# RECENT RESEARCH IN MARINE WOOD PROTECTION

by

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## INTRODUCTION

The battle to protect wood from attack by marine borers and decay fungi has been a long, and not always successful, campaign. Before the time of Christ, shipbuilders had already realized the importance of using durable heartwoods and the need to keep wood dry, and they had attempted to preserve wood by brushing on various extracts and chemicals (1). Even this rudimentary knowledge was lost during the Dark Ages, and real progress was not made again until the 18th and 19th centuries. A resurgence then was due in part to the deterioration of piling in the dikes that protected Holland from the sea and to the prevalence of dry rot in England's "Men of War," which threatened that nation's ocean supremacy. Notable achievements in the 18th and 19th centuries were the development of the germ theory by Pasteur; the improvement of the microscope that permitted Hartig to correctly associate hyphae, fruiting bodies, and wood decay; and the development of pressure methods for preservative treatment by John Bethel. The latter process and the emergence of creosote (a by-product of the destructive distillation of coal) as a wood preservative, became the foundation of the present-day wood-treating industry.

In this century, the establishment of many forest products laboratories has created an information explosion on proper wood design and protection. Application of current knowledge alone could significantly reduce losses to the various agents of deterioration. Unfortunately, much of the knowledge has failed to reach many of those who design, construct, and maintain wooden structures.

Such information is especially critical if wood structures in extreme environemts, such as those encountered in marine exposures, are to have maximum service life. This report concerns the problems associated with marine piling along the West Coast of the United States - specifically those associated with Douglas-fir piling in Oregon - and the means by which we are attempting to minimize or solve these problems. Many of the problems are not new, nor are they likely to change in the near future.

Owing to its availability in large sizes and to its easy workability and superior strength properties, Douglas-fir is the principle timber used for preservative-treated marine piling on the West Coast (2). Although it has numerous advantages, Douglas-fir is only moderately decay resistant and requires preservative treatment at high pressure and temperature (3). Proper preparation before treatment, by air-seasoning, kiln-drying, or Boultonizing, can produce a well-treated sapwood shell surrounding the nondurable heartwood (4) and can enhance preservative penetration. But seasoning the entire pile to in-service moisture levels before preservative treatment is not economically feasible. For this reason, poles and piles are usually treated at higher moisture levels and are seasoned in service. As the wood dries, large checks frequently develop, effectively compromising the treatment zone and permitting entry of moisture and decay organisms into the untreated wood. Kerfing can prevent later development of large seasoning checks, and through-boring may allow heavier treatment of specific zones of the wood, thus decreasing internal decay of newly treated poles (4). But there is still a critical need to protect Douglas-fir already in service.

## AGENTS OF DECAY

Above the waterline, fungi commonly associated with internal decay of Douglas-fir include *Poria carbonica* and *Poria placenta*, as well as a number of other basidiomycetes (5, 6). Although internal decay is perhaps the greatest danger, insects such as the golden buprestid (*Buprestis aurulenta*), termites, carpenter ants, and the wharf borer (*Nacerdes melanura*) may also cause much damage under certain conditions (7).

High moisture levels limit the development of deep checks near the surface of submerged wood and protect submerged wood from conventional decay fungi, but a number of non-basidiomycetes can soften it (8, 9) and may aid the entry of marine borers (10). The organisms that bore into and utilize wood in marine environments can be divided into three groups, each differing in the manner in which they attack the wood.

Pholads are clam-like molluscs that normally burrow into rock but will also attack available wood, forming pear-shaped cavities near the wood surface. Pholads are not important along the Oregon coast, but do become a problem in more tropical waters (11).

Shipworms are elongated, worm-like mollusks with a pair of clam-like shells, near the top of the head, that are used for rasping away wood to expand the burrow. Because they leave only small surface holes as evidence of their presence, shipworms are the most difficult of the marine borers to detect. Through the holes, the shipworms expose a pair of siphons that exchange oxygen and dispose of waste products into surrounding waters. Although an observant diver can detect their presence, shipworm infestations are more frequently discovered after a heavily attacked structure collapses.

A third group of marine borers, the Limnoria, are small, mobile crustaceans that attack the wood surface, particularly in the tidal zone. Because of poor water ciculation in their burrows, *Limnoria*, also called gribbles, generally bore only a short distance into the wood and appear to use it for both protection and food (12).

