Comprehensive Overview of FPL Field Testing Conducted in the Tropics (1945-2005)

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ABSTRACT

Tropical exposure often represents a more severe environment for treated wood and wood based products. Accelerated tropical decay rates are typically attributed to higher mean rainfall and temperatures. The Forest Products Laboratory (FPL) in Madison, WI has been conducting tropical field tests in a variety of locations since the early 1940's. This paper summarizes FPL tests conducted in the tropics from 1945-2005 and discusses some of the difficulties in assessing tropical field data. Where appropriate, test results from tropical sites are contrasted with field data from temperate and sub-tropical exposure in the continental United States.

Keywords: tropical field testing, wood decay fungi, termite damage, above ground decay, below ground decay, Scheffer index.

INTRODUCTION

The AWPA Use Category System is the current metric for setting above and below ground retentions and is largely based on historical performance of past and present preservative systems in the continental U.S. and Hawaii. Accelerated field testing is a common way to shorten the time needed for evaluation of a preservative system by exposing test materials to extreme climatic conditions and can give useful data on biological resistance of candidate treatment systems. The contiguous US is mostly temperate to sub-tropical in the southeast, but regions southward (i.e., the tropics) receive much higher rainfall and experience higher mean temperature thus lengthening the period for conditions conducive to decay and insect damage. Tropical testing has been conducted by researchers at the FPL since before World War II and continued up until 2005. The following is a summary of field tests conducted in various locales throughout the tropics and highlights the performance of past and current preservative systems under such exposure.

Post tests in Puerto Rico (Chudnoff and Goytia 1972)

From 1944-1972, FPL initiated a series of tests to evaluate low-investment, non-pressure preservation techniques to provide best use principles for local farmers on utilization of locally available wood species and currently available non-pressure techniques. Preservatives included pentachlorophenol, creosote, carbolineum and two double diffusion salts (sodium fluoride/copper sulfate and copper sulfate/sodium chromate, sodium arsenate). These treatments were used in cold soak, double dip, hot/cold bath and double diffusion methods. The early demonstration test plots contained only specimens treated using hot-cold dip and diffusion methods, but later trials installed between 1959 and 1960 incorporated more treatments in combination with different incising combinations. Posts were evaluated using the lateral pull test and for failures, and the cause of the failure (decay, termite or both) was noted. Average service life was calculated for each post using MacLean's (1951) mortality curves. A failure was indicated when 60% of specimens within a given treatment failed. Studies were installed at four sites (two mountain, two coastal) near San Juan, Puerto Rico.

Results from these tests indicated that untreated posts lasted approximately 1.5 years in ground contact (0.4 to 3.6 years' average service life within different species). Of 1381 total untreated posts, only 3% remained serviceable after 12 years' exposure. Sixty-one percent of failures were due to decay fungi while 35% failed due to combined termite/fungal attack. Only 1% was destroyed by termites alone. The authors summarized the study as follows:

1) regardless of site, untreated controls averaged 1.5 years
2) termite attack was locally severe, but decay caused the majority of failures
3) mountain plots initially had more failures than coastal, but after 12-13 years, the difference was only about 1-2 years
4) cold soaking in 5% pentachlorophenol had an average service life of 7 years

5) soaking in 5% pentachlorophenol followed by soaking in 50:50 creosote:diesel had an average service life of 8 years
6) vertical cold soaking in 10% pentachlorophenol had an average service life of 12 years
7) hot and cold soaks of pentachlorophenol and creosote resulted in average service lives of 16-17 and 17-18 years, respectively
8) hot and cold soaks of carbolineum had an average service life of 38 years
9) of the diffusible salts, 10% copper sulfate followed by 6.5% sodium arsenate and 6.5% sodium chromate was the most effective, with an average service life of 11 years
10) incised hot and cold soaked pentachlorophenol in diesel had an average service life of 20 years.

