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Title: Serviceability of Douglas-fir Marine Piles and Control of Their Deterioration

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In an exploratory survey of the serviceability of wood in the marine environment in the Pacific Northwest, pressure-creosoted piling with tops protected from wetting by the superstructure provided 40 and more years of service and showed little or no indication of deterioration. The service life of these piling is still to be realized. However, wind driven rain, deck leaks, drainage, and improper construction practices can lead to deterioration of these piles. Fender, marina, bulkhead, and other piles with tops exposed to rain wetting are far more difficult to protect and can contain decay fungi within 1 year and advanced internal decay within 4 years. Brush-coating exposed pile tops with creosote or pentachlorophenol may delay decay by as little as 1 year.

Solid crystals of ammonium bifluoride and a paste of fluor-chrome-arsenic-phenol have prevented decay in 89 and 100% of simulated cutoff Douglas-fir pile tops after 3 years.

Internal decay of pressure-creosoted Douglas-fir piles has been stopped within the 1st year after treatment with volatile fungicides.

Fungitoxic vapors of Vorlex (methylisothiocyanate and dichloropropenes) and chloropicrin (trichloronitromethane) but not Vapam (sodium N-methyldithiocarbamate) remain within these piles 5 years following treatment. Fungitoxic vapors of methylisothiocyanate (active ingredient in Vorlex) moved 1.2 meters upward from the treating site within piles in 1 year.

Internal decay in untreated Douglas-fir piles can be controlled by the use of fumigants but external and top decay are more difficult to control with fumigants alone.

Vorlex or chloropicrin prevented shipworm attack of untreated Douglas-fir panels at Newport, Oregon. Vorlex slowed *Limnoria* attack in San Francisco Bay and Los Angeles Harbor but prevented such attack at Newport. Vapam was ineffective.

Serviceability of Douglas-fir Marine Piles

and Control of Their Deterioration

by

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GRADUATE COUNCIL REP.

DEDICATED TO

my sweet and
loving daughter

MAJ-BRITT ERIKA HELSING

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INTRODUCTION

In the United States, economic loss due to deterioration of wood in waterfront structures has been conservatively estimated to be $500 million annually (9, 30). Roughly one-half of this damage is caused by decay fungi and insects and half by marine wood boring animals (16). A research proposal to the Oregon State University Sea Grant College Program suggested that much of this destruction could be controlled through proper design and construction practices, use of onsite applied preservatives to prevent decay, and the use of fumigants to stop decay (30).

Pressure-treatment of Douglas-fir piles to prevent attack by wood-destroying organisms has been an accepted practice since the early 1900's. However, along the Pacific Northwest coastline, untreated piles are still used in large numbers and not always in waters free of marine wood borers. Little information is available about the service life of wood in the Oregon marine environment.

The American Wood-Preservers' Association Book of Standards (1) guides the wood preserving industry and users in the procurement of adequately treated wood products. In addition, handling and construct-tion practices are suggested to help users obtain the full service life from treated wood products. Although these measures are desirable, it is not known how closely these practices are adhered to and how effective they are in preventing wood deterioration. The quality of wood treatment can be controlled through independent inspection agencies but the quality of construction depends on the local building codes, knowledge of the contractor who builds the structure, and of the owner.

Whether the standards are followed or not, the loss of wood due to decay and marine wood borers indicates the need of a study to identify specific problems and supplementary treatments to reduce this loss.

The following objectives lay the foundation to help fulfill this need:

. To determine the nature and extent of biological deterioration in wooden waterfront structures.

. To determine the ability of various onsite applied preservatives to prevent decay in the cutoff tops of exposed Douglas-fir marine piles.

. To determine the effectiveness of fumigants for controlling deterioration of Douglas-fir marine piles.

LITERATURE REVIEW

Preventing Decay and Marine Borer Damage

The service life of wooden stakes and posts treated with various preservatives and placed in the ground has been well documented by the United States Forest Products Laboratory, Madison, Wisconsin; Forest Research Laboratory, Oregon State University, Corvallis, Oregon; and several colleges, highway departments and railroad companies (7, 8, 28, 32). Test panels have been immersed in the sea to evaluate various preservatives in preventing marine borer attack (17, 22) and to measure leaching and migration of creosote (26, 27). In the sea, molluscan shipworms riddle the interior of piles with holes whereas the tiny crustacean *Limnoria* burrow just below the surface of wood causing it to erode away by tidal action. The effectiveness of creosote as a preservative for wood on land or in the sea has led to its use as a standard for the evaluation of other preservatives (22).

An exploratory survey of wooden waterfront structures along the Oregon coastline is sorely needed to determine how wood is performing and to identify problems that may have ready solutions or to open opportunities for research. One such survey by Scheffer (35) was discussed at a 1966 Navy workshop.

The need for simple and immediate in-place preservative treatment of pile cutoffs (Figure 1) was one recommendation by Scheffer. Although various methods have been suggested to protect pile tops there is little or no evidence of the effectiveness of these methods.

Figure 1. Top decay of piles is frequently found.

Collars driven into tops that are then filled with hot creosote is an accepted practice (1) but has not been evaluated. Other methods include nailing creosote-soaked felt or resin-lade burlap over the pile tops; coating the tops with epoxy resin, asphalt, coal-tar, and application of metal caps.

Brush flooding of creosote onto the pile top is a common practice that needs to be evaluated because penetration and retention of creosote in end grain of Douglas-fir heartwood by non-pressure processes are very limited (2). Tangential and radial penetration into Douglas-fir heartwood is poor even with pressure processes making incisions necessary to obtain the depth and uniformity of preservative penetration required (1, 2). Heating the creosote reduces its viscosity but lack of improved penetration may not warrant this additional, time-consuming step.

Soaking various felts in creosote and applying them to cutoff tops of treated piles will do little to improve penetration but should prevent fungal infection if applied promptly. These felts, referred to as Irish Felt by Bramhall (5), may have more practical application between side grain surfaces of untreated wood (10). Creosote felts can provide a reservoir of protectant that may be needed between side grain surfaces. Gjovik (10) had good preliminary results with pentachlorophenol (penta)-soaked felt for protecting joining wood surfaces exposed to the weather.

Seasoning checks have been recognized as the entry path of wood-destroying fungi and insects since the 1800's (4). In pile tops, extensive end-checking may be several inches deep and can occur several weeks or months following application of preservative. Insufficient penetration of oil-type preservatives and evaporation of the mobile solvent leaves these preservatives relatively fixed in the wood and unable to protect untreated wood that becomes exposed as seasoning checks deepen. Flooding preservatives into checks after they open does not appear promising because decay fungi may already be well established beyond their reach (20).

Waterborne preservatives, especially those that are subject to leaching into checks as they open, promise improved protection over oil-type preservatives. However, the question arises as to whether these preservatives will eventually leach out and allow decay to occur. Nevertheless, there is strong evidence that some waterborne preservatives may protect wood for many years (7, 8, 28, 32).

Crystals of ammonium bifluoride (NH_4HF_2) placed in holes drilled into the tops of 2-foot high Douglas-fir piles and left uncovered prevented decay for 5 years near Gulfport, Mississippi (21). Because annual precipitation and average temperatures are higher in Mississippi than along the Pacific Northwest coastline where the decay hazard rating is lower (34), NH_4HF_2 should protect pile tops at least equally as well in the Northwest as in the Southeastern United States. Fluoride containing preservatives should provide deep protection in pile tops because of the highly mobile fluoride ion in wood (25).

The leachable waterborne preservative, fluor-chrome-arsenic-phenol (FCAP) offers promise for protecting pile tops (20, 21). Because a single brush flooding of 12% FCAP in water on southern pine decking planks (mostly sapwood) prevented decay for 5 years whereas annual brushings with 5% pentachlorophenol in oil did not (21), FCAP should be evaluated as a pile top preservative. However, the presence of arsenic may make it unavailable if the Environmental Protection Agency (EPA) decides arsenic is too hazardous for general public use.

Another waterborne preservative, disodium octaborate tetrahydrate (Polybor) should be a prime candidate for treating pile tops because of its effectiveness and low mammalian toxicity (3).

Stopping Decay

Although leach-resistant wood preservatives protect the critical outer shell of large wood products from fungal infection, they are of little value when checks or cuts expose untreated wood within. In large timbers in place, it is unlikely that decay can be stopped with anything but a fungitoxic gas (14, 20). Liquids generally are restricted in their movement in wood by aspirated pits and encrustations of extractives (24, 42). Gases such as propylene and ethylene oxides, however, have been used to sterilize small test samples of wood in the laboratory when it is desirable to avoid high temperatures (39, 41).

History of the Use of Fumigants to Stop Wood Decay

In the late 1950's export of U.S. oak products to some countries was restricted because of the oak wilt fungus (43, 44). This led to the successful use of chloropicrin (trichloronitromethane) or methyl bromide to kill the oak wilt fungus in 3 to 4 inch diameter, 8-inch long oak stems within 3 days in a gas tight chamber (31). Two years later, Jones (23) demonstrated that infected oak logs 12 to 17 inches in diameter and 17 feet long could be wrapped in plastic under field conditions and methyl bromide dispersed into the air surrounding the logs to eliminate *Ceratocystis fagacearum* (Bretz) Hunt from the wood.

Internal decay of Douglas-fir transmission poles had no cure until a Wood Pole Technical Committee composed of representatives from four Northwest utilities (Bonneville Power Administration, Portland General Electric Co., Northwest Public Power Association, and Pacific Power and Light Co.) and the Forest Research Laboratory (FRL), Oregon State University, proposed that biological deterioration might be stopped *in. situ.* with fungitoxic volatile chemicals (29).

Treatments to control external decay are not likely to be effective against internal decay because movement of the chemicals usually is limited to the outer 1 inch (40) of poles. To be effective fungicides must move through sound-appearing wood to affect the decay fungus where it occurs.

The Bonneville Power Administration (BPA) awarded a cooperative research contract to the FRL in 1961 for studies related to the inspection and treatment of poles in service. The FRL initiated basic research on the nature of decay, its detection and changes in wood properties of poles in service while BPA began to evaluate various chemical treatments of pole sections with internal decay (29). Most chemicals were ineffective but some agricultural soil fumigants sterilized the wood sections. This major discovery was tempered by the thought that poles would soon lose the gases and be reinfected unless some other treatment could provide extended protection.

Poles in service were treated with fumigants by drilling holes into poles in the groundline zone and filling them with Vapam (sodium N-methyldithiocarbamate). Five years later Wetsch (45) of BPA reported to the American Wood-Preservers' Association promising results in stopping internal decay and insect attack in both Douglas-fir and western redcedar poles with these fumigant treatments. Several fungicides were tried by Hand, Lindgren and Wetsch (19) including Chlorodane, Cresan M, ethylene dibromide, Telone, Vapam, chloropicrin, Cyanogas and methyl bromide. The last four were most effective but Vapam was selected for further testing in the field primarily because of its effectiveness, relatively low mammalian toxicity and ease of handling.

In a laboratory study by Hand et. al. (19), Vapam prevented decay of wood in soil block tests (ASTM D1413). The authors speculated that the residual inhibitive action within these wood blocks was a result of a breakdown of Vapam to elemental sulfur and a compound thought to be dimethylthiuram disulfide. They also reported that 14 out of 15 poles randomly selected were free of decay fungi 52 months after treatment with Vapam.

In 1965, Graham (12) of the FRL treated decaying Douglas-fir distributions poles with Vapam, chloropicrin or methyl bromide.