Continuous wave action within the tidal zone can wear away weakened wood surrounding the burrows, forcing the gribbles to bore deeper into sound wood. Long-term exposure to *Limnoria* attack produces pilings with an hour-glass appearance about the tidal zone.

Our knowledge of the biology of marine borers is limited. Thus, one area of interest at Oregon State University is the biology of *Limnoria tripunctata*. This species is capable of attacking creosote-treated wood from San Francisco Bay southward and is distributed as far north as the Puget Sound (13). Work underway by J.J. Gonor has so far shown little physiological difference between populations from northern and southern bays along the West Coast, thus the difference in attack pattern by this species may be related to environmental variation. Previous work has suggested that attack of creosote-treated wood is preceeded by bacterial modification of the creosote (14, 15). If this hypothesis is correct, detailed investigation of Oregon and California coastal waters should indicate variations in microbial flora. Although it is still not clear whether the northern populations of *L. tripunctata* are natural or introduced, their presence provides a unique natural laboratory for studying their biology, and the studies may help to develop more effective preservative systems based upon the nature of creosote resistance to these organisms.

Owing to the insidious nature of most damage associated with marine borers and decay fungi, precise figures on the economic impact of these agents remain unavailable. However, the annual cost of all wood damage in marine environments in the United States has been estimated to be more than $500 million (16). Although this is an imposing figure, more spectacular short-term losses highlight the importance of proper treatment and design of wood used in marine environments. The often cited loss of $25 million from marine borer damage between 1917 and 1921 in San Francisco Bay, California (17) clearly illustrates the economic consequence of failing to use properly treated materials where marine-borer hazard exists.

## LIMITATIONS OF TREATMENTS

Even properly treated materials are vulnerable to deterioration, and all current treatments have certain limitations. Where both *L. tripunctata* and pholads are present, exposed wood must be treated with a waterborne inorganic salt before conventional creosote treatment. In the absence of pholad attack, piling can be treated to high retention with a waterborne inorganic salt (18).

Damage or construction practices that expose the untreated wood beyond the treated shell will permit borer attack. Common practices that result in damage are handling piles with pointed tongs, dumping rip-rap around piles, and cutting cross-bracing below the water line. Untreated wood is also exposed by chafing of treated wood against other wood or metal. Chafing can become serious in areas with excessive wave action or heavy tidal flows. Although the larvae of most marine borers are unable to colonize preservative-treated wood, untreated wood attached to treated piling may become infested; and when the adults are established, they can move through the treated shell of the attached wood and colonize it.

All remedial treatments that have been recommended to prevent internal decay and limit marine borer attack of exposed, untreated Douglas-fir piling (18) must be applied shortly after exposure in order to be effective. Another drawback common to most recommended treatments is their inability to penetrate and protect the wood beyond the surface. This becomes critical in cut-off pile tops or cross-bracing and in oversized bolt holes, where untreated heartwood is exposed to moisture and decay fungi above the water and to marine borers below.

Delay in application of remedial treatments and capping devices can allow entrance of decay fungi or marine borers that then grow beyond the penetration depth of any subsequent treatments. There is a critical need for the development of remedial treatments that effectively protect the wood a long distance from the source of application, as well as for the design of easily applied capping devices that keep the wood dry. Generally, wood kept below 20% moisture content will not decay. Many products are available to keep out moisture, but few effective remedial chemicals have been identified.

## PROTECTION ABOVE THE WATERLINE

Research underway at the Forest Research Laboratory in cooperation with J.J. Gonor from the School of Oceanography at Oregon State University has identified several promising procedures for controlling internal decay of Douglas-fir piling and some remedial chemicals that may prevent and eliminate marine borer attack of exposed, untreated wood. Some of the more promising treatments are volatile fungicides called fumigants. Those tested to date include chloropicrin, Vapam, Vorlex, and methylisothiocyanate (MIT).
These chemicals are applied in solid or liquid form and subsequently diffuse through the wood in gaseous form as far as 8 feet from the application point.

Fumigants have effectively controlled internal decay for 14 years in Douglas-fir electrical transmission poles (Figure 1).

