Chapter 6

Regional Biodeterioration Hazards in the United States

Stan T. Lebow and Terry Highley

Forest Service, Forest Products Laboratory, U.S. Department of Agriculture, Madison, WI 53726

It is well recognized that the rate of wood biodeterioration varies by geographic region across the United States. However, our understanding of the relationship between geographic location and biodeterioration hazard remains largely qualitative. This paper reviews the current state of the knowledge on biodeterioration hazard zones, including a discussion of the basis for, and experiences with, the classic Scheffer climate index for aboveground exposure. The discussion is expanded to cover biodeterioration hazard zones for wood placed in ground contact and the geographic implications for attack by termites and other insects. Finally, this paper discusses the relevance of biodeterioration hazard zones to the development and interpretation of durability tests for wood products.

It has been recognized for centuries that exposed wood deteriorates more rapidly in warm, wet climates than in cold and/or dry climates. Historically, the use of wood as a construction material mirrored this effect, with greatest use occurring in northern latitudes. In the past, the recognition of the geographical differences in biodeterioration hazard was largely based on practical experience, as the causal relationship between fungi and decay was not established until the late 1800s by the German researcher Robert Hartig (*1*). We now have a greater understanding of how temperature and moisture affect the survival and growth of wood-attacking organisms. This knowledge has led to the development of climate indexes and biodeterioration hazard zones for North America.

However, our understanding and application of the relationship of geographic location and climate to biodeterioration hazard remains largely qualitative. For more than 50 years, the widespread use of highly effective wood preservatives such as chromated copper arsenate (CCA), creosote, and pentachlorophenol has allowed builders to ignore regional differences in biodeterioration hazards. When developing new preservatives, the variation in regional biodeterioration hazards is acknowledged simply by testing these systems in the most severe hazard zones of their intended markets. This assures that the preservative treatments are more than sufficient to protect wood in other regions, but it can lead to use of unnecessarily high preservative concentrations. More recently, emphasis has shifted towards developing less toxic preservatives and/or employing lower biocide retentions. As part of this trend, there is increasing interest in matching the extent of preservative protection to the product's end-use and the regional biodeterioration hazard. Accomplishing this objective will require a better understanding and more quantitative application of regional biodeterioration rates.

This paper reviews the current state of the knowledge of biodeterioration hazard zones and includes a discussion of the basis for, and experiences with, the classic Scheffer climate index. The discussion considers biodeterioration hazard zones for wood placed above ground or in ground contact, and the geographic implications for attack by termites and other insects. Finally, this paper discusses the relevance of biodeterioration hazard zones to the development and interpretation of efficacy tests for durable wood products.

Biodeterioration Organisms

In this section, biodeterioration organisms are briefly described in the context of regional biodeterioration hazards.

In most applications for wooden construction materials, decay fungi are the most destructive organisms. Fungi are microscopic threadlike organisms whose growth depends on mild temperature, moisture, and oxygen (2). Wood decay fungi are ubiquitous. Given suitable conditions, wood is vulnerable to attack by some type of fungus. Many species of fungi attack wood, with a range of preferred environmental conditions.

Wood decay fungi are often separated into three major groups: brown-rot, white-rot, and soft-rot. Brown-rot and white-rot fungi are both Basidiomycetes but they prefer different wood species and differ in the way they degrade wood. Nonetheless, the optimal environmental conditions for these fungi are fairly similar. Soft-rot fungi are Ascomycetes or Deuteromycetes. They generally prefer wetter, and sometimes warmer, environmental conditions than do brown- and white-rot fungi. Damage by soft-rot fungi resembles that by brown-rot fungi but is typically slower, with only the outer portion of the wood affected initially.

Termites follow fungi in extent of damage to wood structures in the United States. Their damage can be much more rapid than that caused by decay, but their geographic distribution is less uniform. Like decay fungi, the type and severity of termite attack varies by species. In the United States, termites are categorized as ground-inhabiting (subterranean) or wood-inhabiting (non-subterranean) (2). Most damage is caused by subterranean termites. The threat from these termites has increased with the spread of the non-native Formosan subterranean termite in some areas of the southeastern United States. Nonsubterranean termites are less damaging than subterranean termites because they have a narrower geographic range and degrade wood more slowly.

Other insects, such as powderpost beetles and carpenter ants, can cause notable damage to wood in some situations, but their overall significance pales in comparison to that of decay fungi and termites. Bacteria and mold can also damage wood, and several types of marine organisms degrade wood in seawater. On an economic basis, however, decay fungi and termites are by the far the most destructive pests of wood used in terrestrial applications. Because of their relative importance in wood deterioration, this chapter focuses on decay and termite hazards.

Factors That Determine Regional Hazards

The two greatest influences on regional biodeterioration hazard are temperature and moisture. The growth of most decay fungi is negligible below 2°C and relatively slow from 2°C to 10°C. The growth rate then increases rapidly, with most fungi having an optimum growth rate between 24°C and 35°C (*1,2*). A few wood decay fungi prefer temperatures in the 34°C to 36°C range; these fungi are commonly found in wood exposed to sunlight or in chip piles (*3*). Soft-rot fungi typically tolerate warmer temperatures than do brown- and white-rot fungi, but care must be taken in making broad generalizations about temperature preferences as there is great variation between closely related taxa (*1*). The growth rate of decay fungi declines steeply at high temperatures, with little growth above 40°C and no growth above 46°C. In most locations and applications in the United States, the lower end of this temperature range has the greatest effect on fungal growth. In the north, temperatures may be too low for the growth of decay fungi during several months of the year, and conditions may be only intermittently favorable during other times. Practical experience has indicated that decay progresses more rapidly in warmer regions of the United States. Although temperatures on the surface exposed to sunlight can exceed those favored by decay fungi, the inner portions of wood products are usually cooler. Decay tends to develop more rapidly in wood in shaded locations, but this is usually associated with a slower rate of drying rather with protection from excessive heat.