The population of decay fungi continued to increase in untreated poles but dramatically decreased within the 1st year in fumigant treated poles. In methyl bromide treated poles, the fungal population increased markedly after the 1st year and consequently this fumigant was not studied further. Vapam and chloropicrin remained effective for 3 to 4 years and promised longer protection.

Dr. Theodore Scheffer joined the research effort at the FRL in 1969 to evaluate fumigant use. Pole sections were treated with Vapam and chloropicrin and movement of vapors was followed by three methods: the open-tube bioassay, closed-tube bioassay, and insertion of decaying birch dowels (38). Within 10 months, total eradication of the assay fungus was noted 4 feet above and below the treating site in pole sections treated with chloropicrin. The average rate of movement of fungitoxic vapors was 1 to 2 feet per month. Twenty months after treatment, fungitoxic vapors of chloropicrin but not Vapam were still present within the poles.

In further studies at the FRL, Cooper et. al. (6) determined the lethal dosage of chloropicrin vapors to Poria monticola (now P. placenta) was 20 to 100 mg-hr/liter at room conditions. He also found that chloropicrin moved fastest in permeable Douglas-fir heartwood and in decayed wood. Encapsuling chloropicrin or dissolving paradichlorobenzene into the chemical was suggested to slow its release and increase its duration within wood.

Five years following fumigant treatment, Graham et. al. (18) reported on the inspection of 40 transmission poles that were cultured for fungi and, in addition, bioassayed to detect the presence of fungitoxic vapors of fumigant. Poles treated with Vorlex (methylisothiocyanate and dichloropropenes) or chloropicrin remained free of decay fungi whereas one-half of the Vapam treated poles were infected. The closed-tube bioassay showed that fungitoxic vapors of Vorlex and, especially, chloropicrin vapors were present as high as 8 feet above the groundline. Fungitoxic vapors from Vapam poles were least concentrated. Retreatment cycles, when old holes are redrilled and again filled with fumigant, were estimated to be 6 to 7 years for Vapam and possibly 10 years for Vorlex and chloropicrin.

Meanwhile, commercial wood inspection agencies had obtained registration from the Environmental Protection Agency for the use of Vapam and chloropicrin (Table 21) to stop decay of poles in service. Vorlex has not been labeled for use in poles.

Solid fumigants that sublimate to a gas may become important from the standpoint of ease in use and, more significantly, safety in application. Methylisothiocyanate (MS), the active ingredient in Vorlex was as effective as Vorlex (15). Improved formulations of fumigants for safe and rapid application to wood are being investigated.

Today the use of fumigants to stop decay has gained widespread acceptance and is practiced throughout the United States and Canada on Douglas-fir, western redcedar and southern pine utility poles. The investment in wood poles varies "from a few hundred thousand to more than a billion dollars" for each utility based on replacement costs in

1975 (13). Although the economic impact is difficult to estimate, BPA reports transmission pole investment savings of $2.25 million annually (Electric Power Research Institute Journal, January/February 1980). National savings for electrical utilities must amount to many millions of dollars annually but fumigants also play a very important role in conserving an important renewable resource - our forests.

Protecting pressure-treated and untreated piles is a new and difficult challenge for the fumigants. Most piles must be treated near the top where the closeness of exposed end-grain may cause fumigants to be lost more rapidly than in poles. If wood moisture content is very high, the movement of fumigants may be greatly slowed. Whether or not the fumigants can move to the sapwood and remain at the surface of untreated piles in effective quantities is unknown.

EVALUATION METHODS

Culturing for Decay Fungi

To determine the incidence of decay and to evaluate preservative and fumigant treatments for piles, cylinders of wood (cores) 4.3 mm in diameter and about 15 cm long were removed using an increment borer. The cores were measured for depth of preservative penetration and examined for visible decay. Cores were individually placed into plastic drinking straws, stapled at both ends, identified on a masking tape label, and returned to the Forest Research Laboratory for culturing. If the cores could not be cultured within a short time, they were stored in a refrigerator. The aseptic field-sampling technique described by Ricard and Mothershead (33) was found to be unnecessary.

The hole from which the core was removed was flooded with 5% penta in diesel oil or with creosote from a polyethylene squeeze bottle and then plugged with a tight-fitting treated wood dowel.

In the laboratory, cores were removed from the straws, momentarily passed through an alcohol lamp flame to kill surface contaminates, and then each core was embedded in malt agar medium in a Petri dish. Dishes were stacked in cardboard boxes that were placed in storage at room temperature (about 21°C).

After 1 week, the cores were inspected for the outgrowth of fungi. The location of air borne contaminates was marked with a wax crayon on the bottom of the dish and recorded and then the dishes were returned to storage.

Four weeks following plating, the cores were again inspected for the presence of fungi. Fungi with a dense white mycelial mat typical of *Poria carbonica* or *Poria placenta* were immediately classed as basidiomycetes and noted as "decay" fungi. Mold growths of *Trichoderma*, *Penicillium*, *Paecylomyces*, *Scytalidium* and others were classed as "non decay" fungi. Questionable fungal growths were microscopically examined for the presence of clamp connections and other mat characteristics separating wood rotters from non-wood rotters.

This method of identification will result in decay fungi being missed, especially those decay fungi in the haploid stage that lack clamp connections.

Closed-Tube Bioassay for Presence of Fumigant Vapors

To study the distribution of fumigants within piles, 2.5 cm long segments of cores cut at various distances from the pile surface and from the pile top were placed individually into 13 cm long test tubes below a colony of *Poria placenta* growing on a malt agar slant (Figure 2). The caps were re-installed and the tubes were incubated cap end down to avoid wood contact with the culture medium. A group of tubes without core segments was used to monitor growth of the assay fungus without the influence of fumigant vapors. The tubes were incubated at room temperature (about 21°C) until the growth of the assay fungus in the controls reached the end of the agar slant. At this time, the

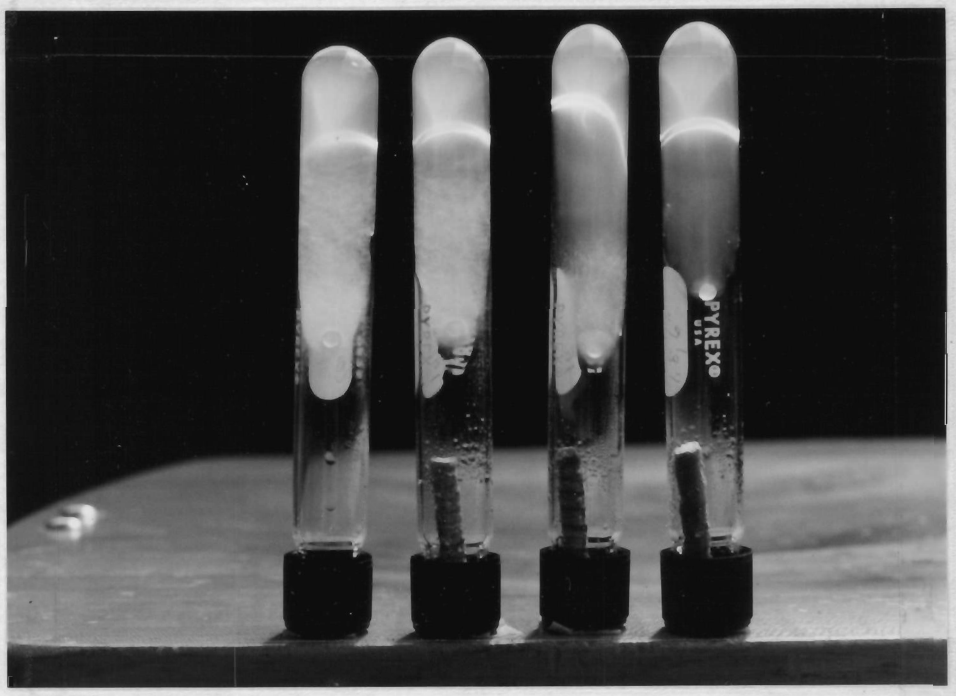

Figure 2. — The closed-tube bioassay was used to detect the presence and distribution of fungitoxic vapors of fumigant. If fungitoxic vapors diffuse from the core segment near the cap, it reduces or stops the growth of the fungus on the agar slant.

maximum radius of each fungus colony in all tubes was recorded.

If fumigant vapors were present in the wood, they diffused throughout the air space within the tube and slowed or stopped the growth of the assay fungus. The closed-tube bioassay is a modification of the open-tube bioassay described by Scheffer and Graham (38) and has been used in subsequent studies on fumigant treated poles (18).

SURVEY OF THE USE OF WOOD IN WATERFRONT STRUCTURES

Method

Piers, marinas, or bulkheads at twelve Pacific coastal ports were inspected to obtain information about the nature and extent of deterioration and service life of various components. Port managers, dock and pier owners, maintenance personnel, engineers, and pile drivers were interviewed. Service records were rarely kept so estimates of service life of piles could not be substantiated in most cases. Increment cores were removed at critical locations, examined for advanced decay, and then cultured for fungi. Moisture contents of selected piles were determined by removing cores, wrapping them in aluminum foil, returning them to the Forest Research Laboratory, and weighing them before and after oven drying.

Results and Discussion

Serviceability of Douglas-fir piles at 12 ports from Brookings, Oregon, to Seattle, Washington varied from replacement after 3 years for untreated piles destroyed by *Bankia* to 62 years and still in service for pressure-creosoted piles in coastal waters with marine wood borers (Table 1).

Untreated piles failed within 3 to 14 years when exposed to marine wood borers whether tops were protected by the superstructure or not.

In waters free of marine wood borers, untreated piles had from 15 to over 20 years of service life when tops were protected and 7 to 12 years when tops were not protected (Table 2).

Years in service of pressure-creosoted piles nearly always exceeded 20 years and sometimes exceeded 33, 45, and 62 years in marine wood borer-inhabited water. Such long service indicates that the present estimates of service life for pressure-creosoted Douglas-fir piles of 20 to 30 years may be conservative.

Piles with tops exposed to rain wetting tended to have lower years of service life than piles with tops protected because of top decay. Pile tops usually are cut off, most of them brush-flooded with creosote and they may or may not be covered with asphalt or metal cone-shaped caps. Decay fungi were present within the tops of 56% of 245 pressure-creosoted piles in service for 0.3 to 15 years (Table 3). All 36 four-year old bulkhead support piles at Florence, OR, that had been cut off at a slant to drain water contained advanced decay beginning 5 to 15 cm below the sound-appearing tops.

Moisture content profiles of both pressure-creosoted and untreated piles in service show that at and below the barnacle line sapwood moisture contents were high (over 70%) whereas heartwood moisture contents were low (35% or less) (Table 4). Barnacles attach to piles in the tidal range up to a well defined line above which untreated wood eventually decays and below which wood is attacked by marine wood borers. These data show that the fumigant movement inside piles would not be restricted greatly because of moisture content (15).

Following are summary reports of port visits highlighting findings about the service life of wood along the Pacific Coastline.

Astoria

Nearly all piers at this fresh water port are supported on untreated piles that were cut off in the intertidal zone and built up from there with pressure-treated framework to support the superstructure (Figure 3). Port authorities estimate that full length untreated piles fail in about 15 years due to top decay. Marine borers are not a problem in Astoria so the submerged portion of untreated piles lasts indefinitely.

Untreated fender piles were all decaying from the tops down in three piers, emphasizing the need for effective pile top protection. The U.S. Coast Guard navigational aids built of creosote-treated Douglas-fir piles usually were in excellent condition although a few contained rot which was associated with seasoning checks. The tops of these piles appeared to be well protected by flooding with creosote and covering with tar which was several inches thick.