For comparison, mean service life (MSL) for all treatments in the Puerto Rico study compared to mean service life predictions based on exposure in Saucier, Mississippi are presented in Table 1. The post studies were conducted on 55 Puerto Rican wood species being evaluated for treatability, so the comparisons between MS and Puerto Rico are not exact. Southern pine and Douglas-fir were included in the Chudnoff and Goytia (1972) study, but the MSL for treatments takes into account of all species evaluated, some of which were more durable which means differences in MSL are likely higher looking at non-durable species alone.

Table 1: Summarized data from the 1972 Puerto Rico (PR) post report compared to similar data from the Mississippi (MS) field site data from the 1975 and 1977 post reports. Ratio indicates mean service life (MSL) in MS divided by MSL in PR.

Treatment	Method	MSL-PR	MSL-MS*	Ratio
untreated	none	1.5	3	2.0
5% pentachlorophenol	cold soak	7	36	5.1
5% penta + 50-50 creosote:diesel	cold soak	8	NA**	NA
10% pentachlorophenol	vertical cold soak	12	50	4.2
5% pentachlorophenol	hot:cold soak	17	NA**	NA
creosote	hot:cold soak	18	41	2.3
carbolineum (coal tar distillate)	hot:cold soak	38	NA**	NA
10% CuSO4 + 6.5% NaAs + 6.5% NaCrO	double diffusion	11	18	1.6
**MSL-MS SYP data obtained from Gjovik and Davidson (1975)*				
**Comparable data not found, see text for details				

Carbolineum was evaluated in this study but comparisons were not made in Table 1 as no comparable data could be found for Saucier, MS. Carbolineum is a coal tar distillate similar to creosote, but according to the 1977 Oregon post farm report (Morrell et al. 1999) only about half as effective as creosote. Hot:cold data for 5% pentachlorophenol was not obtained for Saucier, MS as was the case with the 5% pentachlorophenol soak followed by 50:50 creosote:diesel. The pentachlorophenol service life estimates are severely reduced in the Puerto Rico data, with a 5-fold decrease in MSL for 5% pentachlorophenol and 4.2-fold decrease in MSL for the 10% cold soak. These formulations may not reflect current formulations of pentachlorophenol, but do suggest a higher decay potential in the Puerto Rico sites compared to Mississippi. These treatments are all non-pressure and more uniform penetration would potentially increase longevity of these treatments, but it gives an early indication of how well some of these early systems perform in this environment. Recently, Lebow et al. (2015) published results of pressure treated posts and estimated a service life of 78 years for creosote (service life could not be estimated for pentachlorophenol due to lack of failures at 50 years). The effect of geographic location was initially greater in the Chudnoff and Goytia study with fewer failures in the mountain sites than the coastal sites, but seemed to lessen over time so that posts were failing at about the same time after 12-13 years. However, this trend could be also attributed to fluctuating climatic conditions, which were not reported.

Stake tests

In the late 1930's and early 1940's, FPL researchers initiated a series of stake tests which included a site on Barro Colorado Island, Panama (Woodward et al., 2011). Barro Colorado Island is within the Canal Zone and has a warm, wet tropical climate (Scheffer decay hazard index value of 172). Matching stakes were also installed at a test site near Saucier, Mississippi, and in some cases, sites near Bogalusa, Louisiana and Jacksonville, Florida. These sites in the southern United States (US) fall into

AWPA Deterioration Zone 5 (severe hazard) for wood that is placed in contact with the ground (AWPA, 2015). The Mississippi, Louisiana and Florida sites have Scheffer decay hazard index values of 87, 83 and 97, respectively. All the stakes evaluated in these trials were two-by-four (nominal) cut from the sapwood of the southern pine species group. Preservatives evaluated included formulations of pentachlorophenol, fluor chrome arsenate phenol (FCAP), zinc chloride, chromated zinc arsenate and creosote. The tests in Panama, Louisiana and Florida were terminated in 1956, 1958 and 1960 (respectively), but in many cases there had been sufficient failures within lower retentions to calculate the average years to failure. Longevity for the most durable treatments (higher retentions of pentachlorophenol and creosote) could not be calculated because insufficient failures had occurred when the tests were terminated.

