible symptoms (*See* Fig. 1 for symptomatology). (N = north side of wooden walkway; S = south side of wooden walkway; C = unaffected control area.)

constructed walkway, as well as from piles of treated lumber stacked along the trail. The oil film could be found as far as 1000 m from the source of contamination. Concentrations of PCP in the runoff water were not determined, but attempts to culture various common green algae in water collected from the area failed.

Isolation of soil microorganisms from soil samples taken from the study area and from undisturbed areas was inconclusive but indicated a very low microflora in both areas.

Observations of the feeding habits of animals in the area showed that marmots and ground squirrels would use plant material adjacent to and near the wooden walkway. It was not determined exactly what plants the animals were feeding on but frequently they feed among plants affected by vapors from the walkway.

Conclusions and Discussion

The effects of pesticides on alpine vegetation are poorly documented in the literature. However, this study describes the effects of PCP on *Abies lasiocarpa* and associated vegetation.

From studies conducted under greenhouse conditions it is ap-

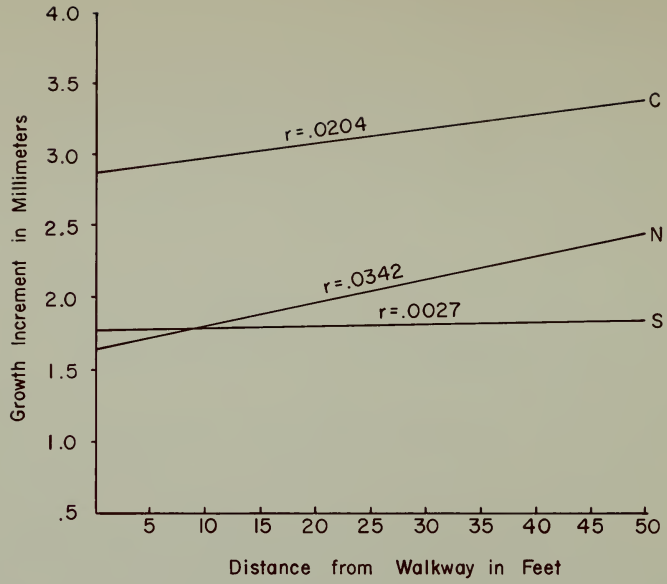

FIGURE 7. Effect of PCP on yearly growth increment as a function of distance from the wooden walkway for *Abies lasiocarpa*, 2 or more m above the soil. (N = north side of walkway; S = south side of walkway; C = unaffected control area.)

parent that low concentrations of PCP vapor are lethal to subalpine fir foliage and ultimately to the entire plant. Foliage subjected to vapors is ultimately lost to the tree. Subalpine fir will withstand repeated defoliation for only 3-4 years, after which the tree is so weakened it will die. Thus, continual contact with PCP vapors emitted from the wooden walkway will cause the death of all adjacent subalpine fir within 3-5 years.

Death of the subalpine fir could lead to a major change in the ecology of the area. Loss of windbreaks could prevent the reestablishment of the subalpine fir either as groves or crumholtz. A succession of cushion plants and grasses would follow. A period of 300-400 years would pass before the probability of any tree species establishing.

The cushion plants and grasses would continue to stabilize the soil. This would prevent any severe erosion problems, with the exception of areas within 1 m of either side of the walkway. In this area vegetation would be nearly, if not entirely, eliminated by the direct leaching of PCP/oil into the soil. Here, erosion could increase, possibly influencing the stability of the walkway. Such erosion, however, could create barren areas which might take 10-100 years to recover after erosion was halted.

The climate of the area would become more severe with the loss

TABLE 5. Reduction in growth increment of *Abies lasiocarpa* as a percentage of the control at three distances from the wooden walkway for the north (N) and south (S) sides

Distance above ground	Distance					
	0 m		8 m		16 m	
	S	N	S	N	S	N
	%	%	%	%	%	%
0-1 m	38.0	14.2	30.0	5.0	15.7	above control
1-2 m	39.1	21.7	0	10.0	above control	above control
2 or more m	39.2	42.8	45.1	35.4	50.0	29.4

of the subalpine fir as a windbreak. Annual soil H_2O would decrease with reduced snow cover in the winter, and during the summer greater fluctuation in temperature extremes would be experienced due to loss of protective cover offered by the subalpine fir grove.