Untreated caps, stringers and deck boards were badly decayed.

Pressure-treated 3-inch thick decking and 14-by 14-inch guard rails and checks appeared sound externally. Cores removed from 16 decking pieces showed no decay but 14 out of 16 guard rails were found to have advanced decay internally.

Figure 3. In Astoria untreated piles are cutoff below the fresh waterline and built up from there with a pressure-treated framework to support the superstructure.

Port of Bandon

The small boat basin at this port is located 0.7 mile from the mouth of the Coquille River. Untreated piles are destroyed within 3-4 years by shipworms (a wood-boring mollusk) with little evidence of damage by Limnoria (a small wood-boring crustacean).

Port of Brookings

The marina at Port of Brookings is located approximately 1.0 mile above the mouth of the Chetco River. About 100 untreated Douglas-fir piling that supported free-floating moorage docks were in poor condition after 14 years of service. Abrasion by the floating dock during tidal changes reduced some piles to one-fourth of their original diameter (Figure 4). Damage to piles by dampwood termites and buprestid beetles was widespread. Shipworms attacked the piles most severely at the mudline indicating the presence of a wedge of intruding salt water below the fresh water flow of the Chetco River. The age of the piling suggested intermittent attack, probably occurring during low stream flow in the summer months.

Our survey helped the Port of Brookings obtain federal funds to install pressure-creosoted piles.

Coos Bay and Charleston

Shipworms are a serious problem to submerged untreated wood at Charleston near the mouth of the Coquille river.

At Coos Bay, 10-15 miles upstream, Limnoria are the principal wood

Figure 4. Floating docks at Brookings, Oregon, during tidal changes abraded some piles to one-fourth of their original diameter.

destroyers with little sign of shipworm damage. Untreated fender piles are commonly used because it is thought that large cargo ships crush these piling or break them off at the mudline before biological degradation occurs. The rapid Limnoria attack is estimated by Dr. J. J. Gonor, Marine Biologist, OSU, to reduce the diameter of untreated piles about 1 inch a year making this marine wood borer a major contributor to pile breakage (Figure 5).

The finding of high populations of Limnoria tripunctata (which attacks creosoted piles in southern waters) within upper Coos Bay (approximately 10 to 16 miles from the river mouth) by Gonor, prompted an inspection to determine if pressure-creosoted Douglas-fir piles in this zone are being attacked. Four hundred and fifty-two piles within the L. tripunctata zone in the upper bay and 468 piles within the Limnoria lignorum zone in the lower bay (river mouth to river mile 10) were inspected for Limnoria attack within the intertidal portion of each pile (Table 5).

The 153 piles with surface attack within the L. tripunctata zone as compared to 5 piles with surface attack within the L. lignorum zone indicate that L. tripunctata are more destructive of pressure-creosoted piles in Coos Bay than L. lignorum. It should be noted, however, that in the upper bay surface-attacked piles had been in service for 50 to 55 years whereas no surface attack was present on the piles in service 3 to 17 years. Also, 75% of the 55-year old piles had patches or vertical strips of inner bark remaining on the pile surface above water suggesting that the surface attack may have occurred in

Figure 5. Surface attack on pile by Limnoria tripunctata in the upper Coos Bay, Oregon.

areas of low creosote retention where strips of bark had not been removed prior to pressure-treatment. Analysis by Timber Products Inspection Company of 17 increment cores removed from within the intertidal zone of these piles showed an average creosote retention of 16.9 pcf. Although less than the 20 pcf required in AWPA Standard C3 (1), this amount of residual creosote suggests that the original retentions probably exceeded 20 pcf. Further studies are needed to resolve whether *L. tripunctata* attack pressure-creosoted wood in Oregon estuaries.

Pressure-creosoted wood was attacked by *Limnoria* when construction practices exposed untreated wood. Cutoff cross bracing was commonly found hollowed out internally from the ends (Figure 6). Oversized bolt holes let in marine wood borers that hollowed out piles and bracing. Piles in the Shinglehouse Slough railroad bridge built in 1930 were free from attack because holes for bracing were drilled 1/8-inch smaller than the bolts (personal communication). Many piles in adjacent newer highway bridges had been reinforced with concrete probably because holes were drilled over-size to speed construction.

The collapse of a portion of the Isthmus Slough Bridge on April 1, 1977 when scouring from boat propellers exposed the untreated piles, caused tremendous concern for the safety of all state highway bridges. Inspection and repair programs were accelerated to locate other bridges that may have been weakened by marine wood borers because of scouring.

A few months later a lumber storage and shipping pier collapsed under the weight of a pile driver, taking the life of the operator.

Figure 6. Cutoff pressure-treated cross bracing hollowed out by Limnoria.

The untreated support piles beneath had been severely damaged by *Limnoria*.

Many Oregon pier owners find untreated wood more readily available and economical to use in superstructures than pressure-treated decking and larger timbers. Untreated decking planks are lasting 8 to 15 years at approximately one-third to one-half the cost of treated material. Longer service life could be expected from application of a preservative during construction to critical decay-susceptible areas such as joining wood surfaces, bolt holes and end grain that retains water.

Florence

All 36 pressure-creosoted Douglas-fir piling in a 4-year-old bulkhead were decaying internally below the slanted sound-appearing tops. In an adjacent marina, untreated dock-support piling in brackish water free of marine borers were in various stages of surface decay after 12 years. Many of these marina piles were in excellent condition, even near the tops. Although protection is needed for cutoff pile tops, one wonders why the unprotected heartwood in tops of creosoted piles appears to be more susceptible to decay than that in untreated piles.

Untreated Douglas-fir support piles below a local restaurant were still sound after 20 years service. The absence of advanced decay and our inability to culture decay fungi from the piles also emphasize the importance of keeping tops of piles dry. One wonders why that portion of the piles just above high water remained free of decay.

During the low rainfall period in spring and summer of 1977, the port manager became concerned about shipworm damage as salinity increased to the point that sea perch were being caught by fisherman off docks constructed of untreated piles at river mile 6. In the past, shipworm damage reportedly did not occur above river mile 2 or 3 in the Siuslaw River.

To study marine borer destruction, Gonor made salinity measurements at river mile 6 during high and low slack tide near the estuary bottom and the water surface, and 0.6 x 4.1 x 15 cm green, clear Douglas-fir sapwood specimens were immersed at 1 foot intervals of water depth. Specimens were removed monthly and inspected for the presence of marine wood borers.

High tide salinity was essentially oceanic (33%) whereas low tide salinity was 16%. Salinities were similar at the water surface and estuary bottom indicating that water in the Siuslaw estuary was well mixed as far upstream as Florence. Although these salinities are suitable for marine wood borers, no attack was seen on the wood specimens.

Longview

Fifty-four untreated western redcedar piling have supported two cargo dock ramps of Weyerhaeuser Company for about 20 years. All had surface decay for a few feet above the groundline on land piles or the high tide level on piles in water. Because of the low river flow during 1977, surface decay apparently was extending lower on the piling standing in fresh water. Internal decay was largely associated with holes and large seasoning checks. The pile tops, protected from wetting by the superstructure, appeared sound. Many of the piles were in excellent condition considering their long service.

Newport

Shipworms are the most important marine wood borer in Yaquina Bay, Oregon. Damage by Limnoria is limited because of the very rapid attack by shipworms.

Pressure-creosoted fender piling are used because chafing by the boats that frequent this harbor is minimal and is controlled by replaceable rubbing strips when necessary.

Untreated greenheart fender piles failed after 6 to 8 years because of shipworm attack. Pressure-creosoted Douglas-fir piles in the nearby "Old Trestle", reportedly installed in the 1930's, are still in excellent condition.

Pressure-creosoted piles with oval holes about 2 inches long within the intertidal area were hollowed by marine borers (Figure 7). Similar holes were found in piles being installed in a new dock. On the shore, a crane was lifting the creosoted piles into place by grasping each pile with pointed tongs near the balance site. American Wood Preservers' Association Standard M4 states "treated piling may be handled with pointed tools provided that side surfaces are not penetrated over one-half inch". Because of the variable preservative penetration depth, the use of pointed tools should be prohibited or limited to a fixed distance from the top or bottom of piling.

Figure 7. Oval holes with hollowing of the pile by Limnoria was a result of using sharp pointed tongs to lift piles. The port manager filled the hollowed piles with concrete to strengthen them.

Port of Oakland

Razing of a warehouse constructed in the 1920's showed that untreated timbers can provide excellent service when protected from the weather. Advanced decay was present in ends of untreated timbers or untreated cut ends of pressure-treated timbers exposed to sun and rain.

Limnoria tripunctata gradually eroded the surface of pressure-creosoted piles while *Limnoria* and shipworms destroyed untreated eucalyptus piles. Concrete jackets that extend from below the mudline to above high tide were effective in stopping marine wood borer attack and strengthening of piles. Jacketed piles failed when improper settling of concrete and scouring below the jackets exposed wood to attack by marine wood borers. Polyvinyl chloride (PVC) wraps applied to this same zone stopped marine wood borer damage by limiting the oxygen supply. On piles that were pulled and the wrap was intact, there was no evidence of living *Limnoria*. Where the PVC wrap had become loose, usually near the bottom or had been torn, *Limnoria* were present in great numbers. PVC wraps are being used with increasing frequency on pressure-creosoted piles at Pacific coast ports.

Port Orford

The superstructure of a decaying untreated wood deck was being replaced with Chemonite-treated (ammoniacal copper arsenate) decking and untreated caps from a dismantled dock in Portland. All of the replacement material appeared sound. The contractors applied a 10%

penta solution and a 30 pound roofing felt cover to the top of each bearing pile and untreated cap (Figure 8).

Port of Portland

Swan Island shipyard is composed of earth-filled steel cells, a concrete-filled steel pile dock, a steel dry dock, a wooden dry dock, and a wood-pile dock. Problems are occurring with steel cells giving way because of gradual seepage of fill from behind the cells. Joints between the concrete decks are widening with no apparent explanation. The wooden dry dock is performing exceptionally well for its 55 year service but it is not without its problems (Figure 9). Soft rot occurs on wood surfaces that are continually wet. Maintaining the caulking in the wooden dry dock is a continuous chore because of swelling and shrinking of wood members. Inspection of the wood-pile dock indicated that all of the pressure-creosoted piles were sound.

Columbia River

Portland District Corps of Engineers indicated that top decay is a problem in both pressure-creosoted and untreated piles. Untreated piles and timbers are used in dikes along the Columbia River to slow flow of water at the sides and speed flow in the main channel to help keep it open. Although piles rot above water, untreated piles and bracing remain sound below the fresh water line for many years.

Figure 8. Preservative brushed over untreated wood members and covered with roofing felt.