In most cases, the stakes exposed in Panama failed more rapidly than their counterparts exposed in the southern US (Figure 1, 2). This effect was particularly notable for the less durable stakes, which sometimes survived 3-5 times longer at the sites in the US (Figure 1). However, it should be noted that there is proportionally greater error in estimating years to failure for non-durable woods. For treatments that were more durable in Panama, the difference between the US and Panama sites was not as great but still apparent (Figure 2). There were also exceptions to the more rapid failure in Panama, as in some cases stakes failed more rapidly in Louisiana. A review of the Louisiana data revealed that all of the rapid failures were associated with one plot, indicating that localized site conditions may have played a role. The sandy soil conditions likely played a role in the longevity of stakes in Florida, which had similar durability to those placed in Mississippi, despite Florida's greater decay hazard index.

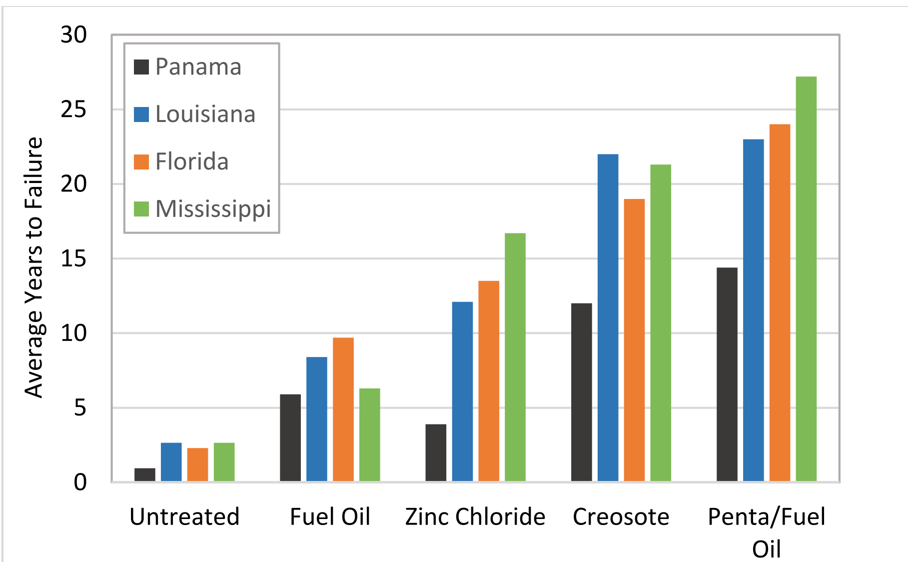

Figure 1. Examples of the longevity of matched stakes exposed in Panama or sites in the southeastern US. The creosote and pentachlorophenol treated stakes depicted here do not meet AWPA standards and this data does not reflect the expected longevity of commodities currently treated with these preservatives.

In general, the comparative stake tests in Panama and the southern US do demonstrate the greater deterioration hazard anticipated in a tropical exposure. However, they also show the difficulty using the results from a US site to predict performance in a tropical location. Localized site conditions can affect the durability of stakes, even within a small geographic area. FPL researchers have observed that untreated stakes placed in an open area at the Mississippi site consistently have greater longevity than those placed in the adjacent forested area. It also appears that the longevity relationship between sites may be a function of the type of preservative (Figure 1).