Virtually no decay fungi were present in cores removed from the Vorlex- and chloropicrin-treated test poles. The level of Vorlex, as measured by the closed-tube bioassay (19), remained at effective levels for approximately 8 years, and chloropicrin levels have remained effective for 13 years (Table 1). Although the Vapam-treated poles rapidly lost their fungitoxic properties, and the percentage of decay fungi isolated had slightly increased 5 years after treatment, the level of infestation has remained constant since that time. From these results, fumigant retreatment cycles of 15 years for chloropicrin or Vorlex and 8 to 10 years for Vapam appear feasible. While decay fungi have been inhibited by fumigant treatment, it is interesting to note that non-decay fungi, which were initially reduced in the poles, have rebounded to fairly high levels (Figure 1). Since many non-decay fungi have been implicated in preservative detoxification, they may be adversely affecting fumigant effectiveness.

Recently, we have evaluated solid methylisothiocyanate (MIT), the active ingredient in Vapam and Vorlex, as replacement for these chemicals. Although it has only been under test for a short while (Figure 2), the 100% MIT treatment appears as effective as treatment with Vorlex. We have also explored encapsulating potential fumigants, including MIT, for safer handling. To date, common gelatin has proven to be the best encapsulating agent. Encapsulating will increase the handling safety, reduce the risk of environmental contamination, and permit the use of these chemicals above ground.

Because internal decay above the waterline, typical of Douglas-fir piling, differs little from that of land-based transmission poles, the potential of fumigants to control internal decay of Douglas-fir piling was investigated at a marina in Florence, Oregon. The 4-year-old piles were found to have well-developed internal decay below the sound-appearing pile tops, which were cut off at an angle, presumably to shed water. The tops were removed and 0.5 liter of either chloropicrin, Vapam, or Vorlex was added to four holes 1 m below the exposed top, which was then sealed with a cap of coal-tar cement and fiberglass mesh. The treatments have been monitored annually by removing increment cores for closed-tube bioassays of residual fumigant levels and by culturing for the presence of decay fungi. All fumigant treatments resulted in a sharp decline in the population of decay fungi after 1 year (Figure 3). Vapam-treated piles showed a slight influx of decay fungi at 5 years; however, this infestation has remained at a constant, low level. The results have continued to parallel closely those achieved with land-based poles, and they suggest that fumigants may be a viable alternative to less effective remedial treatments.

Several other chemical treatments warranting further investigation are being evaluated at a pile top farm near Corvallis, Oregon, and at several sites along the Oregon Coast. They are 10% pentachlorophenol in diesel oil, ammonium bifluoride (ABF), Polybor (disodium octaborate tetra hydrate), and Fluor-Chrome-Arsenic-Phenol (FCAP). The performances of pentachlorophenol or FCAP impregnated felts, Pole Topper, and Pole-Nu were compared with that of a capping device of coaltar cement-fiberglass mesh. Detailed results of these tests were summarized 2 years after treatment (20), and the 6-year evaluations will be published shortly. None of the chemical treatments completely eliminated non-decay fungi. The effect of these fungi on wood properties remains unclear. After 6 years, FCAP and ABF have proven to be the most effective chemical treatments, even when applied without caps. Piles receiving Polybor and pentachlorophenol treatments have been heavily colonized by decay fungi.

An effective capping device significantly reduced the risk of internal decay. The coaltar cement-fiberglass mesh was more effective in preventing entrance of decay fungi than several of the chemical treatments. FCAP-impregnated felt and Pole Topper caps also effectively limited entry, while Pole-Nu failed to fully protect the tops, perhaps because surface cracks permitted entry of moisture and fungi into untreated wood below. The results clearly illustrate that prompt and effective capping is important.

In conjunction with the pile-top farm, pile tops on working piers along the Oregon coast were treated with various combinations of caps and chemicals, including bags of ABF, FCAP paste, and fumigants. The most easily applied of the chemicals, ABF, was placed in bags nailed to the pile top. It then diffused into the wood as the bag was wetted, releasing toxic hydrogen fluoride gas. Results to date have been similar to those found in the pile-top farm, and again illustrate the importance of prompt, effective capping techniques (Figure 4).

Because capping devices on working docks are frequently damaged or vandalized, application of water-soluble chemicals such as ABF or FCAP at the time of capping is advantageous, protecting the pile top when a damaged cap must wait repair. Where decay has already begun, the application of a fumigant and a tight-fitting cap is advisable to ensure rapid and complete control of decay fungi. While fumigant treatments should never replace proper water-shedding caps and careful construction practices, they provide supplemental treatment of pile caps damaged during use.