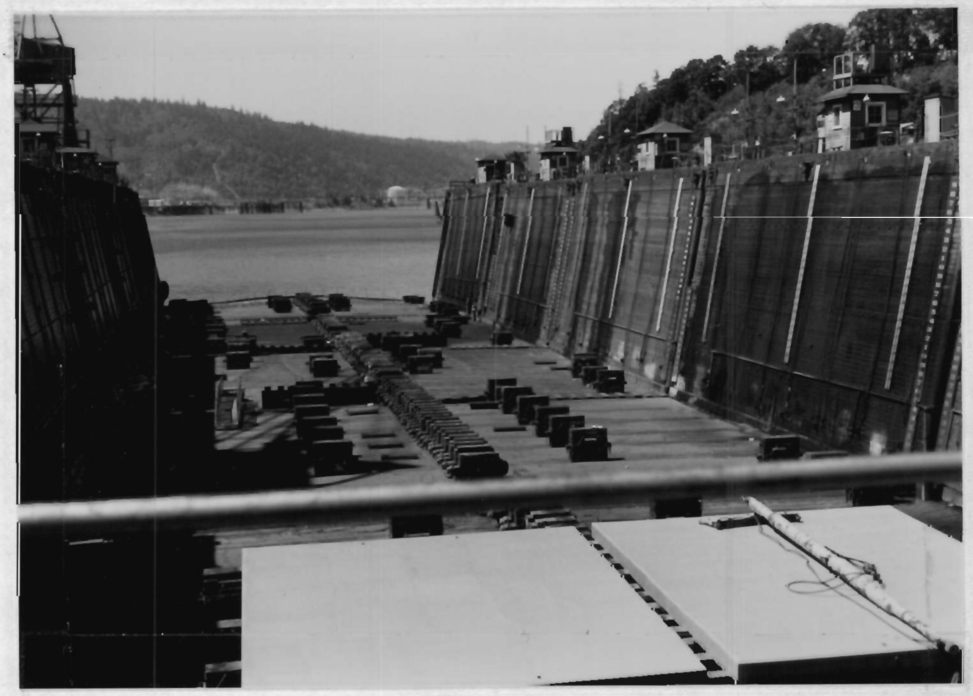

Figure 9. Fifty-five year old wooden dry dock in excellent condition except for soft rot found on the surface of continuously wetted wood surfaces.

Seattle

We met with Dr. Terry Highley, plant pathologist of the U.S. Forest Products Laboratory, to view their in-field preservative treatment projects in the Seattle area.

Seasoning checks led to decay in 10-inch square Douglas-fir timbers, pressure-treated with pentachlorophenol or creosote, but not in timbers pressure-treated with fluor-chrome-arsenic-phenol (FCAP). Apparently FCAP leaches sufficiently into the checks to protect them against infection by decay fungi (Figure 10). FCAP and other salt-type preservatives should be considered in experiments to protect pile tops and larger sawn members of piers and wharves.

Creosote has protected deck planking in piers against surface splintering better than FCAP (Figure 11), possibly because of its water repellent effect that reduces alternate swelling and shrinking of wood. Also, FCAP may embrittle the wood.

Attempts to protect large timbers by flooding FCAP solution into checks with advanced decay do not appear promising. Such a flooding treatment may be beneficial if applied in the early stages of check development as was done with large timbers in a laminated arch which carries the water line across the Nestucca River to Pacific City, Oregon.

Inspection of Pier 66, built in 1913, revealed that the untreated exposed deck was virtually destroyed by decay fungi but that untreated timbers beneath the concrete slab were in excellent condition. However, advanced decay was present where drain holes were cut through

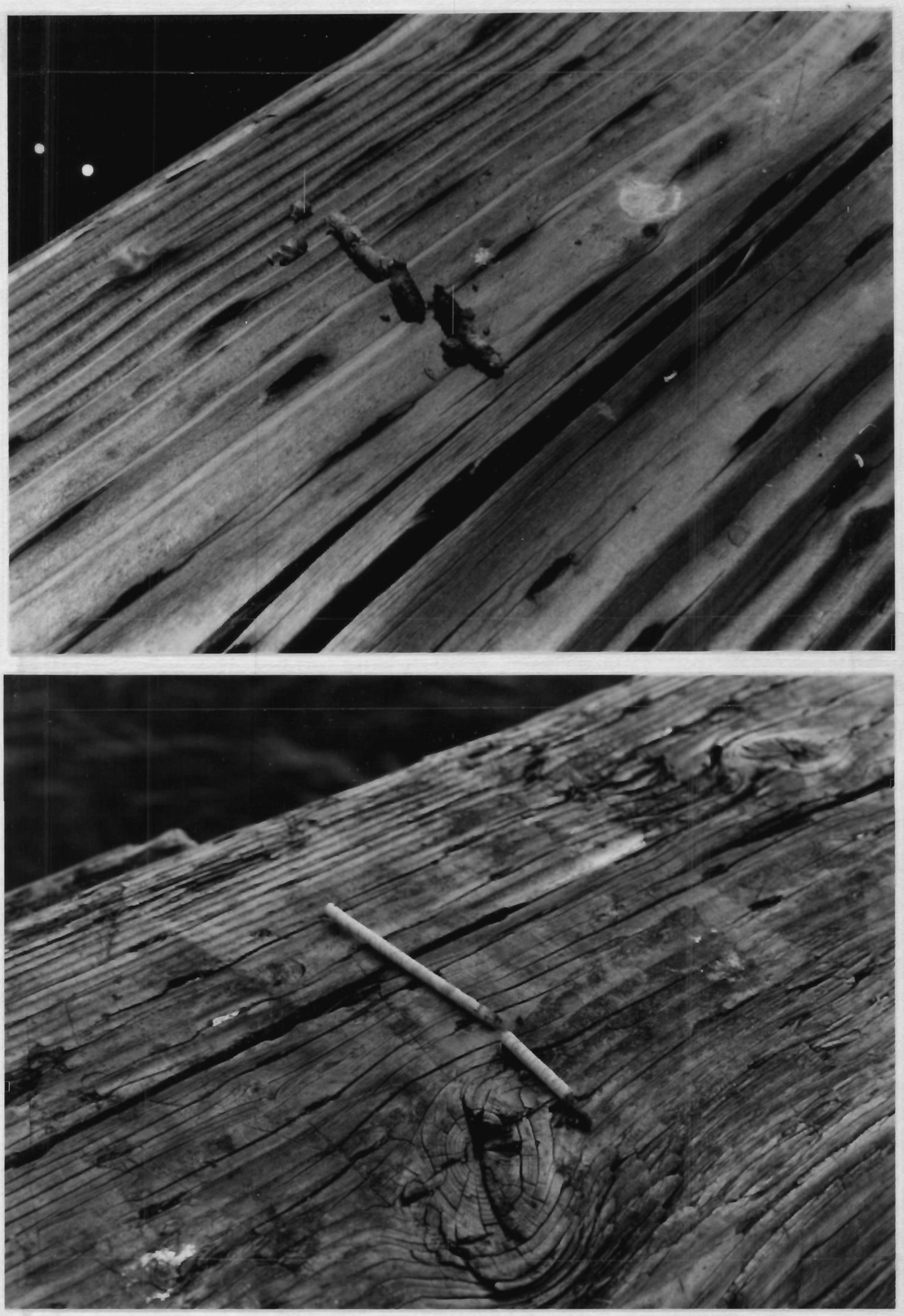

Figure 10. After 20 years this Douglas-fir timber pressure-treated with FCAP had sound wood in the seasoning check compared to the 3-year-old penta pressure-treated timber above with advanced decay at the base of the seasoning check.

Figure 11. Decking planks treated with creosote (above) showing no surface splintering after 10 years as opposed to the surface splintering in 20-year old decking planks treated with FCAP (below).

the concrete slab as space in the pier was rented to small industries.

Meetings with engineers and port authorities clearly demonstrated the need for information on the nature of wood and its preservation to assist design, construction, and maintenance personnel to use wood properly and effectively in both waterfront structures and boats.

Tillamook

Pressure-creosoted piles are providing excellent service, often for over 30 years. Piles are vulnerable to decay when they are cut off and left unprotected. Methods of pile cutoff protection vary from dock owner to dock owner. Bitumen frequently is applied to pile tops but with little success. Cracks soon develop allowing rain water to seep into the wood and, unfortunately, the coating slows drying which favors decay. Some dock owners apply no protection while others apply elaborate caps, e.g. burlap, fiberglass, metal, or marine paints. Decay was evident in untreated wood commonly used in the superstructure of docks.

Summary of Needs

Pressure-treated wood when properly installed is providing excellent service in the marine environment. Untreated wood provides reasonably good service, especially when protected from the weather. Although its serviceability is markedly less than pressure-treated wood, untreated wood will continue to be used because of its availability and relatively low cost.

Nevertheless, much can be done to improve the performance of both pressure-treated and untreated wood. Basic to this improvement in the use of wood by architects, engineers, construction workers, and maintenance personnel, is an understanding of wood and its preservation. Knowing why wood deteriorates and the role of moisture in the decay process, architects and engineers would design structures to shed water, use the proper preservative treatment where wood is exposed to water, and require that wood be properly installed. Knowledgeable construction workers and maintenance personnel would understand why good construction practices are essential for good performance of wood in structures.

Good design and construction practices include:

- Use of pressure-treated wood
- Use of remedial treatments on construction site
  - between untreated joining surfaces
  - into fastener holes
  - into seasoning checks
  - onto cutoff surfaces

Problems in the use of wood that open opportunities for research include:

- Evaluation of various methods and preservatives in preventing decay in cutoff pile tops and timbers.

- Evaluation of onsite treatments in preventing decay of untreated wood members in superstructures.
- Determination and evaluation of methods for preventing decay of untreated piles.

PROTECTING CUTOFF TOPS OF DOUGLAS-FIR PILES FROM DECAY

Materials and Methods

Experimental Design

A test plot containing simulated piles was established at the Northwest Forest Genetics Nursery near Corvallis, Oregon, in 1976 to evaluate promising chemicals for protection of cutoff pile tops (Figure 12). Ninety-nine 5 to 6 foot-long piles about 12 to 14 inches in diameter were pressure-treated with penta in heavy petroleum by a commercial treating plant. Three 6-inch long cores equally spaced around each pile at midlength were removed and cultured for fungi, then the piles were cut in half through the plane of the core holes. The sections were placed with the treated ends down 1.0 foot deep in the soil and 22 different chemical treatments were applied to the cutoff pile tops (nine tops per treatment) (Figure 13). For most treatments, end-matched specimens received the same preservative treatment, but one was capped with a 1/2-inch thick coat of coal-tar cement with fiberglass cloth embedded.

To evaluate whether reservoirs in the pile tops are necessary for liquid and solid preservatives, parallel chainsaw cuts were made about 2 inches apart and 2 inches deep. The tops with sawcuts accepted about three times the quantity of preservative as the tops with no sawcuts.

Figure 12. Simulated cutoff Douglas-fir pile top plot established near Corvallis, Oregon, to evaluate promising chemicals for preventing top decay.

A. Pile tops preservative treated without caps

No sawcuts	Sawcuts	Controls
FCAP paste	FCAP paste	No preservatives
NH_4HF_2 solid	NH_4HF_2 solid	
Polybor paste	Polybor paste	
Penta 10%	Penta 10%	

B. Pile tops preservative treated and capped*

No sawcuts	Sawcuts	Controls
FCAP paste	FCAP paste	Capped only
NH_4HF_2 solid	NH_4HF_2 solid	
Polybor paste	Polybor paste	
Penta 10%	Penta 10%	

C. Pile tops with other protective caps

FCAP soaked felt
Penta soaked felt
Pole Topper (proprietary)
Pole Nu (proprietary)

*Cap consisted of fiberglass cloth embedded in coal-tar roofing cement.

Figure 13. Experimental design for protection of pile cut-offs.

to protect untreated wood exposed when piles are topped, a preservative must diffuse into the wood, leach into the base of checks as they form, and persist for many years. A cap over the pile top may extend such protection. We tested both oil- and water-soluble preservatives with and without a cap.