The role of moisture in biodeterioration, especially by decay fungi, cannot be overemphasized. Decay fungi require wood moisture content of at least 20% to sustain any growth, and higher moisture content (over 29%) is required for initial spore germination (*1–3*). Decay fungi cannot colonize wood with moisture content below fiber saturation (average of 30% moisture content). Free water must be present. Most brown- and white-rot decay fungi prefer wood in the moisture content range of 40% to 80%. Growth at lower moisture content is much slower; typically, wood with less than 25% moisture content cannot be attacked unless the fungus has another source of moisture nearby. Previously established fungi are not necessarily eliminated at even lower moisture contents. Once established, decay fungi produce water as a metabolic product of wood decomposition. This metabolic water may extend the decay period in poorly ventilated areas. Decay fungi have been reported to survive (without further growth) for up to 9 years on wood with around 12% moisture content (*3*). As moisture content exceeds 80%, void spaces in the wood are increasingly filled with water. The subsequent lack of oxygen and build-up of carbon dioxide in free water limits fungal growth (*4,5*). Soft-rot fungi, however, tolerate higher moisture contents.

As with temperature, it is the lower end of the moisture content limitations that has the greatest impact on regional decay hazard. Humidity alone is not sufficient to raise wood moisture content to the level needed for decay, although an equilibrium moisture content (EMC) of over 20% can occur in cool, moist climates (6) (Figure 1). In some types of applications, such as a swimming pool enclosure, the combination of humidity and condensation can wet wood sufficiently for decay to occur. Air is able to hold more moisture at warm temperatures, lowering the relative humidity and EMC. (*6*). Humidity does play a key role in slowing the drying of wood once it is wetted. The drying rate also depends on the length of dry periods between wetting and on construction details that affect the uptake of free water and the loss of water vapor from the wood.

Temperature affects both the extent of activity and geographic distribution of termite species within the United States. The natural range of native

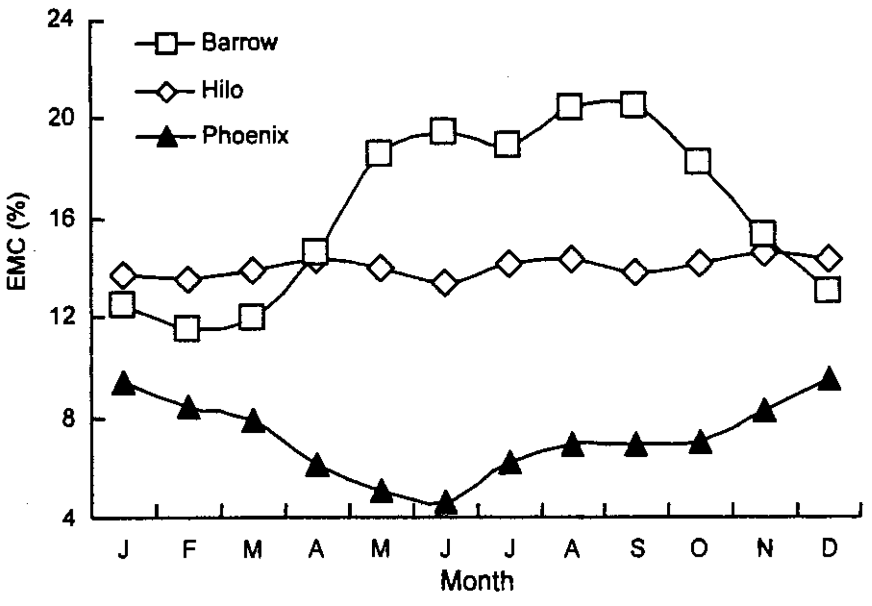
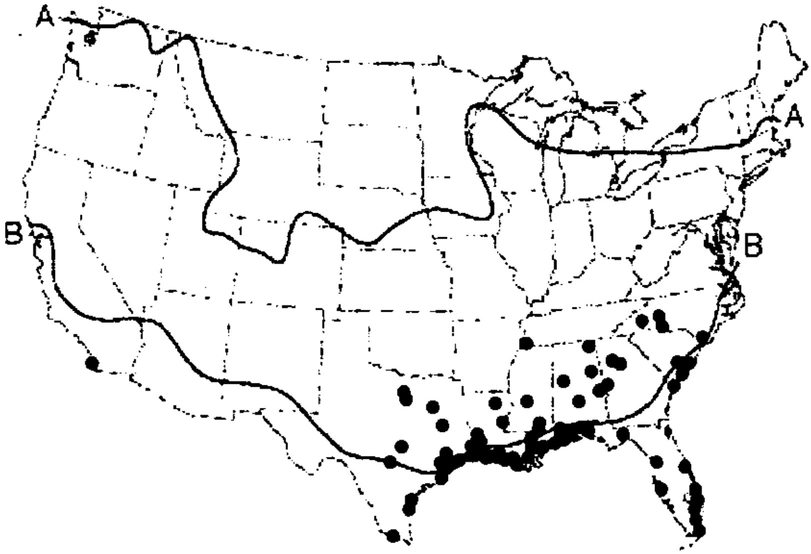


Figure 1. Examples ofequilibrium moisture content (EMC) ofwood exposed outdoors and protected from precipitation in Barrow, Alaska; Hilo, Hawaii; andPhoenix, Arizona.

subterranean termites is generally limited to areas where the average annual temperature exceeds 10°C, although termites have been found farther north where human activity creates pockets of warmer temperatures (*7*) (Figure 2). Within much of the range of termites in the midwestern and eastern United States, insect activity above ground gradually declines and little activity occurs in the winter (*8*). Termites become inactive when the temperature falls below freezing; in cold climates they may burrow more than I m into the ground to avoid prolonged freezing temperatures (7–9). A recent study found that native subterranean termites (*Reticulitermes favipes*) could not maintain normal physiological function at temperatures below 1.0°C to 4.9°C (*10*). Formosan subterranean termites are thought to be even less tolerant of cold temperatures, although the northern limits of their distribution in the United States have not yet been established. For example, Hu and Appel (*10*) reported that Formosan subterranean termites were unable to function at temperatures below 7.2°C to 9.0°C. Maximum temperatures for normal function were reported to be between 44.8°C and 45.9°C for Formosan termites and between 43.5°C and 44.9°C for native subterranean termites (*10*). There is less research on the optimum temperature for termite feeding activity. Fei and Henderson (*11*) reported that the rate of wood consumption by Formosan subterranean termites was



A Northern limit of recorded damage by subterranean termites
B, Northern limit of damage by drywood termites
• Location of Formosan subterranean termite infestations

Figure 2. Approximate distribution of termite species causing the most damage in the United States. Localized populations of subterranean termites have been reported in more northerly regions. Adapted from Highley (2).

approximately doubled when the temperature was increased from 20°C to 30°C. Further increase in temperature to 33°C resulted in only a minor increase in the rate of wood consumption and, in some cases, a decrease.