## PROTECTING WOOD BELOW THE WATERLINE

Protecting exposed wood below the waterline requires more complex and difficult applications. Protective treatments may be preservatives brushed on exposed surfaces, and barriers such as concrete, polyvinyl chloride (PVC) wraps, and metal capping devices (21). Barriers have the dual function of killing established borers by limiting available oxygen and of preventing new entry of borers into the wood. Properly applied, they can ;be effective deterrents and have been used with great success (22). Although concrete has the added benefit of strengthening the pile and has been used extensively, PVC wraps appear to give the user more flexibility (23). For both these barriers to be effective, however, they must remain intact. Any damage that exposes the wood beneath to marine borer attack will render the barrier useless.

Brushed-on remedial treatments, although recommended, generally do not offer sufficient protection because of lack of penetration and because such treatments are easily compromised. There is a critical need for effective remedial treatments for exposed, untreated Douglas-fir wood submerged in marine environments. Fumigants appear to be ideal candidates, as they can be encapsulated for ease of handling, can diffuse as far as 8 feet from the application point, and can remain effective for long periods of time (24).

Preliminary tests have been run with several promising fumigants previously tested above ground. Small, green, Douglas-fir test panels (2 x 4 x 36 inches) were treated with 6 or 40 ml of Vapam, Vorlex, or chloropicrin applied to two holes drilled 9 inches into the upper end of each test panel. The test panels, exposed at sites along the Oregon and California coasts, were removed annually for assessment. Internal shipworm damage was assessed by X-ray, and Limnoria damage in southern waters was assessed by placing a mesh screen over the surface and counting the number of damaged squares. In preliminary results, several fumigants show promise against shipworm attack. Preventing Limnoria attack is proving to be more difficult; only Vorlex has limited surface damage by these organisms.

In tests of untreated panels--which were similarly exposed until shipworms became established and then treated with 40 ml MIT, Vorlex, or chloropicrin--shipworm infestation, monitored by X-ray of the wood, was significantly reduced 1 year after Vorlex or MIT treatment. Chloropicrin failed to inhibit or reduce infestation. The reasons for this failure remain unclear, although reduced chloropicrin movement through the moist wood may have limited its effectiveness (25).

The success of Vorlex and MIT suggests that they could be effective remedial treatments for piling damaged during construction or general use. Such treatments could be applied after conventional preservative treatment and before pile driving. As the fumigant level in the pile declined over time, a diver could re-treat the piles by removing the old treating plugs and adding more encapsulated fumigant. This system could significantly increase pile service life by limiting attack by decay fungi above the waterline and marine borer attack below. As preliminary tests have been run on green, untreated Douglas-fir, the effectiveness of the treatments on seasoned wood treated with preservatives remains unknown. We intend to evaluate the potential of these treatments on larger, preservative-treated Douglas-fir piling.

Although we may never fully eliminate the cost of damage caused by marine borers and decay fungi, implementation of the ideas presented here, along with other work currently underway at a number of institutions, could significantly reduce the annual losses to these agents of deterioration. No amount of chemical treatment, however, can completely overcome poor design and improper construction. Thus, while we encourage the use of effective remedial treatments by those who construct and maintain wooden structures, we should also ensure that those who specify wood in these structures fully understand its properties and employ the best combination of proper design, construction, and maintenance.

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## Table 1

Residual fumigant vapors in Douglas-fir poles 5, 10, and 14 years after treatment, as indicated by growth of the wood-decay fungus <u>Poria placenta</u> in a closed-tube bioassay.[1]

