Wood Decay and Protection

THE decay and protection of wood products are rich areas of study. Humans have been protecting and preserving the wood we convert from trees to use for art, shelter, transportation and tools since our prehistory. Biodeterioration agents and the processes they employ to return converted wood back to the environment are not the only threats to the longevity of wood. Fire, sunlight (ultraviolet radiation) and normal weathering (erosion) must also be addressed if wood in our built environment is to last.

We are accustomed to thinking of wood as a degradable—a biodegradable—material. We have celebrated this characteristic of wood and thus termed it a "natural" building material. Of course, for any biology this has to be the case lest the world be overrun.

A British civil engineer wrote in 1868: "Though sometimes, in ignorance, the perishable character of all surrounding things may be lamented, yet on the other hand, it must not be forgotten that perpetual destruction and perpetual renewal are in reality the essential causes of all life, beauty and harmony" (Clark 1868). We may translate this to mean that death and decay are life processes.

Wood degradation from sunlight and weathering may be inevitable, but its progress is often measured in centuries—about ¼ in. of thickness per century on average, according to the Forest Product Laboratory's *Wood Handbook*, a standard reference.

We are all aware of circumstances where wood has continuously performed its structural, protective or artistic function for centuries, in Japanese temples, stave churches and other ancient timber buildings throughout Europe, China and elsewhere. One attribute these structures share is protection from the organisms (or nonexposure to them) that use wood as their food source or shelter. On the other hand, we all have experienced the wood failures resulting from bioagents. One estimate is that 10 percent of all US domestic lumber production is purchased for replacement of rotted material alone, not including damage by more mobile agents (Lyon undated).

Marine borers have bedeviled navigators and harbor masters, particularly in warmer waters, for as long as both have existed. It has been proposed that throughout history more ships were lost to the ravages of borers than to poor seamanship (Hochman 1973).

By the early decades of the 19th century, the British had learned much about the nature but not the cause of decay (Wade 1815). They knew that moisture, oxygen and moderate temperatures promoted dry rot, and that the absence of those conditions and the addition of certain chemicals and salts—preservatives—retarded its growth. But it was not until the 1870s that fungi were recognized as the cause of decay rather than a result of decay.

Biodeterioration Agents There are four principal groups of biodeterioration agents that attack converted wood: marine borers, fungi, insects and bacteria. Bioagents attack wood for food and for shelter. Sustenance is by far the most significant and frequent reason. Wood and woody fibers are primarily cellulose, hemicellulose and lignin, which together make up 95 percent of the woody substance. The cellulose and hemicellulose, comprised of starches and sugars, offer significant energy stores for all of these organisms, and the lignin is used by some of them as a food source as well.

Besides a source of food, the other requirements for survival of the bioagents are moisture, oxygen, warmth and an acceptable environmental pH level. Without all these necessities the growth of the organisms will not occur or will cease.

Because these organisms cannot generally bring their own moisture, maintaining a low equilibrium moisture content (EMC) in the wood is the easiest way to forestall, arrest or end an infestation. Equilibrium moisture content is a function of the temperature and relative humidity of the air surrounding the wood, and is defined as that MC at which the wood is neither gaining nor losing moisture (Fig. 1).

To be susceptible to attack, wood must be at or above 20 percent EMC, and as high as 30 percent for sustained growth of decay, marine borers and bacteria. Drywood termites, as their name suggests, are not limited by this requirement.

Few natural environments in North America experience humidity and temperature regimes high enough to sustain colonies. Man-made environments, such as crawl spaces, may however provide conditions for such a high EMC.

Temperatures amenable to bioagent growth are the same as for any plant life. Growth virtually ceases at temperatures below 2°C (35°F) or above 38°C (100°F). For decay, growth slows outside of the range of 10°C and 35°C (50°F to 95°F), and for marine borers warm waters between the Tropics of Cancer and Capricorn are much more susceptible. Termites and other wood-eating insects exist only between the latitudes of 50 degrees north and 50 degrees south.

Oxygen, not controllable in any practical way, is readily available to these organisms, at times even under water, sustaining bacteria and marine borers. For decay and insects, submersion terminates growth because these organisms require airborne oxygen to survive.

For pH, decay fungi prefer the more acidic environment that naturally occurs in wood. Thus high alkalinity, even a pH-neutral environment, curtails growth. For marine borers, control of the acidity is difficult. For insects, very high or low pH levels have negative effects on their ability to consume the wood.

Bacteria Bacteria are ubiquitous, one-celled organisms, some of which aid in putrefaction, and distinct from typically multicelled decay fungi (Fig. 2).