The net effect of temperature on termite degradation of wood is similar to that of decay fungi: conditions are most favorable in regions with warmer climates. The temperature effect may be more extreme for termites than for fungi, however, as some regions of the northern United States have virtually no risk of termite attack.

The effect of moisture on termite attack varies with species. To some extent, the type of termite and its dependence on moisture does vary with climate, but it is a loose correlation. Dampwood termites require wood with high moisture content and typically only attack wood in direct contact with the ground. As a result, they have a relatively minor impact on wooden structures. The high moisture requirements of dampwood termites coincide with their preferred habitats in the northwestern United States and southern Florida but these termites are found in the southwestern United States as well.

Native subterranean termites require moisture to prevent desiccation, but they can attack wood with moisture content well below the fiber saturation point by building shelter tubes. The shelter tubes are built across open areas to reach wood above ground, and the termites periodically return to the soil to replenish their water supply. Native subterranean termites are widely distributed in the southern two-thirds of the United States; their distribution is less uniform along the Pacific Coast (Figure 2). Formosan subterranean termites also require a source of moisture to attack wood above ground but are less reliant on proximity to soil for survival. They may establish colonies on upper floors of buildings if a consistent source of moisture is present.

Drywood termites are so-named because they are able to survive in wood above ground and can often derive sufficient moisture solely from the wood. They are commonly found in southern California, Arizona, and coastal areas from South Carolina to Texas (*7*).

Regional biodeterioration hazard is shaped by other factors besides moisture and temperature. Some of these, such as elevation, exert influence primarily through their effect on temperature and moisture. Others, such as soil properties, may be interrelated with moisture but also independently influence biodeterioration. Native subterranean termites, for example, generally prefer sandy soil over a clay base (*7*), and soil properties have been reported to strongly affect both the type and severity of fungal attack. Nilsson and Daniel (*12*) found that soil type can influence the relative abundance of brown-, white-, and soft-rot fungi. Nicholas and Crawford (*13*) reported that addition of composted wood to a forest soil increased both the fungal biomass in the soil and the decay rate of untreated pine sapwood stakes. Factors such as quantity of light and atmospheric pressure have also been theorized to affect rates of deterioration, but little is known about these effects (*1*).

Quantification of Regional Biodeterioration Hazard

Recognition of regional variation in deterioration hazard, and its possible importance in predicting durability of wood products, has led to several efforts to quantify hazard zones. Perhaps the most widely used and recognized of those efforts is the Scheffer index (14). The Scheffer index was developed in an effort to correlate climatic conditions to the decay rate of wood used above ground and fully exposed to the weather. In constructing his model, Scheffer assumed that temperature and moisture would be far more important than other climate factors. He considered various temperature and moisture parameters, and eventually chose mean monthly temperature and number of days each month with at least 0.25 mm of precipitation. Because fungal growth becomes negligible below 35°F (1.6°C), Scheffer subtracted 35°F from the mean monthly temperature. Negative values were converted to zero. He chose days with precipitation instead of precipitation volume on the premise that duration of wetting was the most significant factor. The "days of precipitation" value was somewhat arbitrarily reduced by 3 to keep the index for the driest regions of the United States near zero. The annual sum of the temperature and precipitation products for the entire year was divided by 30, so that most index values fall in the range of 0 to 100. Examples of the annual Scheffer index for various locations are shown in Table 1.

Table I. Examples of Scheffer Index (Annual) for Various U.S. Locations

Location	*Index*	*Location*	*Index*	*Location*	*Index*
Atlanta, GA	67	Houston, TX	77	Philadelphia, PA	50
Chicago, IL	46	Long Beach, CA	4	Phoenix, AZ	7
Boston, MA	51	Miami, FL	131	Seattle, WA	50
Denver, CO	33	Mobile, AL	99	Yuma, AZ	0

The climate index is defined as:

$$\text{Climate index} = \frac{\sum_{Jan.}^{Dec.}\left[(T-35)(D-3)\right]}{30}$$

where *T* is mean monthly temperature (°F) and *D* is number of days in month with at least 0.01 inches (0.25 mm) of precipitation.

Using his model, Scheffer produced the widely published geographical contour map of decay potential (Figure 3) (*14*). This map allows the reader to quickly identify areas of high, low, and moderate decay hazard for wood used above ground. As expected, the areas of the continental United States with the highest decay potential are in the southeast, although a small pocket of moderately high decay potential can be found in the Pacific Northwest. Areas of the intermountain west and southwest have the lowest decay potential.