FCAP and disodium octaborate tetrahydrate (Polybor) were troweled on the pile tops about 1/8 inch thick as 75-80% active ingredient pastes. Moistened ammonium bifluoride (NH_4HF_2) was applied in crystalline form. Ten percent penta in diesel oil, brushed on twice until refusal, was included as a standard because it is commonly applied to wood end grain. Cellulose felt soaked with either 36% penta or 12% FCAP, and commercially available Pole Topper and Pole Nu were applied.

Annually, three cores 15-cm long were removed at equal distances around the piles 6 inches below the tops and the cores were cultured on malt agar medium to detect decay fungi. The bit of the increment borer was dipped in 60 percent ethanol before each core was taken. Holes were plugged with 5-cm long penta-treated dowels. Moisture content of the piles were determined 2 years following initiation of the experiment.

Preservative Distribution in Pile Tops

The *Aspergillus niger* bioassay, developed by Scheffer and Eslyn (36), was used to study the distribution of penta and waterborne preservatives with respect to distance from the pile top. In this bioassay, petri dishes containing malt agar were seeded with spores of *A. niger*. Wood cores removed from pile tops were then placed on the agar surface. In a study by Scheffer and Gollob (37), wood samples with various amounts of penta or tributyltin oxide (TBTO) produced radii of transparent areas around the treated wood (where the fungus does not produce its typical black spores) which can be measured to estimate penta or TBTO concentration. The radius of the transparent area is called the total zone of effect (TZE).

Although the relationship between TZE and treating solution strengths has not been established for the preservatives used in this simulated pile top plot except for penta, the *A. niger* bioassay was used principally to determine location of preservative protection within the top of the piles.

Results and Discussion

Culture Results

No decay fungi were present in the pile sections before they were cross cut at midlength. One year after treatment, seven of nine control piles without caps contained decay fungi.

After 2 years exposure, all nine uncapped piles without preservative and many uncapped piles treated with penta or Polybor were decaying, but FCAP and NH_4HF_2 prevented invasion by decay fungi (Table 6). Of the capped piles, only two without preservative continued free of decay fungi. Pole Topper prevented decay, but the other proprietary treatment did not. Reservoirs of preservative created by sawcuts appeared to reduce decay. Moisture measurements made in August 15 cm below the tops of piles at depths of 1.25 cm to 6.25 cm with a resistance-type meter showed that moisture content was lower in capped than in uncapped piles (Figures 14 and 15). In capped piles, moisture contents were near or below a moisture content of 20%, below which wood does not decay.

Three years following the top treatment, all uncapped control piles and nearly all uncapped Polybor- and penta-treated piles contained decay fungi (Table 7). FCAP and Pole Topper treated tops remained free of decay fungi. One pile from each of capped and uncapped tops treated with NH_4HF_2 contained a decay fungus. Infection of 2 piles treated with NH_4HF_2, one capped, was not consistent with the previous years findings and Highly's results (21) but not discouraging. Capping appears to help prevent infection by decay fungi. Tops with sawcuts and preservative continue to look more promising than tops without sawcuts.

Preservative Penetration

In the *Aspergillus niger* bioassay trial 1 year after top treatment, the average TZE for capped and uncapped piles without preservative was essentially the same as tops with preservative applied. Closer examination revealed that penta-treated summerwood bands from the initial pressure treatment caused TZE's within all groups of piles.

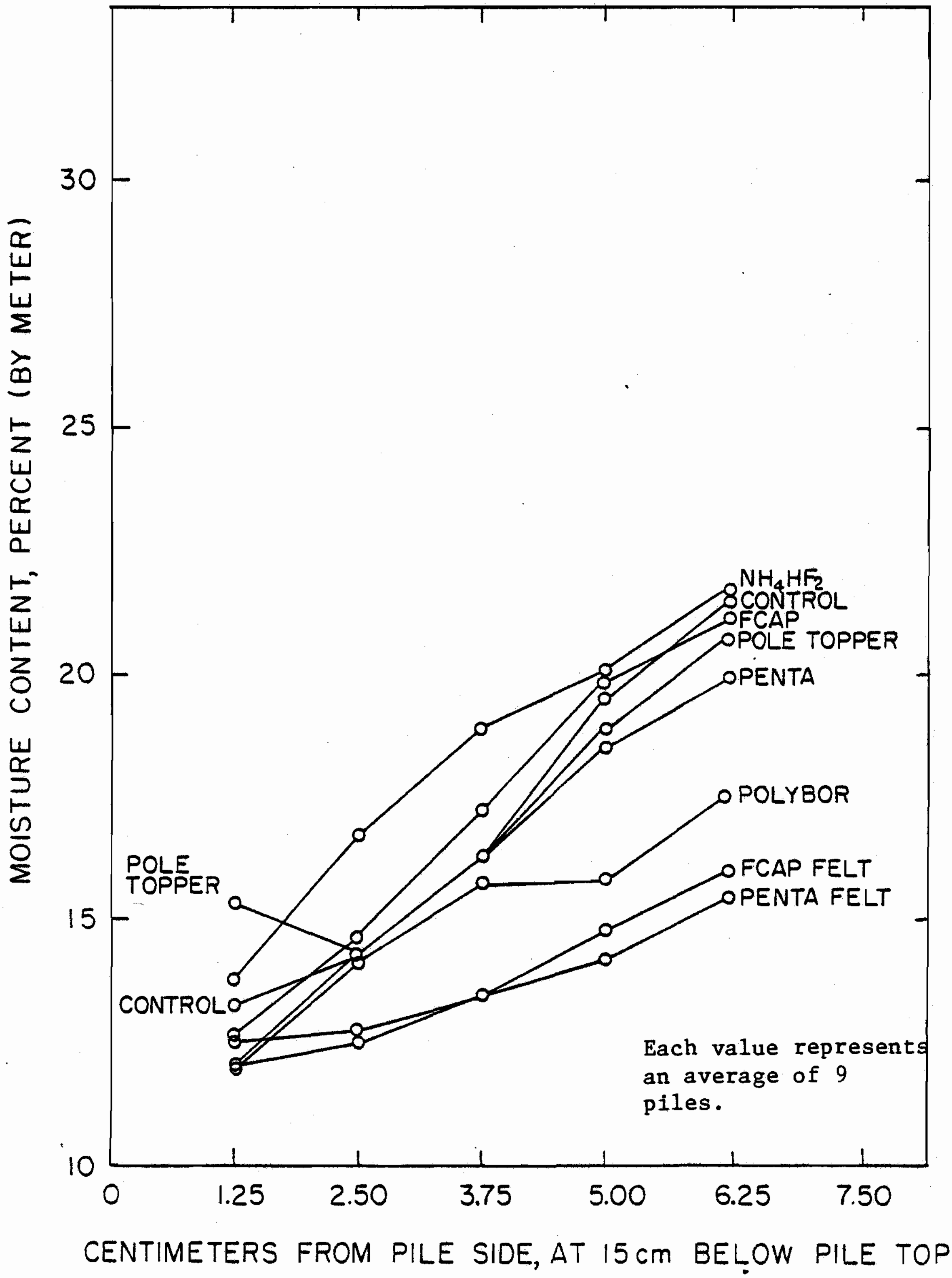

Figure 14. -- Moisture content of capped Douglas-fir pile tops after 2 years exposure.

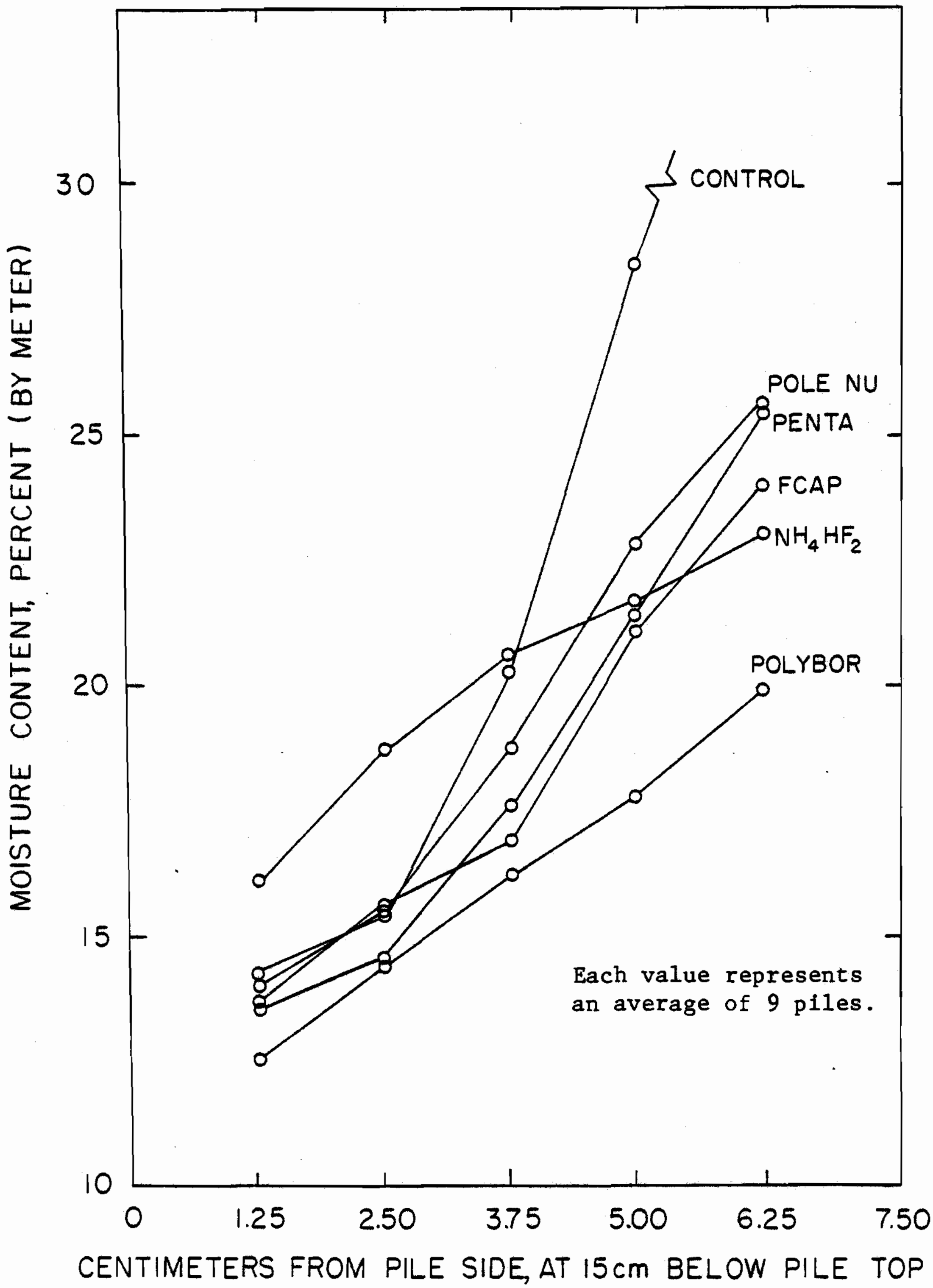

Figure 15.--Moisture content of uncapped Douglas-fir pile tops after 2 years exposure.