The soil teems with bacteria, so it's inevitable that they are found in wood. Despite their abundance, bacterial deterioration is not common in wood. Bacterial degradation, frequently accompanied by a sour smell, is most often associated with fully submerged logs (such as in log ponds), in below-water foundation and marine piles or in piles installed in highly moist soils. Very high moisture content, at least as high as the fiber saturation point (FSP), seems to be necessary for infestation. Progression in log ponds can be rapid, occurring over several months, but structural deterioration occurs only over prolonged exposure.

Bacteria feed primarily on the cellulosic starches in the sapwood, traveling from cell to cell by destroying the pit membranes—the thin carbohydrate semiporous remnant of the primary wall (Fig. 3.)

They progress radially inward from the outside surface of the wood or log via the ray cells and transverse resin canals. The destruction of the pit membranes, creating passages between the cells, is responsible for increased absorptivity of the affected wood, the principal effect of the bacterial degradation. The damaged wood absorbs stains, paints and sealers more readily, leading to uneven finishing, discoloration and wet spots. Generally, this is a cosmetic not a structural issue, but prolonged exposure, measured in decades, has been reported to lead to significant crushing strength losses in softwood foundation piles ranging as high as 20 to 60 percent (Scheffer 1973).

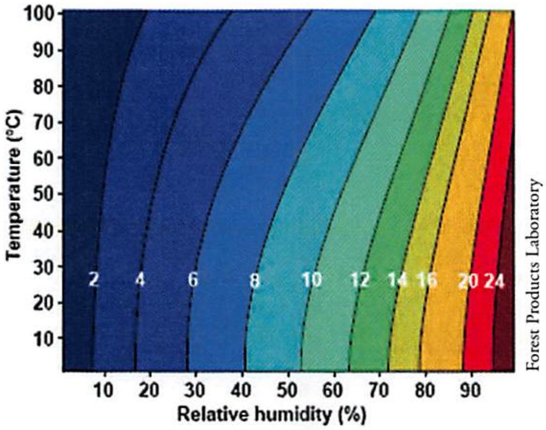
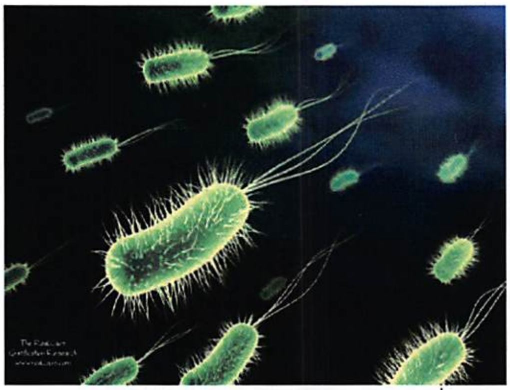
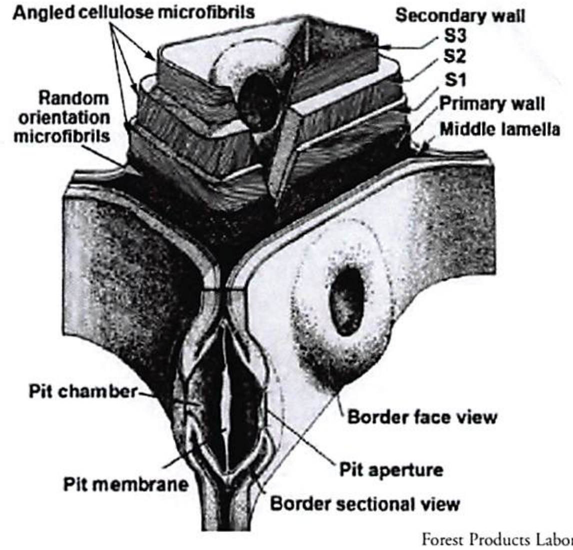


Fig. 1 Equilibrium moisture content as a function of relative humidity and temperature.



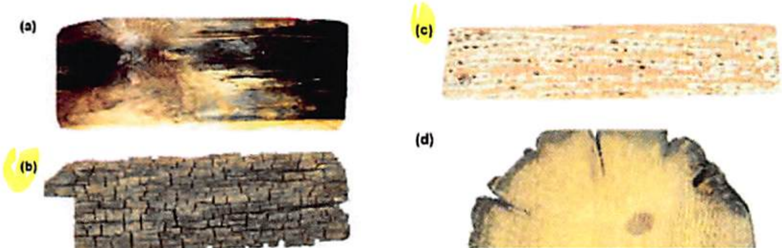
www.realcaos.com

Fig. 2 There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a milliliter of fresh water.



Forest Products Laboratory

Fig. 3 Wood cell wall cutaway. Layers begin with middle lamella. Primary wall shows random orientation of cellulose microfibrils. Secondary wall has three layers, each with specific microfibril angle. Bordered pit sectional view drawing overlaid on near corner of cell wall.



Forest Products Laboratory

Fig. 4 Four types of wood rot: a) mold discoloration; b) brown rot (dark color and cubical checking); c) white rot (bleached appearance); d) soft rot (shallow depth).