Scheffer verified, or evaluated, the model based on untreated 'post-rail" and "flooring" specimens exposed above ground in three locations: Madison, Wisconsin; Corvallis, Oregon; and Saucier, Mississippi (southern) (14.15). Madison and Corvallis have very similar annual decay indexes (39 and 42, respectively), while Saucier has a decay index of 96. Scheffer calculated an estimated time to failure at each location, and an "average yearly increase in decay rating." He found that the rate of decay was essentially identical in Madison and Corvallis, but that it was 1.9 times (post-rail) or 2.5 times (flooring) faster in Saucier than in Madison. These relative decay rates are in good agreement with the relative decay indexes. Verification at more locations

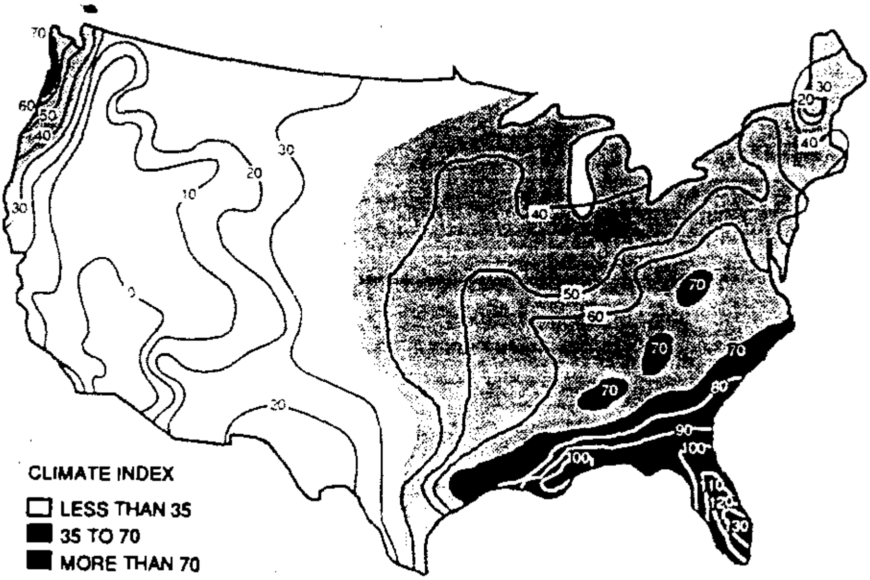


Figure 3. Scheffer climate index map of United States, as adapted from Scheffer (14).

would have been desirable, but little data are available for comparing above-ground decay rates with matched samples.

When calculated on a monthly basis, the Scheffer index produces some interesting comparisons. Although Madison and Corvallis have essentially equivalent annual indexes, the manner in which they reach those values is quite different. In Madison, the index is largely controlled by temperature and peaks during the summer. During several months each year the average temperature is below 1.6 °C, which results in an index of zero (Figure 4). In contrast, the index in Corvallis is largely controlled by precipitation. The index reaches zero for 2 months in the summer because there are 3 or fewer days with precipitation. In Saucier, the rain pattern is similar to that in Madison but the index is higher because of the warmer temperatures.

As Figure 4 shows, the Scheffer index may underestimate decay potential in some situations because it is based on monthly averages. In Madison, for example, the temperature exceeds 1.6°C on many days in November and March, and fungal activity may be "non-zero." This is particularly true of wood exposed in south-facing locations where the sun might heat the wood to well above the ambient temperature. Similarly. it is doubtful that the progression of decay in wood in Corvallis stops for 2 months each summer. In larger lumber or poles, for example, water retained in the wood could allow decay to proceed, whereas Scheffer's model assumes rapid drying. Wood placed in contact with the ground

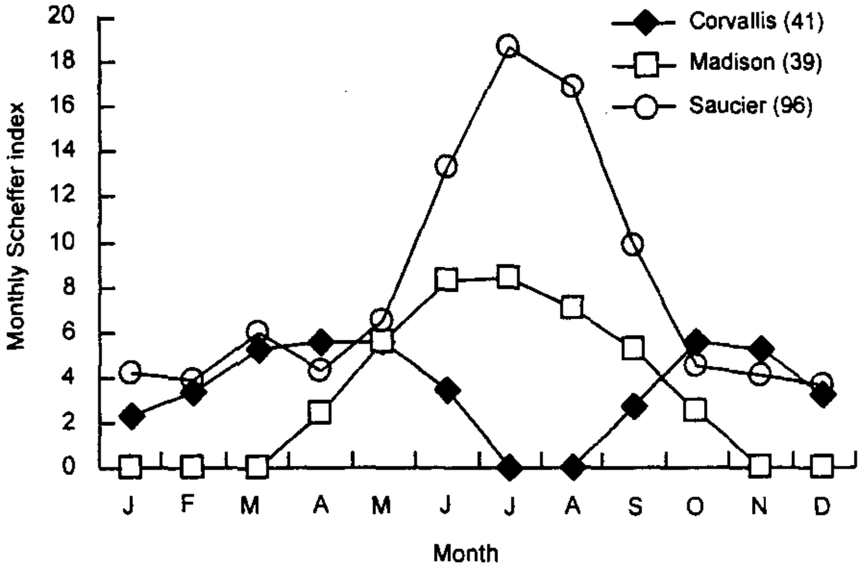


Figure 4. Monthly Scheffer index values for Corvallis, Oregon; Madison, Wisconsin; and Saucier, Mississippi Legend shows annual index values.

also stays moist for much longer periods. Scheffer recognized this and discussed possible modifications of the formula for wood used in ground contact (*14*). For example, in the case of the dry summer months of Corvallis, Scheffer suggests that the model could be adapted to soil contact by averaging the indexes for the months immediately prior to and following the summer months (May and September, for example). This would eliminate the dip that occurs during the summer for Corvallis.

Another type of decay hazard map was developed by the Rural Electrification Administration (REA) of the U.S. Department of Agriculture (*16*). The REA compiled durability data on millions of utility poles installed in rural electric systems across the United States. Based on these data, it divided the 48 contiguous states into five deterioration zones (Figure 5). Scheffer's map of decay potential (Figure 3) and the REA deterioration zones (Figure 5) are generally in good agreement. However, the two approaches show several notable differences in identifying hazard zones. Unlike Scheffer's map, the REA hazard map is based on wood that was treated with preservative and placed in ground contact. These qualities may lend the REA study greater applicability for the relationship between hazard zone and the development of wood preservatives used in ground contact. Conversely, the mixture of wood species and preservatives represented in the REA data can make comparison of decay hazard zones more complex. The wood species used for poles varied by region;