Animal and bird populations in the vicinity would probably be unaffected since most of the species present rely only slightly, or not at all, on the subalpine fir stands.

Although trees located on the perimeter of the affected area probably would not be killed from the volatilizing PCP, the growth rate and vigor would be reduced. The affected trees would therefore be more susceptible to winter kill and disease, thus enhancing the possibility of ultimately losing these trees as well.

Although no specific data are available, speculation suggests that long-term damage results from the use of PCP/oil-treated lumber in the subalpine area. Visual evidence indicated the movement of PCP/oil in runoff water. Since soil microbial activity which breaks down PCP appears to be at low levels, PCP could collect in pockets, concentrate, and remain present for many years. If sufficient quantities concentrated in areas where animals feed or drink, it is possible that toxic or lethal amounts could be consumed, especially by rodents.

Collection and concentration in water sources also presents a hazard to fish populations. It is known that PCP accumulates in fish and that the mean survival time LD_{50} is about 1 hour at 1 ppm, depending on species, pH, and temperature (Goodnight 1942). Quantities which are sublethal to fish could have a very profound effect on other organisms of the food chain and ultimately eliminate some or all species of fish present.

Humans are also subjected to possible effects of PCP-treated lumber comprising the wooden walkway. During the tourist season many individuals walk barefoot on the walkway. Since PCP or its

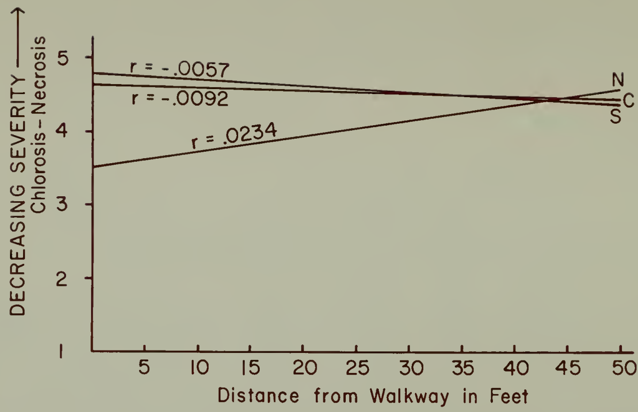

FIGURE 8. Degree of chlorosis/necrosis caused by PCP on *Abies lasiocarpa* as a function of distance from the wooden walkway for foliage 0-1 m above the soil. Range of severity from 1 = total necrosis of needles to 5 = no visible symptoms (*See* Fig. 1 for symptomatology). (N = north side of wooden walkway; S = south side of wooden walkway; C = unaffected control area.)

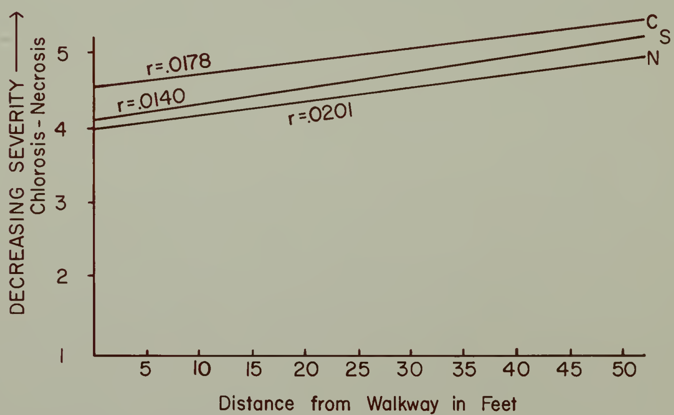

FIGURE 9. Effect of PCP on yearly growth increment as a function of distance from the wooden walkway for *Abies lasiocarpa*, 1-2 m above the soil. (N = north side of walkway; S = south side of walkway; C = unaffected control area.)