Cornell Fungi

Patrick Moffett

Bruce Lindsay

Figs. 5–7 From left, brown rot in timber, white rot in house trim and sapstain in newly manufactured lumber.

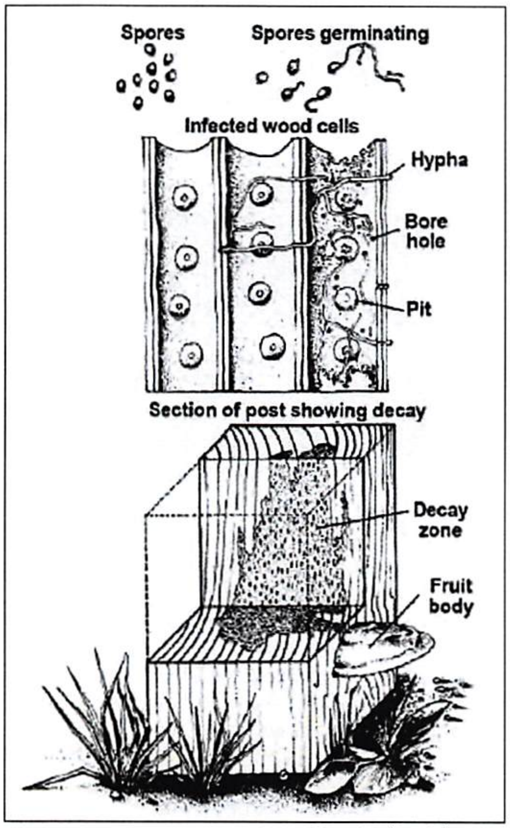
Fungi Dry rot, one of the two ancient scourges of wooden ships, is a common name for the damage caused by decay fungi. Fungi, including decay fungi, number over 60,000 species and, like bacteria, are microorganisms. It's convenient to classify the economically important fungi by the damage that they do (Fig. 4).

They include the decay fungi that cause brown and white rot as well as three other types of damage: soft rot, stain and mold. These five types of fungi (four types of damage) taxonomically belong to two phyla: Ascomycota and Basidiomycota. Their economic and wood-strength impacts differ greatly, but their needs and behavior have more similarities than differences. Together they account for more economic damage than all of the other bioagents combined.

Brown and white rot fungi (phylum Basidiomycota) are decay fungi that attack the cellulose and lignin of cell walls, consuming stored energy and eventually destroying the structure of the wood (Figs. 5 and 6).

Soft rot (phylum Ascomycota) works from the outside in, much as bacteria do, weakening or softening the surface of the wood, but does not typically extend very deeply beyond the surface (Fig. 4d). As the name indicates, staining fungi of the phylum Ascomycota mostly damage (the value of) wood by staining it, sometimes deeply (Fig. 7).

Mold fungi, also of phylum Ascomycota, act similarly to discolor the wood though they are mostly a surface phenomenon.



Forest Products Laboratory

Fig. 8 At left, the decay cycle (top to bottom). "Thousands of spores produced in a fungal fruiting body are distributed by wind or insects. On contacting moist, susceptible wood, spores germinate and fungal hyphae create new infections in the wood cells. In time, serious decay develops that may be accompanied by formation of new fruiting bodies" (Forest Products Laboratory 2010).

inspectapedia.com

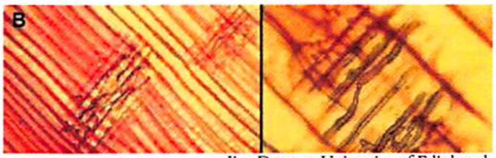
Fig. 9 Advanced *Meruliporia incrassata,* also known as poria.

123rf.com

Fig. 10 Furry mold growth. Color results from pigmented hyphae.

USDA Forest Service

Fig. 11 Sapstain can often begin in log, continues in timber or lumber.



Jim Deacon, University of Edinburgh

Figs. 12-13 Sapstain fungi seen in thin sections of wood stained with safranin. At left, section through two parts of the ray parenchyma traversing the xylem. At right, darkly pigmented fungal hyphae growing in the ray parenchyma.

Although the Basidiomycetes (brown and white rots) cause the most damage, the Ascomycetes (soft rot, stain, mold) often prepare the wood for the more damaging Basidiomycetes.

Fungi spread via spores, which are analogous to seeds. Spores are spread by wind, water, insects and contact, and millions can be produced by a single fruiting body (think mushroom). Once the spores find purchase on a moist wood surface, they divide and grow into *hyphae*, rootlike threads composed of haploid cells—cells with a single set of chromosomes. These hyphae branch and grow, "decaying" the wood as they do (Fig. 8).