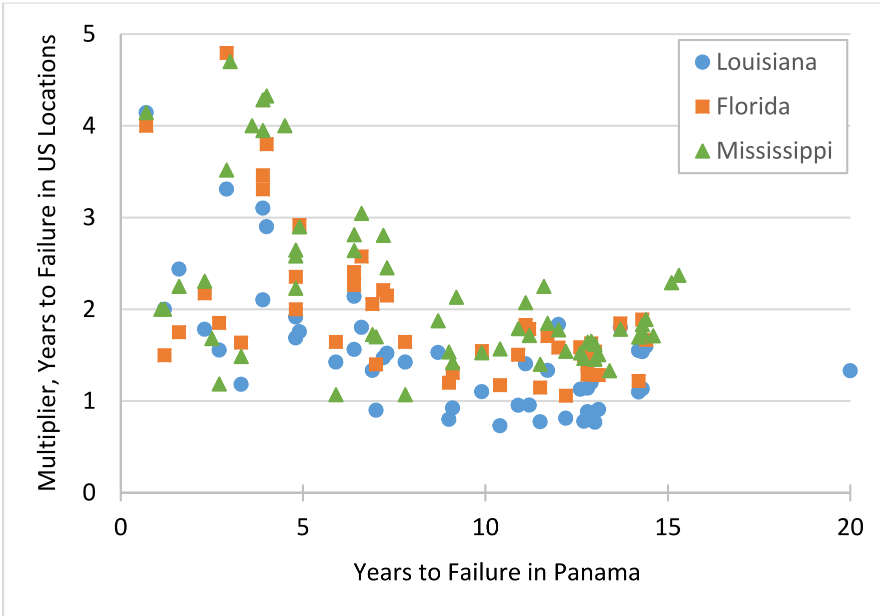

Figure 2. Longevity of stakes exposed in sites within the southeastern US relative to those exposed in Panama. Y-axis represents the ratio, Years to failure in US sites/Years to failure in Panama. Note that the general trend is that the ratio of early failures is many times greater in US sites, but for later failures the ratios are much lower.

Above ground box tests

In the 1980's FPL researchers cooperated with US Army personnel to evaluate potential preservatives for use in protection of wooden packaging materials (DeGroot and Stroukoff, 1986). Nailed pine (lodgepole or ponderosa) boxes and wire-bound gum (sweet or black) boxes were assembled by fastening side panels to corner cleats (thicker strips of wood). The authors noted that the pine did contain some heartwood. The boxes were exposed in a partially shaded location at FPL's test site near Saucier, MS, in an open field in central Panama, and under a three-tiered forest canopy (jungle) in a high-rainfall area of Panama bordering the Gulf of Mexico. In addition to being shaded, the jungle area had greater average annual rainfall (3.3 m) than that of the open field location (2.0 m). The boxes were stacked on supports 0.5 m above the ground. After 36 months in Panama, or 47 months in Mississippi, the untreated boxes were rated for extent of biodeterioration. Researchers used a 0, 1, 2, 3, 4, 5 rating scale, with 0 representing no attack and 5 representing destruction. The available data does not allow a direct Mississippi to Panama comparison for the preservative-treated boxes.

Despite the shorter exposure period, untreated boxes exposed in Panama suffered greater degradation than those in Mississippi (Figure 3). The one exception was gum panels, which had slightly more deterioration in Mississippi than the open field site in Panama.

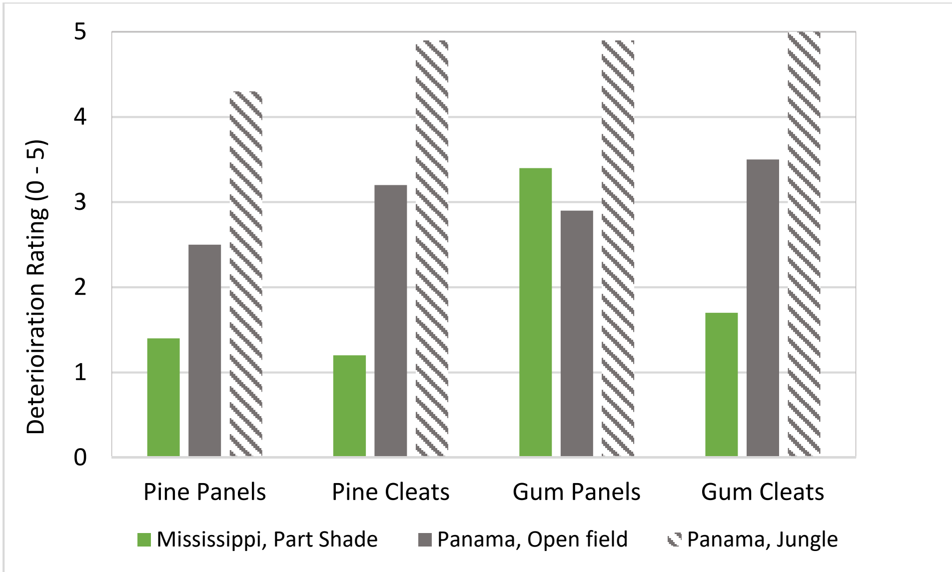

Figure 3. Mean deterioration ratings for untreated wooden boxes exposed in Mississippi or Panama. Boxes were rated on a scale from 0 (no attack) to 5 (destroyed). The exposure period was 47 months in Mississippi and 36 months in Panama.