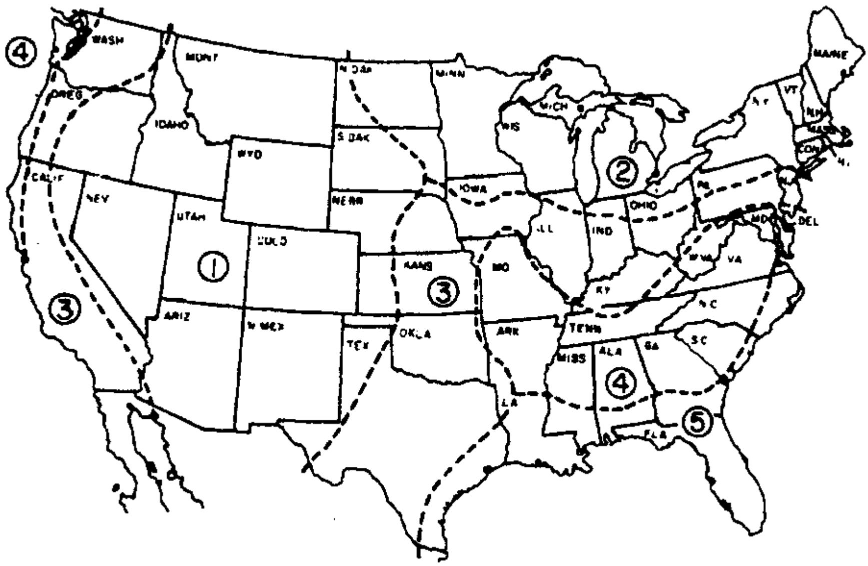


Figure 5. Deterioration zones for wood utility poles as defined by the REA (16). Hazard is least severe in zone 1 and most severe in zone 5. (Reproduced from reference 16.)

most poles used in the western United States were Douglas-fir, western redcedar, or lodgepole pine, whereas most poles in other areas were Southern Pine. In addition, a range of preservatives was used, although the majority of poles were treated with creosote. The value of the REA pole data was recognized by the American Wood Preserver's Association (AWPA), which added Alaska and Hawaii to the map and incorporated this information into Commodity Specification D: Poles (*17*). Section 1.4.1 of the standard refers the reader to the REA Deterioration Zone map for assistance in determining the retention level needed to protect utility poles. This is one of the few cases where AWPA standards recognize and refer to differences in regional biodeterioration hazards. It should be noted, however, that the REA divisions do not actually quantify the differences in rate of deterioration, as was attempted with Scheffer's index. For example, the REA divisions are not meant to imply that wood exposed in zone 4 will deteriorate twice as quickly as wood exposed in zone 2.

There have also been efforts to develop models of regional deterioration hazards in Australia. Foliente et al. (*18*) described efforts to model both aboveground and in-ground decay using methods somewhat similar to that of Scheffer (*14*). Their model for aboveground decay utilizes data on average annual temperature, average annual rainfall, and humidity. The inclusion of humidity is thought to help account for differences in the drying rate of wood after wetting. The in-ground model is a function of average annual temperature and rainfall. To account for soil moisture, an additional factor is added for the number of months in a year in which rainfall is less than 5 mm (*18*).

Review of Durability Data Across Hazard Zones

Aboveground Exposure

More than three decades after Scheffer's classic publication on aboveground decay hazards, there remains relatively little comparative data on aboveground decay rates in different regions of the United States. Most aboveground data are generated during development and evaluation of new preservatives, and, in those cases, researchers tend to test only in high hazard areas. One exception to this trend is data published by Highley (*19*) comparing the durability of wood exposed aboveground in Madison, Wisconsin, and Saucier, Mississippi. This large study included a range of hardwood and softwood species exposed unpainted as 1.9- by 7.6- by 15.2-cm specimens nailed together at their centers to form a cross. The deterioration rate in these specimens was relatively slow, even in southern Mississippi, because the design and small size of the specimens prompted rapid drying. Based on Scheffer's index, the rate of decay in Saucier (index 98) was expected to be approximately twice that of Madison (index 39). However, this was not the case for the softwoods evaluated (Figure 6). where the estimated service life was only slightly greater in Madison than in Saucier. Southern Pine sapwood, for example, had an estimated life of 13 years in Madison and 10 years in Saucier. For the hardwoods, however, the relative service life at the two locations was closely predicted by the Scheffer index. The difference in zone effect between softwoods and hardwoods is noteworthy and may reflect differences in the types of fungi predominant at each site. The results of an earlier study support this conclusion. When decay fungi were isolated from the specimens, only half as many fungal species were found in Wisconsin as in Saucier; little overlap occurred between the most commonly isolated fungi (*20*).

Another comparison of Southern Pine specimens exposed above ground reported a much greater regional difference (*21*). In that study, specimens were exposed in Hilo, Hawaii (Scheffer index an extremely high 312), and near Charlotte, North Carolina (index 64). L-joint specimens reportedly decayed at least three times faster in Hilo than in Charlotte. Specimens exposed in Hilo declined to 70% soundness in 18 months and had all failed within 3 years. The relative decay rates in this study correlate fairly well with that predicted by the Scheffer index.

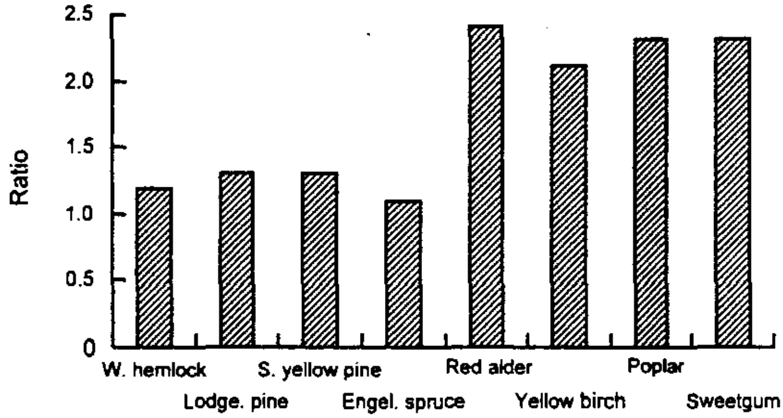


Figure 6. Ratio of estimated life in Madison to that in Saucier for various wood species exposed above ground.