Fungi have no chlorophyll, so they must obtain their energy requirements from plants that once did. To initiate the biochemical reaction, fungi secrete catalyzing enzymes that weaken and break the bonds of the crystalline cellulose in the cell walls and lignin polymers in and between the cell walls. The solubilized molecules released in this reaction can then diffuse back to the hyphae.

The biochemical process requires high moisture content. Water provides the solvent for the enzymes and causes swelling of the molecular polymers, stretching the bonds of the crystalline structure and allowing access for the larger enzyme molecules. Water conducts the enzymes away from the hyphae to break down the cellulose and lignin and conducts the catalyzed sugars back to the hyphae for consumption.

Wood is susceptible to these organisms only under specific conditions. Fungi prefer the same temperatures that green plants do and cease growing at temperatures outside this normal range. And, despite the misnomer "dry rot" (likely referring to the dry, cracked appearance of the wood after the brown rot decay has progressed significantly), decay and discoloration fungi of almost all species require high moisture content in the wood—around or above the fiber saturation point (usually 25 to 30 percent MC).

Under most circumstances, wood will not decay or discolor if it is kept air dry (generally considered to be 15 percent MC), and any decay or discoloration already present from prior infection will not progress. For decay to progress, wood must be exposed to water. Naturally occurring humidity, even at high levels, is generally not sufficient for these fungi to grow unless sustained by such surroundings as a damp crawl space. There is also an upper limit to suitable moisture content, usually at or above the saturation level for the wood species. Submerged wood will not decay from fungi as the oxygen necessary to sustain the decay fungi—which can be as little as 1 percent—is unavailable.

An important exception to this general rule is *Meruliporia incrassata* (the "house eating" brown rot fungus) found in the Gulf States, California and along the West Coast north to the Pacific Northwest. This fungus grows thick hyphal strands called rhizomorphs, which act like vines carrying water, typically from the ground, to the fungal infestation sites, thereby sustaining the fungus even when the surrounding wood is initially dry. If not arrested, this aggressive fungus can destroy large areas of wood construction in months (Fig. 9).

The two principal decay fungi are brown rot and white rot (Figs. 5 and 6). With some exceptions, brown rots prefer softwoods and white rots prefer hardwoods. Early in the infestation, decay fungi often penetrate the cells via the pits but move to boring holes through the cell walls very soon. Both types of rot create cavities parallel to the cell axis and the microfibrils, the bundles of crystalline cellulose that align longitudinally to give wood its distinctive grain structure and strength. Lignin is the "glue" that bonds these microfibrils together, allowing them to act in concert. Brown rot fungus processes and consumes the carbohydrates by dissolving the layers of the cell walls. The lignin portion, mostly in the middle lamella and primary wall of the cells, remains, giving brown rot its name.

As the cell walls are progressively consumed, the weak lignin lattice fails and the cell structure collapses, causing the wood to shrink and crumble. Brown rot also shortens the length of the cellulosic polymers, even in the early stages of the infestation, which is manifest in the distinctive cross-grain cracking and dramatically degrades the strength of the wood.

Natuurhistorisch Museum Rotterdam

Figs 14–17 Marine borers, here all *Teredo navalis.* Above, indication of individual creature's length and appearance. At right, white boring shells at head. At far right, a dense infestation. Drawing above right shows siphons that remain at entry end of borehole to pump seawater and clear the hole of debris.

15

chestofbooks.com

16

US Geological Survey

Filip Nuyttens, US Geological Survey

White rot fungus, besides consuming the cellulose, also breaks down and consumes the lignin. By removing most of the color constituents (pigments) of the wood including the lignin, white rot leaves the wood with a bleached appearance. In a white rot infestation, the fungus dissolves and consumes the cell walls starting at the lumen (cell void) surface, thinning the cell wall layer by layer to the middle lamella. This gradual thinning leaves the wood shape and structure largely unaffected until the late stages of decay. Highly degraded wood is spongy to the touch, because the internal structure is far more open and less dense. The deceptively sound appearance of earlier stages can have significant structural implications.

Soft Rot Fungi A third, generally less important, kind of decay is soft rot. Soft rot fungi belong to the Ascomycota phylum and are related to stain and mold fungi rather than to decay fungi. Their hyphae move through the lumen and the rays, attacking the S2 cell wall layer (see Fig. 3) and creating diamond-shaped, spiraling cavities. Like bacteria infestations, they primarily travel from cell to cell through the pits, living on the stored carbohydrates. Soft rot effects are also similar to bacteria infestation effects, typically affecting the outer surface of wood and resulting in relatively shallow damage. The affected wood is significantly degraded and soft when wet; however, immediately beneath the zone of rot, the wood may be firm (Fig. 4d).

Because soft rot usually is rather shallow, it is most damaging to relatively thin pieces of wood, such as slats in cooling towers. It is favored by wet situations but is also prevalent on surfaces that have been alternately wet and dry over a substantial period of time. Heavily fissured surfaces, familiar to many as weathered wood, generally have been quite degraded by soft rot fungi.