| Treatment | Height (meters) | Growth of assay fungus (%)[2] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2.5-5 cm deep | | | 7.5-10 cm deep | | | 12.5-15 cm deep | | |
| | | 5 yr | 10 yr | 14 yr | 5 yr | 10 yr | 14 yr | 5 yr | 10 yr | 14 yr |
| Vapam | 2.4 | 39 | 36 | 59 | 62 | 56 | 90 | 62 | 64 | 90 |
| | 1.8 | 54 | 44 | 45 | 69 | 52 | 83 | 69 | 64 | 83 |
| | 1.2 | 54 | 28 | 59 | 54 | 56 | 79 | 62 | 60 | 72 |
| | 0 | 54 | 40 | 66 | 69 | 56 | 86 | 54 | 56 | 100 |
| Vorlex | 2.4 | 39 | 28 | 55 | 62 | 44 | 79 | 54 | 40 | 86 |
| | 1.8 | 23 | 20 | 38 | 8 | 24 | 69 | 15 | 32 | 72 |
| | 1.2 | 23 | 8 | 52 | 15 | 20 | 66 | 8 | 24 | 59 |
| | 0 | -[3] | 24 | 41 | 23 | 44 | 69 | 23 | 48 | 48 |
| Chloropicrin | 2.4 | 31 | 0 | 14 | 31 | 2 | 0 | 8 | - | 0 |
| | 1.8 | 15 | - | 0 | 8 | 0 | 0 | 0 | 0 | 7 |
| | 1.2 | 0 | 2 | 35 | 0 | 0 | 24 | - | 0 | 20 |
| | 0 | - | 0 | 38 | 0 | 0 | 79 | 0 | 16 | 48 |
| Control | 2.4 | na[4] | 40 | 83 | na | 84 | 72 | na | 84 | 62 |
| | 1.8 | na | 32 | 62 | na | 88 | 100 | na | 72 | 93 |
| | 1.2 | na | 24 | 79 | na | 68 | 72 | na | 88 | 97 |
| | 0 | na | 32 | 52 | na | 36 | 100 | na | 96 | 83 |

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[1] A 2.5-cm-long core segment was placed in the mouth of an inverted test tube containing a transplant of <u>P. placenta</u> on a small agar slant. The tube was closed and incubated for 2 weeks at room temperature before measuring the growth of the assay fungus.

[2] Growth in tubes with core segments expressed as a percentage of growth in an agar slant containing the test fungus but no wood. Average growth for these slants was 13 mm in 1974, 25 mm in 1979, and 29 mm in 1983. The data from 1974 represent three cores from each position on seven poles from the Vapam and Vorlex treatments and on six poles from the chloropicrin treatment. Data from 1979 and 1983 represents results from thirteen Vapam poles, seven Vorlex poles, six chloropicrin poles, and three control poles.

[3] Average growth less than 1 mm.

[4] Data not available.