Deterioration was consistently more severe in the Panama jungle location than the Panama open-field location, possibly reflecting the combination of higher rainfall, shading, and possibly deposition of organic detritus. All of these factors likely caused the boxes in the jungle to maintain a higher moisture content than those exposed in the open field. Shading alone has been previously reported to accelerate decay of wood exposed above ground because of higher sustained moisture contents (Brischke and Rapp, 2008). The results of the DeGroot and Stroukoff (1986) study confirm that localized conditions can also affect exposure hazards within tropical climates. The authors also caution that the patterns of decay may vary between open field and jungle exposures, making it difficult to use the results to predict performance at a dissimilar site. Similar studies in similar locales in the Panama Canal Zone found complete failure of southern pine and Douglas-fir field stakes in less than 12 months in both above and below ground exposure (Bultman and Southwell 1976).

Above and below ground studies in Puerto Rico

Woodward (unpublished data, personal communication) evaluated untreated southern pine at two sites [wet (Jardin Botanica) and dry (Ceiba forest)] near San Juan, Puerto Rico to establish baseline decay data for continued field testing at these sites as an alternative to Hilo, Hawaii. San Juan has a climate very similar to Hilo although Hilo receives more rainfall on an annual basis. Scheffer decay hazard estimates for San Juan and Hilo are 250 and 380, respectively. Three test setups were evaluated, the AWPA E7 stake test (in-ground), the AWPA E16 horizontal lap-joint test and the AWPA E18 ground proximity test. Solid blocks of southern pine were used in the E18 ground proximity test, and lap-joints and IUFRO stakes were used for the E16 and E7 tests, respectively. After two years, the data for the ground contact IUFRO stakes indicated that the dominant mode of failure in the wet forest site was fungal, while termite attack predominated at the dry forest site. Unfortunately, rating data for the E16 and E18 were not reported. It was also noted that termites and decay were not frequently found together, suggesting that the termites of Puerto Rico prefer wood not previously colonized by fungi.

DeGroot above ground study (1992)

DeGroot conducted a series of tests in the 1990's to evaluate different above ground test configurations to gauge decay response and longevity (DeGroot 1992). Eighteen different designs were evaluated at an installation in an open field site in south Mississippi and a rainforest site in Panama. The overall goal of this study was to develop an accelerated field test method that would be conducive to rapid decay. The test variations ranged from simple stacks of different dimension lumber oriented upright and at 45 degrees, to mortise and tenon units and overlays of test samples placed vertically on trays. The results of these tests indicated that test design had very little effect on decay outcome in the Panama site and that specimen size was a major contributing factor in the performance of the different tests at the Mississippi site with respect to wood decay. A major contributing factor in the MS site was the potential for the test units to hold and retain water next to the test specimens. Several interesting points were raised in the discussion section of this study. First, it was suggested that the rating system used in the study was not sufficient to account for the variety of decomposition being observed and that the system failed to distinguish between soft and brown rots, internal decay versus surface degradation, and degradation due to wood-metal interactions. Secondly, it was concluded that out of the 18 evaluated above ground field test methods, two designs (three horizontally stacked beams exposed at 45 degrees and horizontal beams in cross section) influenced decay outcome and met the desired criteria for continued study using non-destructive measurement of decay in the field.

In-service utility pole studies

Chudnof et al. (1973) evaluated ground line wraps for creosote treated poles in Puerto Rico. Poles were treated by gauge to 14 pcf creosote and installed at a tropical site. Prior to ground contact, these poles were stored outside for 8 years (1958-1966). In 1966, seven foot sections of these poles were installed in San Juan, Puerto Rico to a depth of three feet. After a six month lag time to allow moisture uptake, several ground line applications (fluoride-creosote paste, fluoride-arsenic paste, and penta gel) were applied in order to compare to untreated controls. It was concluded that all of the ground line treatments were effective against decay and controls were severely attacked by decay fungi after 5 years of exposure.