Samples exposed well above ground are not usually attacked by termites, which can greatly alter the rate of biodeterioration. when conditions are favorable for termite attack, wood samples can fail much more rapidly than they do when exposed to decay alone. The rate of deterioration is also a function of the type of termite. Samples of softwood species exposed 60 to 80 mm above ground in Lake Charles, Louisiana, were severely degraded by Formosan subterranean termites within 6 months and by native *Reticulitermes* spp. within 12 months (*22*).

Ground Contact Exposure

As is the case for aboveground evaluations, most ground-contact data are generated during the development of new wood preservatives, and these tests tend to be conducted in areas with high deterioration hazard. The primary exception is the Forest Service exposure site in Madison, Wisconsin. Data on small (19 by 19 by 457 mm) Southern Pine sapwood stakes in Madison (REA deterioration zone 2), Starkville, Mississippi (zone 4), and Saucier, Mississippi (zone 5) showed good agreement with the expected relative rates of deterioration for those locations (Figure 7). Forest Service data (*23*) on untreated Southern Pine and lodgepole fence posts also indicate a trend of shorter life expectancy in higher deterioration hazard areas (Figure 8). However, the lodgepole pine exposure sites were concentrated in areas with relatively low decay hazard (mostly the intermountain west or Madison). The correlation between deterioration hazard and longevity within those low hazard regions was relatively poor.

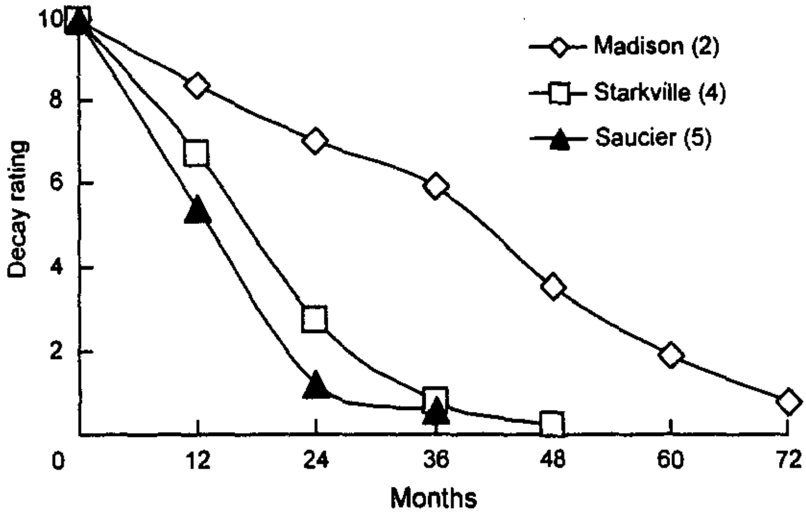


Figure 7. Average decoy ratingsfor stakes exposed in Madison (REA deterioration zone 2). Starkville (zone 4), andSaucier (zone 5).

These data show how variability in service life increases as regional deterioration hazard decreases. As might be expected, in areas where deterioration is slower the deterioration rate becomes harder to predict. This problem is also demonstrated by comparing the longevity of sets of 19- by 19- by 457-mm Southern Pine sapwood stakes exposed in Madison and Saucier over three decades (Figure 9). The average life of the stakes was 5.4 years in Madison but only 2.3 years in Saucier. This difference in durability corresponds well to the Scheffer indexes (Figure 3) and REA deterioration zones (Figure 5) for those locations. However, the range of average stake longevity was also greater in Madison (3.6 to 7.4 years) than in Saucier (1.5 to 3.6 years). The cause of the difference in longevity of Southern Pine stakes in Madison is unclear. It could be related to variations in weather patterns over the period, or to differences in soil conditions within the Madison plot. Differences in wood properties are also a possibility, but this effect was not evident in the matched sets of stakes exposed in Saucier. There was essentially no correlation (R^2 = 0.03) between the longevity of matched sets of stakes at the two sites.

Challenges in Applying the Hazard Zone Concept to Preservative Use and Development

Little recognition is currently given to regional biodeterioration hazard in the development and use of treated wood. Regional differences are