Mold and Stain Fungi Like soft rot fungi, these fungi attack mostly sapwood. Though stain fungi may be better known for attacking softwood, stain and mold fungi attack both hardwood and softwood. Both discolor the wood; sap or blue stain (which manifests in a variety of colors, not just blue, in specks or streaks as well as uniformly over the entire sap band) can go deep into the wood and cannot be surfaced off, while molds are mostly surface fungi, often with a furry growth that can be brushed off and surfaced clean (Fig. 10).

The discoloration is caused by pigment within the hyphae, so various species of fungus color the wood differently. The hyphae have been reported to pass through the cells mechanically rather than chemically, pushing through the pits and the ray parenchyma cells, rather than through boreholes as the decay fungi do (see Fig. 3). This is likely because these stain fungi consume stored carbohydrates in the sapwood rather than the wood itself, except in long-term exposures when they act more like soft rot fungi. As most producers and users of wood know, stain fungi infest sapwood rapidly when the circumstances are favorable—freshly cut logs in humid conditions. As long as the wood remains wet, stain and mold fungi can infest it at any time in the manufacturing, storage, transportation or construction process (Figs. 7 and 11–13).

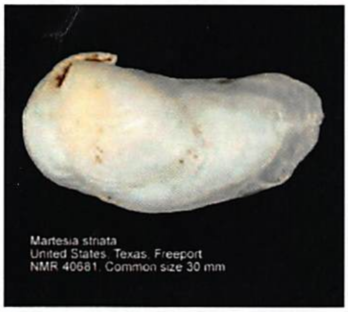
Strength Effects of Fungi Infestations All fungi affect the strength of wood, if in somewhat different respects. Soft rot and mold and stain fungi reduce toughness and impact resistance, as much as 30 percent. The other common effect of these fungi, like that of bacteria, is to increase the absorptivity of the wood at the damaged surface. The affected wood may absorb disproportionate levels of paints, stains, adhesives and sealers. Most important, greater absorbency means the wood will take up higher levels of water, putting the affected wood at increased risk of attack by decay fungi.

Decay fungi have a far greater effect. Laboratory tests demonstrate that a mere one percent loss in weight can result in a loss of toughness as high as 50 percent (Forest Products Laboratory 2010). Bending, tensile and compressive strength do not diminish as quickly; however, with only a 10 percent loss in weight the loss in mechanical strength properties ranges from 20 percent to 50 percent depending upon the property. In existing structures, this level of weight loss is not easily detectable. Further, both brown and white rot damage is latent; the wood retains its appearance except for a loss in luster until far into the decay process, after substantial loss of weight. If the damaged wood is structural, the building and its occupants may be at risk. Additionally, tests have shown that damaged wood fails rapidly, in a brittle fashion, much faster than undecayed wood (Scheffer 1973). An awl thrust into a timber to any appreciable depth likely indicates a significant loss of structural capacity.

Marine Borers Marine borers are an ancient scourge of wooden boats and waterside structures. Relative to fungi, marine borers consist of only a handful of species, but even within species their behavior, appetite and resistance can vary from harbor to harbor, making control of them challenging and unpredictable.

Marine borers belong to two different phyla: Mollusca and Arthropoda (subphlyum Crustacea). Molluscan borers or shipworms, such as the *Bankia* and *Teredo* genera, active along the borders of North America from Alaska to Maine, are bisexual bivalves, though most species do not retain that structure over their lives (see below). Crustacean borers, such as *Limnoria* and *Sphaeroma*, resemble insects also classified within Arthropoda.

Teredo, Molluscan borers, start life at a diameter of about 250 microns (less than 0.01 inches) and free-swimming, expelled by the adult borers after insemination. In a year's time, they can grow 35-fold in diameter (Figs. 14–17).



Natuurhistorisch Museum Rotterdam

Figs. 17–18 Examples of Pholad genera that maintain bivalve morphology. *Martesia*, at left, prefer warmer North American waters. *Xylophaga*, at right, live at depths of 2000m worldwide.

Auguste Le Roux

Fig. 19 Distinctive seven pairs of legs help identify *Limnoria quadripunctata*, also known as gribble, male and female shown above. The most common North American crustacean borers, they range the Atlantic, Pacific and Gulf coasts, attacking wooden docks and piers.

R. T. Springthorpe, Australian Museum   Ming Bell, Endless Blue

Figs. 20–24 Sphaeromatidae family members resemble pill bugs, comprise over 65 genera and range the world. Cabable of destroying marine structures, they generally are less destructive and perhaps more photogenic than *Limnoria*.