DeGroot conducted several surveys of in-service utility pole condition in Guam (with Lauret, 1986) and the Panama Canal Zone (DeGroot 1986). The Guam study evaluated creosote, pentachlorophenol, CCA or ACA treated Douglas-fir utility poles of class 1-5 and found that Formosan termites (*Coptotermes formosanus* Shiraki) were able to attack untreated heartwood in all of the treatments except ACA, suggesting that ACA treatment had a protective effect on the heartwood. It was also concluded that CCA treated Douglas-fir should not be considered for use in Guam due to the high incidence of termite attack. It was also suggested that supplemental ground treatments with chlordane significantly improved resistance to termite attack; 95% of the ground line treated poles showed no sign of *C. formosanus* attack after 14 years' exposure. Douglas-fir treated with pentachlorophenol showed mixed results with respect to decay and termites which was attributed to variation in carrier formulations of the pentachlorophenol and lag time prior to installation. In one particular line of poles, 90% of poles were attacked by soft rot fungi, which was often followed by termite attack. Utility pole surveys in Panama yielded similar results, indicating that soil line decay is more severe in tropical rain forest biomes and supplemental treatments may be necessary to adequately protect the wood. Regarding termites, it was concluded that current specifications (circa 1986) do not adequately protect heartwood from tropical termite species attack.

Subterranean termite studies on the Midway Atoll

Various studies were conducted by the USDA-FS Termite Research Unit, now part of FPL, in the early to mid-1980's (Kard et. al. 1989) on the Midway Atoll. Midway is an interesting choice as a field test site because it is a very small isolated island in the Pacific and does not have naturally occurring termites. *Coptotermes* spp. was allegedly introduced in Midway during the early 1900's from contaminated soil from Honolulu, Hawaii (Apple and Swedberg 1979). The Midway studies mostly consisted of concrete slab tests to assess termite penetration of soil applied termiticides and ground board tests, which are also placed on top of a treated soil surface. In the Midway Atoll, termite attack on untreated ground boards was reported to be very slow and only 40% of untreated ground boards were attacked after 5 years' exposure (Mauldin et al. 1987). Additional studies conducted on Midway by Kard (1996) evaluated stainless steel mesh barriers and basaltic sand as ground barriers beneath concreate slabs, which were very effective. The data for untreated slabs and ground boards showed almost no attack of ground boards and an average of 14% of untreated slabs were attacked; these numbers were lower than Mississippi (69% and 85%, respectively) and even lower than Arizona (57% and 45%, respectively). It is interesting that Midway has such low termite pressure as its climate data would suggest it is suitable. However, there may simply not be enough termite dispersal into the area to sustain an active population and may contribute to the paucity of termite pressure. The effects of island size have been discussed in Simberloff (1976) and many others.

DISCUSSION

Dimensional trends-comparing poles, posts and stakes

The DeGroot (1992) study indicated that size and configuration of a test has less of an impact under typical tropical exposure. Due to the constant inundation of the wood with moisture, decay progresses quickly and uniformly within the samples. As discussed in the Chudnoff and Goytia (1972) and DeGroot (1992) studies, poles are prone to damage from the inside out if not treated properly. As far as comparing dimensions, untreated 18 inch two-by-fours failed within a year, posts averaged about 1.5 years, and the untreated utility poles failed within 5 years. With larger dimension pieces, such as poles, shell treatments seem ineffective due to constant termite pressure by more aggressive species. If materials are not treated to sufficient penetrations, termite attack ensues on the heartwood, especially in the case of refractory species (ex. Douglas-fir).