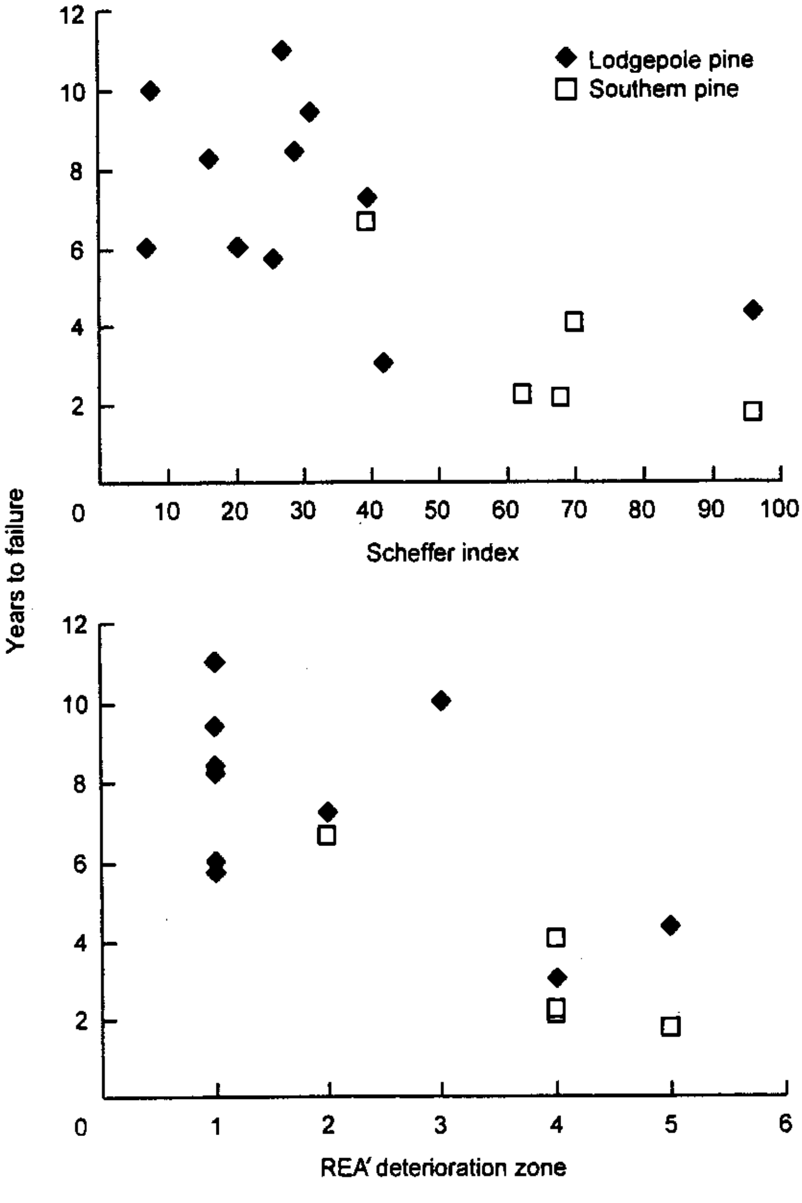


Figure 8. Durability of untreated pine fence posts relative to Scheffer index and REA deterioration zone.

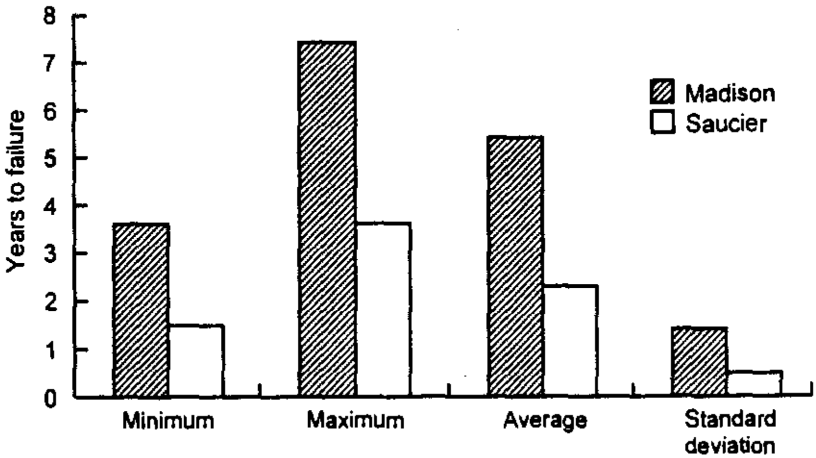


Figure 9. Durability of matched sets of Southern Pine stakes exposed in Madison or Saucier from 1939 to 1971.

acknowledged simply by evaluating new preservatives at test sites in the most severe deterioration zones. This approach is logical because in most cases it ensures that preservatives will perform well in regions with lower deterioration hazards. However, this "worst case" approach also means that the wood is over-protected in much of the United States. In northern regions, more chemical is used than is actually needed; in some areas, it is possible that less expensive or less toxic chemicals could be substituted for current formulations. As the cost of preservative formulations increases and as society's acceptance of chemicals decreases, it would seem advantageous to tailor preservative treatments more closely to the extent of biodeterioration hazard in a region.

However, there are serious challenges to matching preservative formulations to regional deterioration hazards. As discussed previously in this chapter, considerable variability can occur in the durability of untreated wood exposed in areas with similar deterioration hazard. This variability in deterioration rate increases in the northern regions of the United States, although differences in the distribution of termite populations can also cause variability in southern regions. The deterioration rate is also a function of wood species, although to some extent this problem can be ignored because the treated wood market is dominated by a single species group (Southern Pine). Thus, predicting the service life of untreated wood based on region is difficult enough. The addition of preservative to the wood appears to further increase variability.

In a comparison of matched sets of treated stakes exposed in multiple locations, the longevity of untreated controls corresponded well to the expected deterioration hazard of the site but the performance of the treated samples was less predictable (*24*) (Figure 10). For example, the durability of sodium pentachlorophenol was substantially greater than that of the other preservatives in the Panama Canal, but wood treated with this biocide did not perform as well as the other preservatives in Madison. All the treatments were less durable in Bogalusa, Louisiana (Scheffer index 89) than in Jacksonville, Florida (index 98) or Saucier, Mississippi (index 96). Moreover, wood treated with sodium pentachlorophenol and fluor chrome arsenate phenol deteriorated as or more rapidly in Madison than in Jacksonville. The reason for the durability difference between these treatments across these sites is not known. At least two factors influence the performance of preservative treatments: permanence and the presence of tolerant organisms.

Preservative Permanence

Climatic and exposure conditions can potentially contribute to regional differences in preservative permanence within the wood. In some cases, the effect is similar to that of, and may compound, the climate effect. For example, a preservative that is water soluble will tend to leach more quickly in the same types of climate that favor decay and termite attack. In other cases, such as a preservative that is susceptible to ultraviolet degradation, the effect of climate might be most severe in areas with relatively low deterioration hazard. Regional effects on preservative permanence in wood placed in ground contact are not well understood. Leaching in soil has been shown to be a function of soil chemistry and microorganisms, but the complexity of the soil system has made these relationships difficult to define (*25–28*). The relationship between exposure environment and preservative permanence is further complicated by the variability in depletion between similarly treated and exposed samples (*27*).

Preservative-Tolerant Organisms

Some regions have organisms that are tolerant to preservative components. Biocides with excellent fungicidal properties may have little or no insecticidal properties, rendering the wood vulnerable to attack by termites or other wood-boring insects. This risk tends to correspond to regional deterioration hazard because insect attack is most severe in the southern regions Even within those zones, however, preservative tolerance can vary. An example of this problem is the erratically distributed Formosan subterranean termite in the southern United States. These termites are more tolerant of preservatives than are native termite species (Table II), but their presence may not be known until after attack has occurred (*22*).