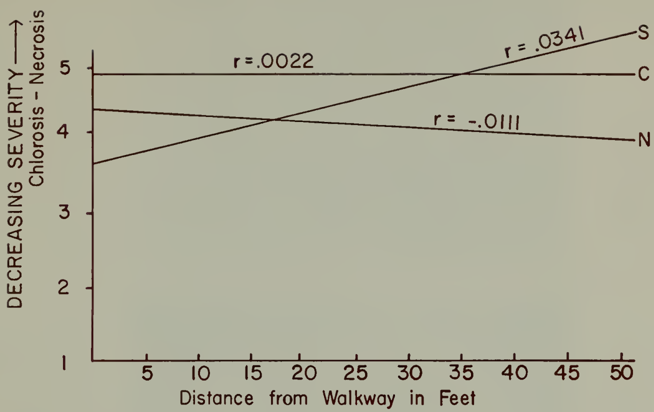

FIGURE 10. Degree of chlorosis/necrosis caused by PCP on *Abies lasiocarpa* as a function of distance from the wooden walkway for foliage 2 or more m above the soil. Range of severity from 1 = total necrosis of needles to 5 = no visible symptoms (*See* Fig. 1 for symptomatology). (N = north side of wooden walkway; S = south side of wooden walkway; C = unaffected control area.)

TABLE 6. Degree of Chlorosis/Necrosis of *Abies lasiocarpa* as a percentage of the control at three distances from the wooden walkway for the north (N) and south (S) sides

Distance above ground	Distance					
	0 m		8 m		16 m	
	S	N	S	N	S	N
	%	%	%	%	%	%
0-1 m	26.5	28.6	0	18.4	above control	above control
1-2 m	13.0	10.8	13.0	7.7	12.9	1.9
2 or more m	26.5	12.2	6.1	16.3	above control	18.3

sodium salt penetrates the skin by repeated and/or prolonged contact in quantities sufficient to cause death, skin contact must be avoided (Am. Ind. Hyg. Assoc. 1970). Case histories of death due to contact with PCP have been reported by Menon (1958). In this study, workers handled treated lumber.

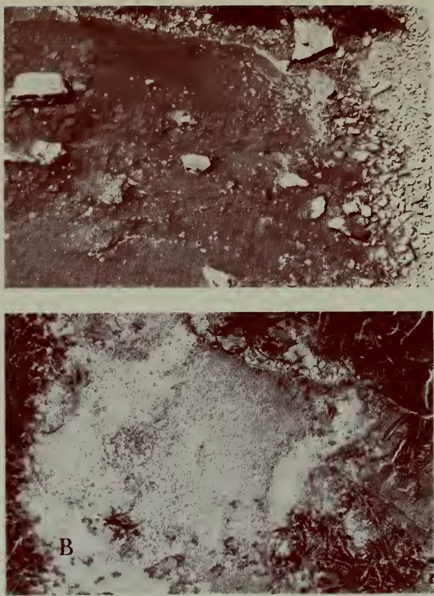

FIGURE 11. Runoff water near wooden walkway, showing oily film and froth resulting from oil contamination.

The chances of individuals absorbing sufficient PCP to cause death by walking on seasoned, treated lumber is remote. On the other hand, under the conditions presented by the use of treated lumber in the wooden walkway, skin rashes and lesions are entirely possible.

In addition to environmental dangers present, esthetic degradation of the area was noted. In tourist interviews, 88% of those interviewed found the odor of the walkway offensive (Seibel 1974). Also, the oozing of oil from the treated lumber on hot days presented a hazardous, slick surface on which to walk. Furthermore, the oozing oil carrier was picked up on shoes and clothing, causing stains or permanent damage.

Based on personal judgment and opinions of other environmentalists and ecologists, I feel that the *wooden walkway* best fulfills an important need to control random movements of tourists over the delicate alpine ecosystem. I believe the treatment of lumber in this environment is unnecessary since untreated material would decay only very slowly. By using untreated lumber, all environmental objections to the wooden walkway would be eliminated. Only personal bias and esthetic consideration would then have to be dealt with.

It is my conclusion that it is essential to remove *all* treated material and that no serious long-lasting damage would be sustained.

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