Scheffer as an index for both above/below ground decay and termites

The Scheffer index was originally developed as a relative measure of decay potential for wood above ground, but the inputs that base the calculation would definitely govern the same processes below ground. Soil temperature is not considered but should track closely with the mean temperature. Annual rainfall should track closely with soil moisture content (MC) and should drive decay rates up until soil saturation. Since basidiomycete wood decay fungi typically operate within a range of 40-80% MC (and more efficiently on the drier end of that range), once MC goes above 80% the substrate becomes overly saturated and ascomycete soft rot fungi become the predominant forms of decay under those conditions. In excessively wet conditions, bacteria would be the only biologically relevant sources of degradation, but bacterial wood degradation works on a completely different time scale under normal conditions.

One interesting example of when the Scheffer index over-predicts decay hazards would be in the case of Midway presented earlier. According to the calculations, decay and termite pressure should be equivalent to Honolulu, Hawaii (Scheffer decay hazard index value of 150), however, untreated materials were untouched by termites for two years after installation and only suffered 40% attack by termites at the five-year mark. The Scheffer index is a valuable tool for predicting decay and termite hazards but only if the causal agents (i.e. decay fungi and termites) are present and active in a given locale. Proper characterization of the insect and decay fungi of a given area is critical for estimating biodeterioration potential.

Termite pressure

The tropics definitely hold more potential for accelerated testing of materials against termites. More days conducive to termite activity combined with greater diversity and abundance of termite species lead to higher rates of attack and wood consumption. In addition to subterranean termites (such as *Reticulitermes* and *Coptotermes*), tropical sites typically have greater diversity and abundance of termites. It should be noted that termites were the cause of failure for nearly all of the studies installed in San Juan, Puerto Rico and that only the metal tags remained at the final inspection (personal communication). This is important because these test sites harbor different modes of potential termite failure than seen in the continental United States and even Hilo, Hawaii. The DeGroot (1992) studies in the Panama Canal do not emphasize termites as much, but other studies indicate very high termite pressure (Bultman and Southwell 1976, Kard et al. 1989). Out of these studies mentioned, Guam seems to be the most severe locale for termite attack, with 80% failure of creosote treated Douglas-fir poles at 14 years. The Formosan termites located in this area are very aggressive and feed readily on exposed heartwood of most of the pressure treated species.

Local effects

As noted in the results of several of these studies, local effects can greatly impact biodeterioration rates at a given site. These can be attributed to any combination of the following factors: overstory, soil characteristics, soil-drainage, and predominant biological fauna. In particular, past studies have shown that fungi occupy different niches in the forest landscape (Lodge and Cantrell 1995), so test site landscape should have a definite effect on fungal decay. The same patterns can be seen in the untreated box test and initially on the non-pressure post-tests around San Juan. The lack of termite pressure discussed in the Midway data would also be a case of local effects with significantly less termite pressure than comparable locations such as Hilo, Hawaii or Honolulu, Hawaii.

Effects of climate change

The studies highlighted here all took place within a 60-year span (1945-2005) and historical weather data and current climate models suggest a general warming trend across the tropics. However, the other consequence of climate change is that of drought, which has been experienced in many areas of the tropics. As mean sea temperature increases, the risk of tropical storms and hurricanes also increase. The local effects mentioned previously could also become more pronounced as patterns of severe weather (severe hurricanes, seasonal wet periods and droughts) are predicted to become more common. More studies of recent climatic conditions and woody biomass decomposition rates for both untreated and treated wood in tropical locales would be valuable tools for making comparisons of this data to historical records such as the studies presented in this paper. Peterson (2010) discussed the effects of climate change on termite distribution and indicates that warming climate could allow for range expansion of termite species normally confined to sub-tropical areas into more northern locales.

CONCLUSIONS

Tropical test data is a useful tool for predicting performance under extreme conditions. However, local effects need to be given full consideration when interpreting the data. Decay and termite pressures can fluctuate within a region, and field conditions and untreated materials should be looked at very carefully to ensure proper biodeterioration hazards are validated. Also, characterization of biological agents of deterioration in and around test sites can be useful tools for predicting decay potential. Continued testing in tropical environments, such as the Hawaiian Islands and Caribbean Basin, would provide useful comparative data to adapt current service life to predictions in severe hazard zones.

DISCLAIMER

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