Table II. Degradation Comparison of Treated Specimens by Formosan or Native *Reticulitermes* Termites at Lake Charles, LA

Preservative Formulation	*Retention (kg/m³)*	*Rating[a]*	
		Formosan termite	***Reticulitermes* spp.**
Boarx–copper	0.60	5.7	8.5
Borax–copper	1.20	6.6	8.1
Borax–copper	2.40	7.4	8.8
Borax–copper	3.53	7.8	8.9
Disodium octaborate tetrahydrate	4.19	7.7	9.3
Chromated copper arsenate (CCA)	6.13	9.2	9.7

[a] Rating of 10 denotes sound and 0 denotes failure.

Similarly, conditions that slow the rate of drying (e.g., shade, construction design) and deposition of leaves or other organic matter can create areas where wood is exposed to a greater deterioration hazard than might be predicted for a particular climate. The nearly endless variety of the ways in which wood is cut and used also creates a broad range of potential moisture conditions. In a recent study in Minnesota, Schmidt and Jordan (*30*) noted that millwork components in some buildings had completely failed within 5 to 7 years, while untreated specimens exposed above ground suffered only slight to moderate decay during an equivalent period. In this case, condensation and moisture retention appear to have accelerated decay beyond that expected by climate alone. Many localized conditions cannot be controlled or predicted, even by the retailer of the treated product. As with the broader differences in regional deterioration hazards, the response to this problem has typically been to evaluate and develop preservatives for worst-case conditions.

Summary and Research Needs

It has long been recognized that wood exposed in some areas of the United States, such as the Southeast or Hawaii, deteriorates more rapidly than does wood exposed in other locations. Regional differences in deterioration rate are linked to factors such as temperature, precipitation, and insect population. Temperature and precipitation have been recognized as the primary factors and have been used in attempts to model and quantify rates of deterioration, especially in aboveground applications. A review of the data revealed that although models such as the Scheffer index often correlate well with observed

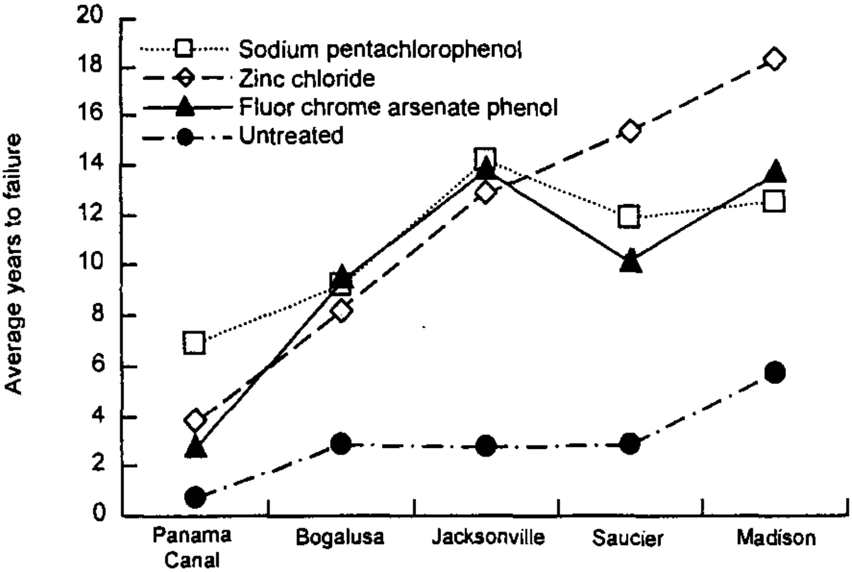


Figure 10. Relative durability ofmatched sets oftreated stakes at five exposure sites.

Copper tolerance by some types of fungi is a similar problem, although the presence of or colonization by these fungi is even less predictable than that of Formosan subterranean termites. Copper-tolerant fungi often colonize only one or two stakes within a exposure plot, or may rapidly destroy a stake that has not shown signs of colonization for more than a decade (29). The geographical distribution and concentration of these fungi is not well understood. Even less understood is the role that non-wood-degrading organisms, such as bacteria, molds, and other fungi, may play in altering preservatives so that they are less effective against wood-degrading organisms.

Local Variations in Deterioration Hazard

Perhaps the greatest difficulty in tailoring preservative treatment to regional deterioration hazard is local variability in conditions and in types of applications for treated wood. As discussed previously, localized populations of organisms such as the Formosan subterranean termite or copper-tolerant fungi can create problems for some types of preservatives. Localized deterioration zones also exist. Even in the driest climate substantial deterioration hazard may exist in low-lying areas, and irrigation can create artificial deterioration hazards.

rates of biodeterioration, there remains variability that is difficult to quantify or predict. In untreated wood, factors such as wood species, type of application, and localized insect population can influence the rate of deterioration. Variability is greatest in regions with relatively low deterioration hazard. Further variability is introduced when preservative-treated wood is evaluated because individual preservatives may be affected differently by regional conditions and wood degrading organisms. Finally, there remains the problem of localized deviation from regional hazard because of irrigation, shading, drainage, condensation, or other factors, particularly those that affect the rate at which wood dries.

These sources of variability within and between regions have made it difficult to tailor the development and use of treated wood for specific regional biodeterioration hazards. As in the past, preservatives continue to be evaluated under high-hazard conditions and used as if these conditions exist throughout the United States. As a result, preservative concentrations or the spectrum of preservative toxicity may be greater than necessary in many parts of the country. This situation will continue until research quantifies the deterioration rate under a broader range of conditions. Specifically, data are needed on the deterioration rate of wood exposed above ground in the northern two-thirds of the United States. Research is also needed on moisture content and deterioration rate for a broader range of exposure scenarios and wood dimensions. Even with such research, however, conservative assumptions will still be required to account for localized increases in biodeterioration hazard.

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Tor P. Schultz, Editor
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Michael H. Freeman, Editor
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Barry Goodell, Editor
University of Maine

Darrel D. Nicholas, Editor
Mississippi State University

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