Discussion

The rapid invasion by decay fungi into unprotected cutoff pile tops emphasizes the need for the prompt application of effective methods of protection. Onsite application of oil-type preservatives without a cover may delay decay as little as 1 year. Apparently these chemicals do not protect the surfaces of numerous seasoning checks that continue to deepen in pile tops after supplemental treatment. To date, the waterborne preservatives, FCAP and NH_4HF_2, have proven successful without a cap for 5 years at Gulfport, Mississippi (21), and for 3 years at our test site. These waterborne preservatives must leach into cracks as they form and at the same time remain in cell walls near the surface of checks in the pile tops. The highly water soluble Polybor, which apparently is lost rapidly in areas of heavy rainfall, requires a protective cap.

Because the time required for pile tops to become infected by decay fungi is unknown, applying top protection soon after tops are cut off makes good sense. Further research is needed to determine how soon pile tops are infected and how critical is the timing of preservative application. Once decay fungi are established in pile tops it is unlikely that decay can be stopped with anything but fumigants (15, 20).

Sawcuts or drilled holes provide reservoirs that can contain two to three times as much preservative as tops without sawcuts. Sawcuts improved the protection afforded by Polybor- and penta-treated tops. Whether or not sawcuts will help increase the effectiveness of treatment with FCAP or NH_4HF_2 is still to be determined. A coal-tar cement cap improved effectiveness of Polybor and penta, however the coal-tar cement alone also provided protection. Pole Topper includes a bituminous pad, much like the coal-tar cap, which may explain the effectiveness of this product. A cap helps to prevent infection of the tops by airborne fungal spores and reduces rain wetting of the tops which keeps the wood moisture content too low for fungi to become established.

The type of protective covering needed over pile tops depends upon the exposure. Most marina pile tops are out of reach of hawsers, ropes, and vandals. Unexposed pile tops are well protected from wetting by the superstructure but are subject to wind-driven rain and water seepage from leaks and drains. FCAP and NH_4HF_2 promise improved protection of pile tops in all exposures, especially on piers where caps can be quickly damaged.

CONTROL OF INTERNAL DECAY IN PRESSURE-CREOSOTED PILES

Bulkhead Piles

Materials and Methods

In a bulkhead near Florence, Oregon all 36 pressure-creosoted piles cut off at a slant had advanced internal decay just below the sound-appearing top after 4 years in service. Five cores were removed from each pile at 0.3, 0.6, 0.9, 1.2 and 1.8 m below the tops and cultured on malt-agar medium for detection of decay fungi.

The piles were randomly divided into three groups for treatment with either Vapam, Vorlex, or chloropicrin, (500 ml per pile). The slanted tops were cut off horizontally. Four treating holes, 1.9 cm in diameter and about 50 cm long were drilled to accept fumigant. Three of the holes were drilled 0.2-0.3 m below the tops spaced about 50°'s apart on the landward side of the piles at a downward angle of about 50° to 60°. A fourth hole was drilled vertically down through the top about 8 to 10 cm from the seaward side of the piles.

The liquid fumigants were poured from 500 ml polyethylene squeeze bottles into the three side holes to within 7.5 cm of their tops. The remaining chemical was poured into the fourth hole. All holes were then plugged with 5 to 7.5 cm long penta-treated dowels.

A pile top cover of coal tar cement with fiberglass embedded was applied as described earlier. The cover was used to slow fumigant vapor loss, and to prevent re-infection of pile tops. No control piles without fumigant were included because the Port of Siuslaw could not risk the loss of its bulkhead. Also, the decay situation in Douglas-fir piles is similar to that in Douglas-fir poles for which similar research included controls (18). Poria carbonica and Poria placenta are the principal decay fungi in both products (16) and viable fungi can be cultured readily from them.

Increment cores for culturing and for testing in the closed-tube bioassay were removed annually for 5 years.

Results and Discussion

Prior to treatment, advanced decay was present for about 0.3 to 0.6 m below the sound appearing tops and decay fungi were found 1.8 to 2.4 m below the tops. All piles were heavily infested with 59 to 73% of the cores containing decay fungi prior to treatment with Vapam, Vorlex, or chloropicrin (Table 8).

Irregardless of chemical used, the population of decay fungi was reduced greatly within 1 year and no decay fungi were cultured at 2 years. At 5 years, seven piles (20%) contained decay fungi although the number of infested cores was only 5% (Table 8). The closed-tube bioassay showed that fungitoxic concentrations of fumigant vapors were present in all piles but less concentrated in piles treated with Vapam (Table 8).

The slight increase in decay fungi in the 4th and 5th years implies that fumigants may have a shorter effective life in exposed pressure-treated piles treated near the top than was previously estimated for transmission poles treated near the groundline (18). The close proximity of treating holes to end grain exposed at the top pile undoubtedly increases fumigant loss rate to the atmosphere even when tops are covered with coal-tar cement. This vapor loss was noticed 3 months after the fumigants were applied for the black coal-tar cement temporarily turned green or orange depending on the fumigant used.

Marina Piles

Materials and Methods

At Port of Bandon, Oregon, pressure-creosoted Douglas-fir piles had been driven in 1976 and 1977, the tops cut off, and the exposed end grain immediately brush-coated with creosote. Within 1 to 3 months, the port installed galvanized metal cone-shaped caps over the tops. One to 2 years later, we inspected 39 piles for decay by removing four increment cores, two each at 0.15 and 0.6 meters below the tops along two convenient sides of the piles. The treated portion of each core was discarded. All holes were flooded with creosote and plugged with 5 cm long treated plugs. Later we returned and removed additional cores at 0.6 m intervals from the top to the barnacle line from each pile that had at least one decay fungus in cores removed in the prior inspection. These cores were cultured as before to detect the presence of decay fungi. Moisture content measurements at 0.15 and 0.6 m below the pile top were made by meter prior to treatment.

Four groups of five piles each that contained decay fungi were selected for treatment with methylisothiocyanate (MS). Polyethylene bottles containing solid MS were heated in a hot water bath and 125, 250, or 500 mls of liquid MS per pile were poured into three holes drilled 3 m below the pile tops. One group of five piles was not treated.

To evaluate the treatment 1 year later, we removed and cultured six cores at 0.15, 0.3, and 0.9 m below the tops along the same two sides for decay fungi. Additional cores were removed at 0.3, 0.6, 1.2, 1.8, and 2.4 m below the tops for the closed tube-bioassay. The first 2.5 cm segment inside the treated shell and the last 2.5 cm (12.5 - 15.0 cm from the pile surface) were placed in tubes. All holes were flooded with creosote and plugged with 5 cm long creosote-treated plugs.

Results and Discussion

Twenty of 39 pressure-creosoted piles inspected contained 1 to 4 cores with decay fungi within the top 0.6 meter. No decay fungi were cultured from additional cores removed at 0.6 meter intervals down to the barnacle line.

Moisture content averaged between 25 and 33 percent at a 6.25 cm depth into the piles at 0.15 and 0.6 m below the tops.

One year following treatment, the incidence of decay fungi in the top 0.9 m of the piles was little affected by the fumigant (Table 9). The closed-tube bioassay indicated that in all 15 piles treated 3.0 m below the tops, fungitoxic quantities of MS vapor had moved upward 1.2 meters (Table 10).

The consistent movement of MS 1.2 meters upward is encouraging. Whether or not the chemical will continue its upward movement remains to be determined. Although the effect of quantity of chemical was insignificant at this time, larger quantities of MS may increase the duration of effectivenss.

The moisture data indicate that the cone-shaped caps are not preventing wetting of the pile tops although they do ward off seagulls and pelicans. Well designed and installed caps that shielded the tops from wetting would complement the fumigant treatment. If the decay fungi can be eliminated, piles could conceivably dry to below 20% moisture content and remain sound indefinitely without a preservative.

The movement of MS as well as changes in fungal population and moisture content in these piles will be followed annually for several years.

CONTROL OF EXTERNAL AND INTERNAL DECAY OF UNTREATED PILES

Marina Piles

Materials and Methods

Untreated marina piles in various stages of decay after 12 years in brackish waters free of marine borers near Florence, Oregon, were inspected and 18 piles worth saving were selected for treatment with fumigants. Pile height above the barnacle line ranged from 3.0 to 4.2 m. Vapam, Vorlex or chloropicrin (750 ml per pile) were applied in three holes drilled at both 0.9 and 2.1 m above the barnacle line. The six treatment holes were plugged, and the pile tops were left uncovered.

Before treatment and annually for 4 years, cores were removed starting at 0.3 m and then at 0.6 m intervals below the unprotected top. Each 15 cm long core was divided into 5 cm long segments, and cultured for the presence of decay fungi using one segment per petri dish.

Additional cores were removed 3.5 years after treatment at 0.3, 0.9, 1.8 and 3.0 m below the tops and the cores were divided into 3 segments from the pile surface, 0-2.5 cm, 6.25-8.75 cm, and 12.5-15.0 cm for the closed-tube bioassay.

Results and Discussion

Prior to treatment all 18 piles and 41% of the cores removed from them cultured decay fungi (Table 11). Decay fungi tended to be more concentrated in the interior of the piles than in the outer 5 cm (Table 12) and towards the tops of the piles (Tables 13, 14, and 15).

Decay fungi were eliminated in all but two piles, irregardless of treatment, within 2 years (Table 11). After 2 years decay fungi increased in all piles especially in Vapam treated piles. The increase in fungi could be progressing from the outer 5 cm into the piles but this may be a result of incomplete elimination of decay fungi from this zone and not from reinfection (Table 12). This is supported by the results of the closed-tube bioassay indicating markedly lower concentrations of fumigant vapors in the outer 2.5 cm than in the interior of piles treated with Vorlex or chloropicrin (Table 16). Fungitoxic vapors of Vapam appear to be present in lower concentrations than of Vorlex or chloropicrin. There does not appear to be a relationship between distance from pile top and increase in the incidence of decay fungi which could also suggest incomplete elimination of decay fungi (Tables 13, 14, and 15). Nevertheless, concentrations of fungitoxic vapors tended to decrease in the top 0.3 meter of piles (Table 16).

Fender Piles

Materials and Methods

Near Florence, Oregon, 14 untreated Douglas-fir fender piles driven 1 to 2 years earlier were inspected by removing cores from two sides alternating at 15 cm intervals from the sloped tops to about 2.5 m below the pile tops. Cores were divided into two sections, the outer 5 cm and the remainder of 15 cm long core. These were cultured for the presence of fungi using one core section per petri dish.

For fumigant treatments, four holes were drilled vertically down through the top, equally spaced, with one in each quadrant. Two additional holes were drilled in each side about 3 feet below the top. Piles were randomly assigned for treatment with Vapam or chloropicrin (1300 mls per pile) which was distributed equally among the holes. No cover was applied to the pile tops.

Annually for 2 years following treatment, cores were removed and cultured for decay fungi as described earlier. Cores were removed 1.5 years following treatment and they were divided into three segments, 0-2.5 cm, 6.25-8.75 cm, and 12.5-15.0 cm for closed-tube bioassay.

Results and Discussion

Prior to treatment 29% of the cores removed for culturing and all 14 piles contained decay fungi (Table 17). The decay fungi were most concentrated within the interior of piles (5-15 cm core segments) and within the top 0.9 meter of the pile tops (Table 18).

Although one-half of the fumigant-treated piles contained decay fungi 2 years after treatment (Table 17), the population of decay fungi was reduced markedly throughout the piles irregardless of treatment (Table 18). The closed-tube bioassay indicated the presence of higher concentrations of fumigants in the interior than in the outer 2.5 cm of the piles (Tables 17 and 19), except for chloropicrin near the tops of the piles (Table 19) where the treating holes were located.