Teredo has about two days to find a place to bore before losing the ability to do so. After landing on wood, it crawls around on the surface using an amoeba-like foot, seeking a bore site. Given its size, it needs only bore a small hole to start a burrow. Once inside the wood, the borer rapidly grows a pair of boring shells on its head to consume the wood and extend the hole (Figs. 15–16). The bivalve structure is lost by this point. The borer also develops a siphon, a tubelike structure, to pump seawater through its body to obtain nutrients and to clear the hole of debris. As the borer extends the depth of the burrow, its siphon end remains at the initial borehole. Imprisoned within this tunnel, *Teredo* can grow up to 35cm (14 in.) in length and 1cm (⅜ in.) in diameter in a year. The small entry hole masks the extent of the damage, which in highly infected waters can lead to rapid infestation and unexpected collapse of wood structures.

Bankia, also shipworms, live a very similar life to *Teredo*, though the eggs and sperms are separately ejected via the siphon into the surrounding water where fertilization occurs. *Bankia* species spend up to a month free-swimming as larvae before infesting wood. After finding a home, *Bankia* can grow to lengths of 1.2m (4 ft.).

Pholads A third important genus of Molluscan borer is *Pholas*. Pholads such as the *Martesia* and *Xylophaga* species retain their bivalve structure to maturity (Figs. 17–18).

Pholas's life cycle is identical to *Teredo's*, from free-swimming larvae to lifelong imprisonment in their burrow of choice. Their clam-like structure limits their burrow to shorter but wider dimensions. Pholads generally do not exceed 65mm (2.5 in.) in length or 25mm (1 in.) in diameter. They also leave little evidence of their presence because they do not enlarge the initial borehole, just their burrows as they tunnel. Pholads are active in Hawaii and other Pacific islands, off the coast of Florida, and to some extent, off the South Carolina coast. They are not generally seen in waters off the western United States north of San Diego. They have been found at depths as great as 2200m (1.4 miles).

Crustaceans Borers such as those of the *Limnoria* and *Sphaeroma* genera are typically small, segmented animals with seven pairs of legs that end in sharp, hooked claws. The much more common and economically important *Limnoria* species (often called gribble) are 3 to 6 mm (⅛ to ¼ inch) in length and about 1 to 2mm (¹⁄₁₆ in.) wide (Fig. 19).

The *Sphaeroma* species, which resemble pill bugs and do much less damage, are typically larger, growing to 13mm (½ in.) in length and 6mm (¼ in.) in width. These borers move freely on the surface of the wood until they find suitable places to burrow (Figs. 20–24).

In low borer-population densities, only one male and one female inhabit a tunnel. The female settles in the blind end. Once tunneled in, they reproduce and spread within the timber, subsequent generations creating their own branching tunnels. They burrow just below the surface of the wood and often puncture the roof of the tunnel for ventilation. These shallow tunnels are prone to erosion by tidal action and floating objects. The erosion exposes the borers, causing them to tunnel ever deeper. Eventually, this process gives rise to the distinctive hourglass shape often seen on eroded piers at low tide. The attacked wood can become spongy and friable.

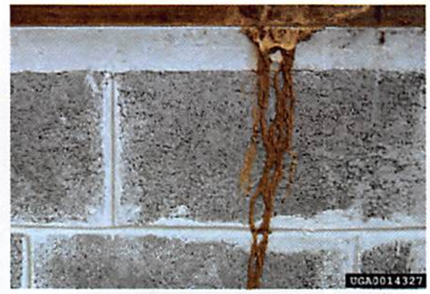
All marine borers are affected by temperature. Relatively small changes in temperatures such as 6°C (11°F) can increase the growth rate by sixfold in a month or 27-fold in three months (Hochman 1973). Salinity and oxygen, though not wholly independent of temperature, also play a role in growth rates. These factors are important for river estuaries where variations in river flow can change the levels of both oxygen and salinity, promoting infestations that had not previously occurred. Restoring health to a river system can also create the unforeseen consequence of improved

Scott Bauer, USDA

Fig. 25 Formosan subterranean soldier and worker termites *Coptotermes formosanus* feeding on Sudan-red-stained filter paper. Tracking termites stained with dye allows estimates of foraging range and population size.

Gerald J. Lenhard, Louisiana State University

Fig. 26 Enlarged view of *Coptotermes formosanus* adult worker (top) and soldier. Note soldier's powerful wood-destroying mandibles (open here) and dark, oval head contrasting with broader pale head of worker. Wing length 14–15mm, maximum head width 1.5mm. Worker often misnamed as wood-eating white ant.



USDA Forest Service

Fig. 27 Shelter tubes on concrete block surface, built by subterranean termites *Reticulitermes Holmgren* to communicate with ground, shown in Gulfport, Miss.

Rudolph H. Sheffrahn, University of Florida

Fig 28 Multiple castes, workers and soldiers, of West Indian drywood termites, *Cryptotermes brevis*.

conditions for infestations. Not merely boats but boathouses, docks and and piers are potentially at risk of infestation by borers.