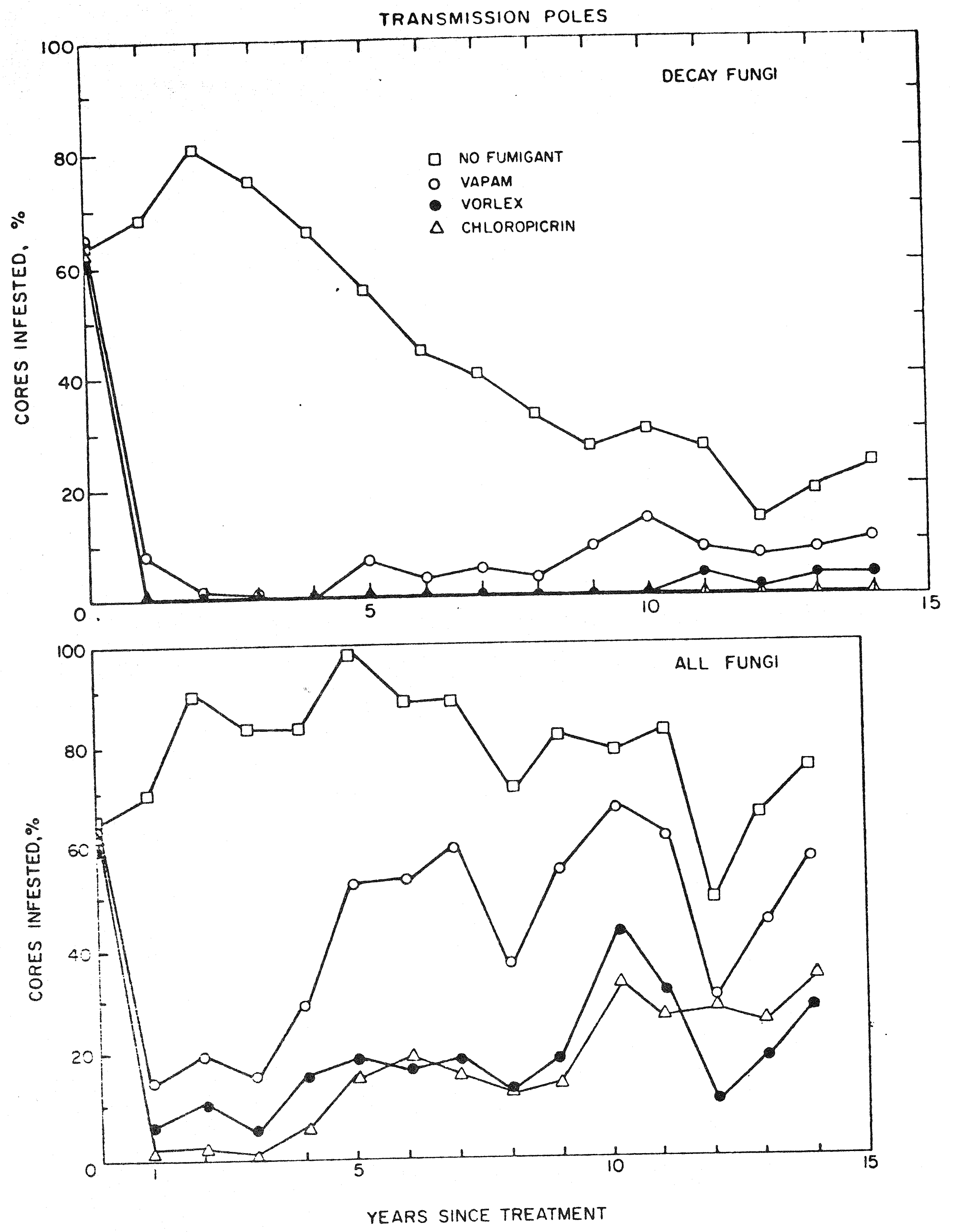

Figure 1. Populations of decay fungi and of all fungi isolated from internally decaying pressure-treated Douglas-fir poles treated with Vapam, Vorlex, chloropicrin, or left untreated. Each value is the average of 12 cores removed annually from various heights above and below the ground line.

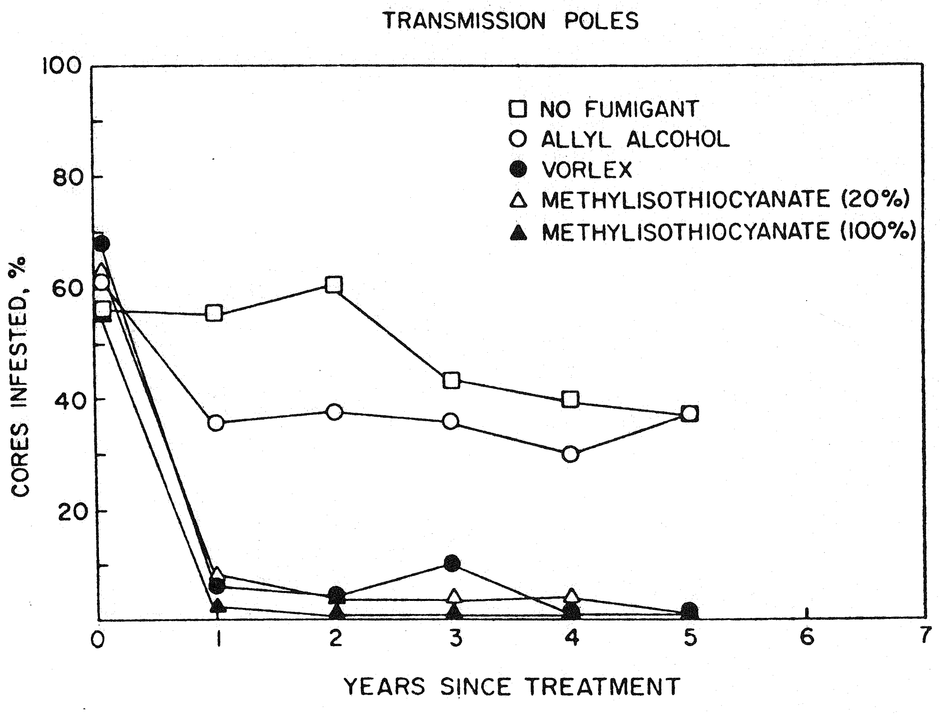

Figure 2. Populations of decay fungi isolated from internally decaying pressure-treated Douglas-fir poles treated with allyl alcohol, Vorlex, methylisothiocyanate (20% or 100% in diesel oil), or left untreated. Each value is the average of 15 cores removed at sites -0.3 to 2.4 m from the ground line.