These findings suggest that the serviceability of untreated piles can be increased by a durable wrap such as black polyethylene film that slows loss of fumigant vapors as suggested by Goodell (11) for southern pine timbers.

In addition, the treating method used needs to be evaluated. For example, the distributions and depth of treating holes could be located to apply more fumigant toward the surface and top of piles in addition to the treating holes found to be effective for internal treatment.

A combination treatment of fumigants applied internally, a water-soluble preservative onto the tops of piles, and perhaps a vapor barrier wrap around the pile to help retain the fumigant would be an effective treatment for untreated piles.

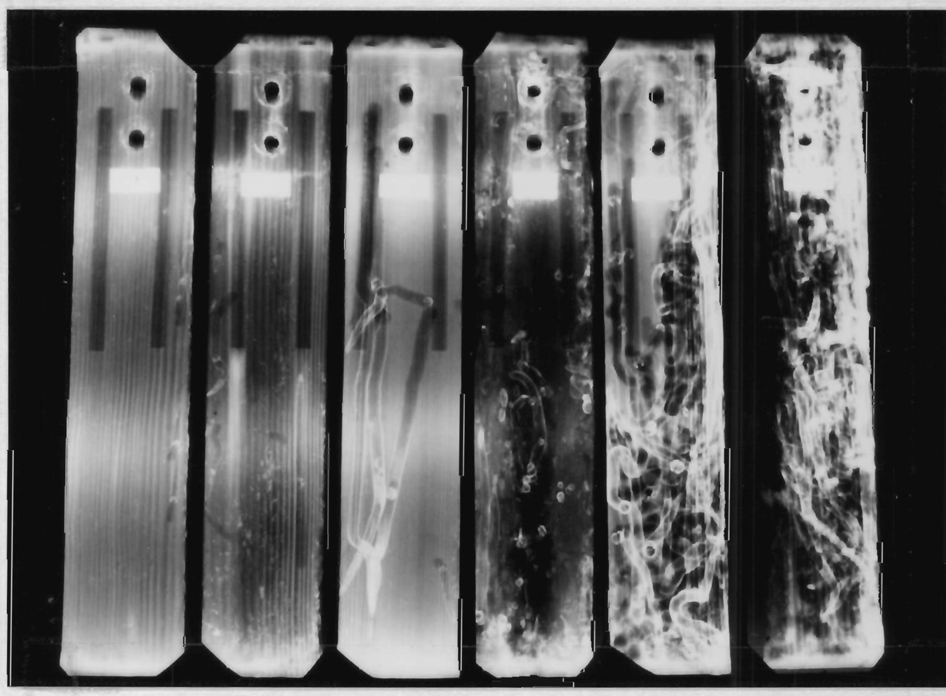

Figure 16. Shipworm attack ratings of 0 to 5 from left to right.

CONTROL OF MARINE BORER ATTACK ON DOUGLAS-FIR

Materials and Methods

In this exploratory study, test panels of green, rough-sawn Douglas-fir 5 by 10 cm were treated by placing 6 or 40 cc of Vapam, Vorlex, or chloropicrin in two 1.25 cm diameter holes drilled half the 46 cm length of the panels. Twenty-eight panels mounted on two metal bars were immersed in marine borer infested sea water at Newport, Oregon, San Francisco and Los Angeles, California. The panels were suspended at mean low tide attached to concrete weights by nylon rope. One set of panels was removed annually for 3 years and returned to the Forest Research Laboratory for evaluation.

Evaluation

X-ray prints were made of all panels to expose internal shipworm attack (Figure 16). Hardware cloth with 0.63 cm squares was laid over the prints and the number of squares with shipworm damage recorded.

To estimate damage by Limnoria, the hardware cloth was placed over the front and back wide faces of each panel and number of squares with attack was recorded.

Results and Discussion

San Francisco and Los Angeles panels were either destroyed by

Limnoria or missing after 2 years immersion. Although Newport panels were recovered after 3 years, one of the two racks of panels was buried in the sand and had to be retreived by a diver. The rack was in its proper position at the 2 year inspection. It is difficult to say how long the rack was buried and not subject to marine borer attack during the 3rd year.

Newport panels without chemical were the only ones with substantial shipworm attack after 2 and 3 years (Table 20). At Newport, panels with 40 cc's of Vorlex or chloropicrin exhibited exceptional control with shipworm attack ratings of 1 and 0. Control of attack with Vorlex is consistent with the 1st year's findings but not by chloropicrin (20% damage in 1st annual inspection). This is probably a result of few replications, presence of sapwood which has a very high moisture content, and excessive slope of grain (the latter two affecting movement of fumigant).

Attack by *Limnoria* proved again to be more difficult than shipworms to control with fumigants (Table 20). Panels with 40 cc's of Vorlex, however, displayed very good control, slowing greatly attack in San Francisco and Los Angeles (ratings of 2 and 1) and preventing attack at Newport (rating of 0).

Besides *Limnoria* attack being more severe at San Francisco and Los Angeles, *Limnoria tripunctata* is probably the predominant invading species whereas in Newport it is *Limnoria lignorum*. Because these two *Limnoria* species differ in their tolerance to creosote there is the possibility that they have different tolerances to fumigants.

Although these data are limited, further testing is warranted to evaluate the usefulness of fumigants, particularly Vorlex and its active ingredient, methylisothiocyanate, for preventing and stopping attack by marine wood borers.

CONCLUSIONS

In coastal waters of the Pacific Northwest pressure-creosoted Douglas-fir piles can provide over 40 years of service when properly installed.

Improper handling that scars or punctures piles and construction practices that leave unprotected cuts and holes in piles are major contributors to deterioration of pressure-creosoted piles by marine wood borers, decay fungi and insects.

Untreated Douglas-fir piles in waters free of marine wood borers may provide over 20 years of service if the pile tops are protected from the weather.

Effective yet simple in-place treatments are needed for cuts and holes in pressure-creosoted and untreated piles and timbers, especially pile tops. Similar treatments are needed for joining surfaces of untreated piles and timbers.

A better understanding of wood and its preservation is needed by those who design, use and maintain wooden waterfront structures.

Water-soluble fluoride preservatives applied to pile tops promise increased protection from decay where caps are likely to be damaged as compared to creosote or pentachlorophenol.

Internal decay of pressure-creosoted Douglas-fir piles can be controlled by the use of Vapam, Vorlex or chloropicrin. Vorlex and chloropicrin will be more persistent than Vapam and will have retreatment cycles, when old treatment holes are refilled, in excess of 5 years.

Internal decay of untreated Douglas-fir piles exposed to the weather can be controlled by fumigants but external and top decay will be difficult to control by fumigants alone.

Fumigants merit further study for control of marine wood borer attack, especially in Pacific Northwest coastal waters.

Table 1. -- Serviceability of untreated and pressure-creosoted Douglas-fir piles exposed to marine wood borers.

Tops protected by superstructure			Tops unprotected		
Coastal port	Years in service	Estimate of service life[1]	Coastal port	Years in service	Estimate of service life[1]
Untreated piles					
Coos Bay	--	7	Bandon	--	3-4
Coos Bay	--	5-8	Brookings	--	14
			Coos Bay	--	7
Pressure-creosoted piles					
Coos Bay	--	20-25	Coos Bay	22	22+
Seattle	62	62+	Coos Bay	--	15
Tillamook	27	27+	Coos Bay	--	20-25
Garibaldi	33	33+	Newport	45	45+

[1]Estimates made by port authorities or owners of structures.

Table 2. — Serviceability of untreated and pressure-creosoted Douglas-fir piles in waters free of marine wood borers.

Tops protected by superstructure			Tops unprotected		
Coastal port	Years in service	Estimate of service life[1]	Coastal port	Years in service	Estimate of service life[1]
Untreated piles					
Astoria	--	15	Florence	12	12+
Florence	20	20+	Mapleton	--	7
Pressure-creosoted piles					
Port Orford	20	20+			
Portland	22	2+			

[1]Estimates made by port authorities or owners of structures.

Table 3. — Incidence of decay in pressure-creosoted and untreated Douglas-fir piles along the Oregon coastline.

Location and structure	Years in service	Number of piles	Piles with decay fungi	Piles with advanced decay
Pressure-creosoted				
Bandon				
Marina	2	39	20	0
Brookings				
Marina	5-6	61	29	6
Florence				
Bulkhead	4	36	36	36
Marina	3	5	4	3
Bulkhead	11	16	10	10
Winchester				
Marina				
B dock	0.3	10	1	0
B, I dock	0.5	40	12	0
C, D dock	2	32	20	8
F dock	15	6	4	1
Total		245	136	64
Untreated				
Florence				
Marina	12	21	17	10
Fender	1-2	14	14	4
Marina	20	2	2	2
Bearing	20	12	0	6
Total		49	33	32

TABLE 4. — Moisture content of untreated and pressure-creosoted Douglas-fir marine piles in service.

Meters from barnacle line	Average moisture content of cores removed from piles at centimeters from surface[1]		
	Untreated piles		Pressure-creosoted piles
	0-5	5-15	5-15
1.8	39	29	—
1.2	53	29	—
0.6	56	33	22
0.0	80	33	26
-0.3	83	35	35
-0.6	72	32	35

[1]Each value is the average moisture content (oven dry basis) of cores removed from 3 to 10 piles in service from 10 to 40 years.

Table 5. — Condition of pressure-creosoted Douglas-fir piles exposed to Limnoria in Coos Bay, Oregon

Piles inspected	Years in service	Piles with bark	Piles with Limnoria attack: Surface	Piles with Limnoria attack: Internal[1]	Reinforced piles
Limnoria lignorum zone (lower bay)					
468	?	-	5	20	0
Limnoria tripunctata zone (upper bay)					
320[2]	50 - 55	-	153	32	35
68[2]	55	51	-	-	-
20	17	0	0	2	0
19[3]	15	0	0	0	0
26	10	0	0	2	-
26	7	0	0	1	-
41	3	0	0	0	-
452	3-55	51	153	37	35

[1]Internal attack was associated with oval holes made by pointed tools-36 piles, cross braces and bolts - 16 piles, or other surface breaks during handling - 5 piles.

[2]From same structures.

[3]Dolphin, fender and support piles were removed from service a few weeks prior to inspection. Support piles with roofing felt protection were free of top decay. Six of the remaining piles had top decay.

TABLE 6. — Decay in Douglas-fir piles 2 years after application of top protection[1]

Treatment	Capped piles infected: No sawcuts	Capped piles infected: Sawcuts	Uncapped piles infected: No sawcuts	Uncapped piles infected: Sawcuts
Brush flooded				
Fluor-chrome-arsenic-phenol	0	0	0	0
Ammonium bifluoride	0	0	0	0
Polybor	0	0	9	4
Pentachlorophenol	0	0	8	5
Impregnated felts				
Fluor-chrome-arsenic-phenol	1	--	--	--
Pentachlorophenol	3	--	--	--
Proprietary				
Pole Topper	0	--	--	--
Pole Nu	2	--	--	--
Controls	2	--	9	--

[1]Each value represents 9 piles. Three cores were removed 6 in. below each pile top and cultured for decay fungi.

TABLE 7. — Decay in Douglas-fir piles 3 years after application of top protection[1]

Treatment	Capped piles infected: No sawcuts	Capped piles infected: Sawcuts	Uncapped piles infected: No sawcuts	Uncapped piles infected: Sawcuts
Brush flooded				
Fluor-chrome-arsenic-phenol	0	0	0	0
Ammonium bifluoride	1	0	0	1
Polybor	0	0	9	8
Pentachlorophenol	1	0	9	5
Soaked felts				
Fluor-chrome-arsenic-phenol	1	--	--	--
Pentachlorophenol	3	--	--	--
Proprietary				
Pole Topper	0	--	--	--
Pole Nu	2	--	--	--
Controls	0	--	9	--

[1]Each value represents 9 piles. Three cores were removed 6 in. below each pile top and cultured for decay fungi.