Insects Though wood-eating insect damage is frequently more apparent, often quite severe and still economically significant, its aggregated cost is not nearly so great as the cost of damage by decay and stain fungi. From the familiar termite to the more obscure timber worms, all are classified as Arthropods, as are the Crustacean marine borers, and all belong to the class Insecta (no surprise there). There are hundreds of thousands of species within Insecta, and thousands of species that consume or otherwise destroy wood, wood fibers and trees. We'll focus on only the most important families, genera and species that destroy converted wood.

Most wood-attacking insects prefer wood with a high moisture content, either for nourishment or for ease of burrowing. Unlike in the case of decay fungi, keeping wood air dry is not always sufficient to forestall infestations. Even if the wood is air dry at 15 percent MC, species such as the Pacific powderpost beetle attack seasoned sapwood, often repeatedly until the wood is pulverized. Species such as subterranean termites can source their water from the soil they nest in and bring it to the infestation site. But most species of wood-attacking insects prefer wood with MC near or above the FSP. Beetles and weevils are thought to attack wood with high MC because they obtain nutrition from the decay fungi that precede them.

Most species of insects leave telltale signs of their presence, though the damage they cause is often hidden. Some termites build tubular covered passageways on surfaces. Powderpost and other beetles leave tiny accumulations of fine, powdery, flour-like dust, or frass, outside pinholes, even on vertical surfaces. Carpenter ants and bees, which tunnel in wood for shelter not food, carry or push the sawdust and wood particles outside the entries of their burrows, where an accumulation of the spoil signals their presence.

Termites Termites belong to the order Isoptera. Social insects, they live in colonies in a well-defined caste system of adults, workers and soldiers. Subterranean termite colonies can grow extremely large and require warmth, high levels of moisture and carbon dioxide, and low levels of light, making damp soil an ideal environment. Subterranean termites connect their colonies to feeding sites by building exposed, covered passageways that run around or over obstructions and up concrete or masonry walls, piers or slab edges (Figs. 25–28).

They prefer slab-on-grade construction, where wood is close to the soil, or crawl spaces, damp, dark and enclosed. Subterranean termites live worldwide between the latitudes of 50 degrees north and 50 degrees south, though they are better established in the warmer climes.

Nonsubterranean or *drywood* termites (Fig. 28) do not require high moisture levels or a connection to the soil. They can establish colonies in timbers and successfully develop in environments with EMC as low as 5 to 6 percent. They multiply more slowly, but left alone they can seriously damage a structure over years.

Wood-inhabiting termites can be transported in lumber and furniture to establish new colonies in distant locations. Their US range is currently limited to Hawaii and to a narrow strip of land that extends from central California down the coast, across the South to Florida and up the East Coast to Virginia.

All termites possess large, sharp mandibles, a distinctive and indispensable anatomical apparatus they use to tear off wood fibers before passing them to their crop, where the wood particles are ground and ingested. Termites rely upon protozoa or bacteria in their gut to digest the cellulose and obtain the stored energy, but they do not digest the lignin. Subterranean termites prefer to consume wood with high moisture content, and they prefer earlywood to latewood, which might explain why they typically tunnel longitudinally with the wood grain.

Powderpost Beetles These insects are members of the order Coleoptera (beetles), which contains over 350,000 species. Three families, Anobiidae, Bostrichidae, and Lyctidae, constitute the most economically significant wood-destroyers besides termites in the Insecta class. Unlike most wood-damaging insects, all three families of beetles attack seasoned wood.

Anobiidae are known as *death-watch* beetles because of their characteristic ticking sound, associated in folklore with the rapid passage of time as a forewarning of death. The death-watch beetle produces sound by striking the back of its exoskeletal head on the first segment of its thorax.

Bostrichidae and Lyctidae only attack the sapwood of broad-leaved species (hardwoods), consuming the starch and stored carbohydrates in ray parenchyma cells. The heartwood is not attacked. Anobiidae beetles, however, attack both sapwood and heartwood of softwoods and hardwoods (Figs. 29–30).

All three families of beetles bore small diameter holes (1 to 2mm or 1⁄16-in.-dia.) when they are in the larval stage. The wood is reduced to a flourlike consistency and accumulates in the galleries and at the entrances.

Pinhole Borers Two important families of pinhole borers, the Scolytidae and Platypodidae, belong to a group of beetles known as *ambrosia* and *bark* beetles. The adults, which do the boring, are 3 to 6 mm (1⁄8 to 1⁄4 in.) long and cylindrical in shape (Figs. 31–33).

Not as economically important as powderpost beetles, they attack hardwoods and softwoods, dead or dying trees, trees with damaged bark, newly cut trees (boring into the bark) and unseasoned lumber with a moisture content of 50 percent or more. Ambrosia boreholes are roughly round, 1.5 to 3 mm (1⁄16 to 1⁄8 in.) in diameter. When attacking newly felled trees, pinhole borers leave a light-colored frass at the entry point.