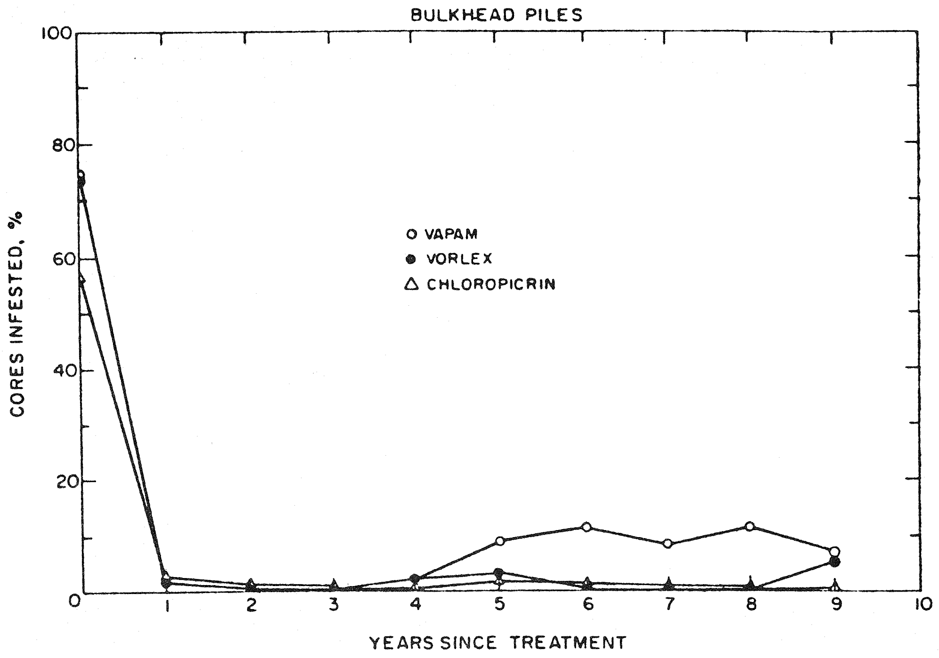

Figure 3. Populations of decay fungi isolated from pressure-creosoted Douglas-fir piles treated with Vapam, Vorlex, or chloropicrin. Each value represents the average of 60 cores from 12 piles.

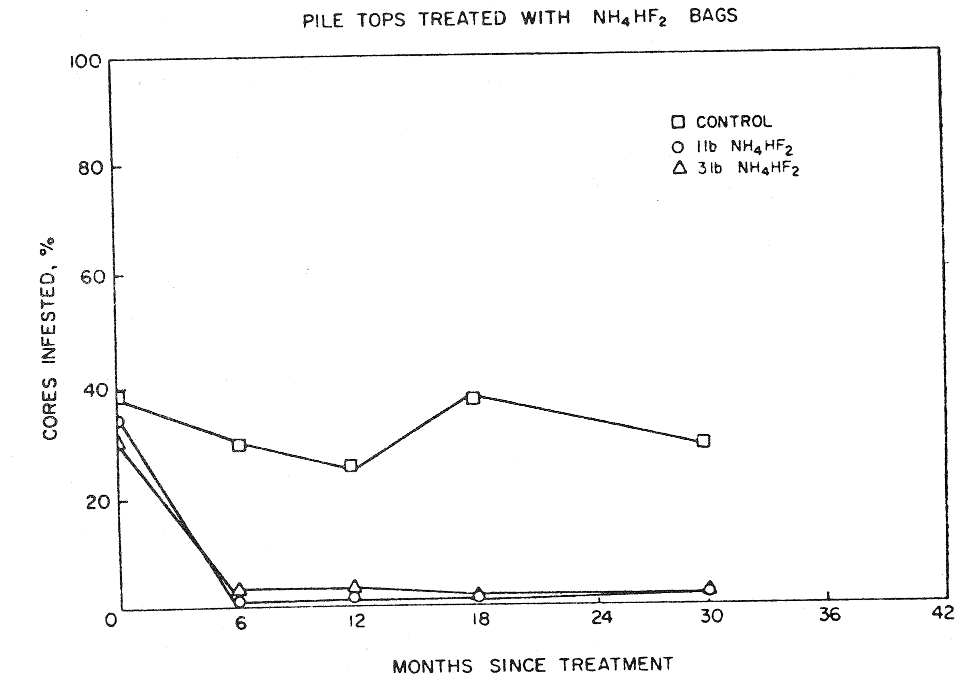

Figure 4. Populations of decay fungi isolated from cores removed from creosote-treated Douglas-fir marine piling treated with 1 lb or 3 lb semi-permeable bags of ammonium bifluoride nailed to the top of each pile.