Table 8. — Presence of decay fungi and fungitoxic vapors of fumigant in pressure-creosoted Douglas-fir bulkhead piles.

Treatment	Number of piles and % of cores with decay fungi at years since treatment[1] 0	1	2	3	4	5	Average growth (mm) of *Poria placenta* in closed-tube bioassay at meters below pile top[2] 0.3	0.9	1.8
Piles									
Vapam	12	1	0	0	1	3			
Vorlex	12	1	0	0	1	2			
Chloropicrin	12	2	0	0	0	2			
Total	36	4	0	0	2	7			
Cores									
Vapam	73	2	0	0	2	8	16	17	19
Vorlex	72	2	0	0	2	4	4	4	13
Chloropicrin	59	4	0	0	0	3	2	1	4
Average	68	3	0	0	1	5			

[1]Each value represents 12 piles or 54-60 cores.

[2]The assay was run 4.5 years following fumigant treatment on the first 2.5 cm of untreated wood within the treated shell and the last 2.5 cm of a 15 cm long increment core. Twelve control assay tubes without wood averaged 31 mm growth. Each value represents 18-24 core segments.

Table 9. -- Presence of decay fungi within the top 0.9 meter of pressure-creosoted Douglas-fir marina piles treated 3.0 meters below tops with methylisothiocyanate (MS) 1 year earlier.

Years since treatment	Percent of cores with decay fungi from piles with various quantities (mls) of MS			
	0	125	250	500
0[1]	40	30	60	40
1[2]	30	33	37	37

[1]Each value represents 20 cores from 5 piles.
[2]Each value represents 30 cores from 5 piles.

Table 10. — Presence of methylisothiocyanate (MS) vapor with respect to distance from pile top and quantity of chemical in pressure-creosoted Douglas-fir marina piles treated 1 year earlier.

Meters from top		Average growth (mm) of *Poria placenta* in the closed-tube bioassay at various quantities (mls) of MS applied[1]			
		0	125	250	500
0.3		19	18	16	21
0.6		17	16	18	20
1.2		14	14	16	11
1.8		16	2	2	1
2.4		15	1	1	1
3.0	Treating level				

[1]Each value represents 20 core segments from 5 piles.

Table 11. -- Presence of decay fungi and fungitoxic vapors of fumigant in untreated Douglas-fir marina piles following fumigant treatment.

Treatment	Number of piles and % of cores with decay fungi at years after treatment[1] 0	1	2	3	4	Average growth (mm) of *Poria placenta* in the closed-tube bioassay at centimeters from pile surface[2] 0-2.5	6.3-8.8	12.5-15
Piles								
Vapam	6	2	1	3	4			
Vorlex	6	3	1	3	2			
Chloropicrin	6	3	0	3	2			
Total	18	8	2	9	8			
Cores								
Vapam	32	5	8	8	16	23	20	19
Vorlex	37	5	1	3	8	17	7	6
Chloropicrin	55	3	0	7	4	12	4	3
Average	41	4	3	6	7			

[1]Each value represents 6 piles or 74-90 cores.

[2]Each value represents 24 core segments. Fifteen control assay tubes without wood averaged 28 mm growth.

Table 12. — Presence of decay fungi with respect to distance from pile surface in untreated Douglas-fir marina piles treated with fumigants.

Years since treatment	Percent of cores with decay fungi at centimeters from pile surface[1]								
	Vapam			Vorlex			Chloropicrin		
	0-5	5-10	10-15	0-5	5-10	10-15	0-5	5-10	10-15
0	17	22	20	9	19	32	14	38	43
1	1	5	4	5	5	5	1	2	1
2	8	4	1	1	0	0	0	0	0
3	1	3	4	3	3	4	3	7	0
4	13	5		5	3		3	1	

[1]Each value represents 54-82 core segments.

Table 13. -- Incidence of decay fungi with respect to distance from pile top within untreated Douglas-fir marina piles treated with Vapam.

Meters from top	Percent of cores with decay fungi at years since treatment[1]				
	0	1	2	3	4
0.3	7	3	3	0	3
0.6	6	1	3	3	4
1.2	8	1	1	3	1
1.8	6	0	1	1	6
2.4	4	0	0	0	1
3.0	3	0	0	1	0
All levels	34	5	8	8	15

[1]Each value represents 12 cores from 6 piles.

Table 14. — Incidence of decay fungi with respect to distance from pile top within untreated Douglas-fir marina piles treated with Vorlex.

Meters from top	Percent of cores with decay fungi at years since treatment[1]				
	0	1	2	3	4
0.3	7	1	1	9	3
0.6	8	3	0	1	0
1.2	13	0	0	0	0
1.8	7	0	0	0	1
2.4	4	0	0	1	3
3.0	1	1	0	3	1
All levels	40	6	1	6	8

[1]Each value represents 12 cores from 6 piles.

Table 15. — Incidence of decay fungi with respect to distance from pile top within untreated Douglas-fir marina piles treated with chloropicrin.

Meters from top	Percent of cores with decay fungi at years since treatment[1]				
	0	1	2	3	4
0.3	10	1	0	0	1
0.6	13	1	0	1	0
1.2	11	0	0	3	1
1.8	11	0	0	0	0
2.4	7	0	0	1	0
3.0	4	0	0	0	1
All levels	56	2	0	5	3

[1]Each value represents 12 cores from 6 piles.

Table 16. -- Presence of fungitoxic vapor of fumigant with respect to distance from pile surface and pile top in untreated Douglas-fir marina piles treated 4 years prior.

Meters from top	Average growth (mm) of *Poria placenta* in the closed-tube bioassay at centimeters from pile surface[2]								
	Vapam			Vorlex			Chloropicrin		
	0-2.5	6.25-8.75	12.5-15.0	0-2.5	6.25-8.75	12.5-15.0	0-2.5	6.25-8.75	12.5-15.0
0.3	25	27	26	23	20	17	14	10	7
0.9	17	21	20	10	5	5	12	5	1
1.8	26	20	16	10	1	1	10	1	1
3.0	24	13	14	23	1	1	10	1	1
Average	23	20	19	17	7	6	12	4	3

[1]Inoculum growth in 15 closed tubes without wood averaged 28 mm.
Each value represents 6 core segments.

Table 17. — Presence of decay fungi and fungitoxic vapors of fumigant in untreated Douglas-fir fender piles treated with fumigants.

Treatment	Number of piles and % of cores with decay fungi at years since treatment[1]			Average growth (mm) of *Poria placenta* in the closed-tube bioassay at centimeters from pile surface[2]		
	0	1	2	0-2.5	6.25-8.75	12.5-15.0
Piles						
Vapam	7	4	5			
Chloropicrin	7	5	2			
Total	14	9	7			
Cores						
Vapam	36	9	4	24	14	3
Chloropicrin	21	4	3	21	7	1
Average	29	7	4			

[1]Each value represents 7 piles or 113-118 cores.

[2]Each value represents 19-21 core segments.
Fifteen control assay tubes without wood averaged 28 mm growth.

Table 18. -- Presence of decay fungi by distance from surface of untreated Douglas-fir fender piles treated with fumigants.

Treatment	Meters below pile top	Number of core segments with decay fungi by years since treatment at centimeters from pile surface[1]					
		0 yr.		1 yr.		2 yrs.	
		0-5	5-15	0-5	5-15	0-5	5-15
Vapam	0.15-0.9	8	18	4	3	1	0
	1.05-1.8	4	12	1	2	0	0
	1.95-2.55	4	9	4	5	3	0
	0.15-2.55	16	39	9	10	4	0
Chloropicrin	0.15-0.9	4	19	3	1	2	1
	1.05-1.8	3	5	0	1	0	0
	1.95-2.55	0	0	0	1	0	0
	0.15-2.55	7	24	3	3	2	1

[1]Each value represents 34-42 core segments.

Table 19. -- Presence of fungitoxic vapor of fumigant within untreated Douglas-fir fender piles 1.5 years after fumigant application.

Treatment	Meters below pile top	Average growth (mm) of *Poria placenta* in the closed-tube bioassay at centimeters from pile surface[1]		
		0-2.5	6.75-8.75	12.5-15.0
Vapam	0.3	25	14	3
	0.9	22	6	1
	1.8	25	18	4
Chloropicrin	0.3	0	4	0
	0.9	19	1	1
	1.8	22	8	1

[1]Each value represents 7 core segments from 7 piles. Inoculum growth in 15 closed tubes without wood inserted averaged 28 mm.

Table 20. — Marine wood borer attack of 2- by 4- by 18-inch long green Douglas-fir panels treated internally with fumigants and immersed in the sea for 2 or 3 years[1].

Fumigant	Quanitity (ml)	Limnoria attack rating by site and years of exposure: Newport 3 years	San Francisco 2 years	Los Angeles 2 years	Shipworm attack rating by site and years of exposure: Newport 3 years	San Francisco 2 years	Los Angeles 2 years
Vorlex	40	0	2	1	1	0	0
	6	1	5	5	4	0	3
Vapam	40	2	5	5	3	0	0
	6	--	5	5	--	0	0
Chloropicrin	40	3	5	4	0	0	0
	6	3	5	4	2	0	0
None	0	3	5	5	5	1	3

[1]San Francisco and Los Angeles values represents the attack rating of one panel. Each Newport value represents ratings on two panels except the control (none) which is one panel. Panels were rated for marine wood borer damage as follows:

Rating	Damage, percent	Description of damage
0	0 - 5	little or none
1	6 - 10	light
2	11 - 20	light to moderate
3	21 - 40	moderate to heavy
4	41 - 60	heavy
5	61 -100	severely damaged

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APPENDIX

Table 21. -- List of experimental chemicals

Chemical	Text name	Proprietary name	EPA registration no.	Active ingredients
Volatile fungicides				
Vapam	Vapam	Vapam[1], WoodFume[2]	[1]476-2094 [2]3008-33	33% sodium N-methyl dithiocarbamate
Vorlex	Vorlex	Vorlex	None for use in wood	20% methylisothiocyanate 80% chlorinated hydrocarbons.
Methylisothiocyanate	MS	Methylisothiocyanate	None for use in wood	95% methylisothiocyanate
Chloropicrin	Chloropicrin	PICFUME[1], TimberFume[2]	[1]21327-4 [2]3008-39	99% trichloronitromethane
Water-soluble preservatives				
Ammonium bifluoride	NH_4HF_2	Ammonium bifluoride	None for use in wood	96% ammonium bifluoride
Disodium octaborate tetrahydrate	Polybor	Polybor	None	15% sodium oxide 67% boric oxide
Fluor-chrome-arsenic-phenol	FCAP	OSMOSALTS	3008-7	34% sodium bichromate 29% sodium fluoride 23% disodium arsenate
			3008-7	8% 2, 4-dintrophenol
Oil-soluble preservative				
Pentachlorophenol	Penta	Penta-Plus 40	1022-120	10% pentachlorophenol
Proprietary Products				
Pole Nu	Pole Nu	Pole Nu	1022-46	10% pentachlorophenol
Pole Topper	Pole Topper	Pole Topper	3008-19	10% pentachlorophenol