Ambrosia beetles do not consume the wood. They bore branching galleries to cultivate for consumption certain stain fungi (Ascomycota) that stain the wood black, degrading its appearance while not reducing its structural value.

Timber Worms Two families, Brentidae and Lymexylidae, also of the order Coleoptera, comprise only a few species each and define this group. Brentidae, designated as straight-snouted weevils, and Lymexylidae, called *ship-timber* beetles, do their damage as larvae (Figs. 34–35).

Timber worms, as adults winged beetles, are small, 4 to 20mm (5⁄32 to 25⁄32 in.) long, with narrow, parallel-sided bodies. The adult females drill holes the same size as ambrosia beetles in the wood and lay their eggs in the holes. The adults do not consume or damage the wood. The larvae feed on the wood, extending the burrows as they do. They also feed opportunistically on fungi in their burrows. Timber worms prefer hardwood species such as oak, beech and poplar, and they attack already damaged trees and newly cut logs.

Old-house Borer *Hylotrupes bajulus,* common name *old-house borer,* belongs to the family Cerambycidae and prefers seasoned softwood (Figs. 36–37).

Often infesting during the tree stage or in lumber yards, brown or black adults 15 to 25mm long (5⁄8 to 1 in.) deposit the larvae in natural cracks and crevices in the tree or checks in the lumber. The larvae grow to be 30mm (1¼ in.) long and bore into the wood, scraping the sides of the tunnel with their mandibles before consuming it and leaving the digested remains behind.

The larvae have been variously reported to take two to three years and five to seven years to mature. The differing reports may reflect differences in the moisture content of the wood affecting growth rate. The long larval stage may suggest a reason for the beetle's name, though at seven years a house would hardly be thought old.

The borers become apparent when they emerge as adults from the 6 to 10mm-dia. (1⁄4 to 3⁄8 in.) oval holes they cut. Damp spaces, poorly ventilated attics and leaky roofs reportedly can experience serious damage in short periods of time. The old-house borer makes an audible rasping sound while chewing with its hard jaws. Its range is from Maine to Florida and as far west as Texas and Michigan.

Hymenoptera: Carpenter Ants and Bees Belonging to the family Formicidae and the genus *Camponotus,* black and brown carpenter ants, with variant colors including red, are widespread and common in North America (Fig. 38).

They burrow in wood for shelter and can do considerable damage while creating extensive galleries over periods of months (Fig. 39). While they prefer wet or moist wood for ease of burrowing and because immature ants require a high relative humidity, they are found in many species and under many conditions of wet or dry, in logs, stumps, porch structures and foundation timbers or plates.

Carpenter bees, small and large varieties, belong to the family Xylocopidae (Fig. 40).

The larger bees, similar in appearance to bumblebees, nest in trees, wood and wood structures. Carpenter bees nest in most species though they prefer seasoned wood of the softer species—pines, cedars and redwood. They excavate chambers by vibrating their bodies as they rasp the sides of the burrow (Fig. 41).

The nests are as large as 15mm wide and 50cm deep (9⁄16 by 18 in.). The gallery may be compartmentalized for nursery and food storage purposes, and branching tunnels have been reported. They do not eat the wood, either discarding the frass or using it for partitions. Carpenter bee damage is not economically significant.

—Mack Magee

This article is the first of two on wood decay and protection. The second article will treat protection and preservation methods. Mack Magee (mmagee@fraserwoodindustries.com) is Business and Market Development Manager for FraserWood Industries in Squamish, British Columbia, and a principal at Fire Tower Engineered Timber in Providence, R.I.

Bibliography

Clark, E. "On Engineering Philosophy: The Durability of Materials." *Minutes of Proceedings, Institution of Civil Engineers,* 27:554-81. London, 1868.

Forest Products Laboratory, US Department of Agriculture. *Wood Handbook, Wood as an Engineering Material.* Madison, Wisconsin, 2010.

Hochman, Harry. "Degradation and Protection of Wood from Marine Organisms." In *Wood Deterioration and Its Prevention by Preservative Treatments,* Vol. 1, *Degradation and Protection of Wood.* Darrel D. Nicholas, ed. Syracuse, New York, 1973.

Lyon, William F. "Wood Rot," HYG-3300-96, Ohio State University Extension Fact Sheet. Columbus, Ohio, undated.

Scheffer, Theodore C. "Microbiologial Degradation and the Causal Organisms." In *Wood Deterioration and Its Prevention by Preservative Treatments,* Vol.1, *Degradation and Protection of Wood.* Darrel D. Nicholas, ed. Syracuse, New York, 1973.

Wade, Thomas. *A Treatise on Rot in Dry Timbers.* London, 1815.