Taken from *Slayers, Saviors, Servants, and Sex: An Exposé of Kingdom Fungi* by David Moore; published by *Springer-Verlag, New York: 2001,* ISBN 0387950982.

Chapter 3 Decay and degradation, a fungal speciality

The biological character that sets off the fungi from the rest of the higher organisms, animals and plants, is that fungi 'leak' their digestive enzymes into their surroundings. They digest food sources outside themselves, and then absorb the products of digestion as their nutrients. And, boy, can they digest. Pretty well any material you can think of will be digested as food by some fungus, somewhere - even somewhere close to you now!. It could be argued that our most memorable encounters with fungi center around their abilities to deteriorate things. Fungi can cause decay and ultimate destruction of standing trees, felled timber and all sorts of timber constructions - and that can be expensive! It was probably dry rot that made the *Speedwell* so unseaworthy that it could not accompany the *Mayflower* in its crossing of the Atlantic Ocean towards the New World in 1620. And it was 'the decayed state' of the *Investigator* that caused Captain Flinders, the explorer and navigator who first charted the entire Australian coastline, to put in at Mauritius and abandon the ship. Despite the fact that England was then at war with France, and the French authorities on the island imprisoned him as a spy for almost seven years.

Wood is a prime target, but fungi have such an enormous range of digestive capabilities that they can cause deterioration of electrical and electronic equipment, leather goods, paper and textile products and even optical equipment (some can extract mineral nutrients from glass!). They cause food spoilage, of course, and if food is destroyed in store, it's not only the pocket that suffers.

Even without digesting things, fungi can be destructive. Mushrooms may be soft and squashy, but they have been known to lift stone slabs and force their way through tarmac. Back in the 1860s a famous mycologist called M. C. Cooke wrote *A Plain and Easy Account of British Fungi* in which he told of '...a large kitchen hearthstone which was forced up from its bed by an under-growing fungus and had to be re-laid two or three times, until at last it reposed in peace, the old bed having been removed to a depth of six inches and a new foundation laid.' Cooke also tells of a comparable observation made by a Dr Carpenter: '...Some years ago the [English] town of Basingstoke was paved; and not many months afterwards the pavement was observed to exhibit an unevenness which could not readily be accounted for. In a short time after, the mystery was explained, for some of the heaviest stones were completely lifted out of their beds by the growth of large toadstools beneath them. One of the stones measured twenty-two inches by twenty-one, and weighed eighty-three pounds...' Don't go away with the idea that only 19th century building standards are prone to fungal attack. The Spring 1998 issue of the *Air France magazine* sported a beautiful colour photograph of a fruit body of a fungus called *Coprinus* which had forced its way through the tarmac of street in Paris. Another interesting pictorial example is a back cover picture on the April 1991 issue of the *Mycologist*, a magazine published by the British Mycological Society. This photograph shows fruit bodies of a puff-ball (proper name *Scleroderma bovista*) coming up through a tennis court. In this case the constructional history was recorded as: the original hard porous court made of fly ash was overlaid in 1989 with seventy-five millimetres of gravel and then a twenty millimetre layer of tarmacadam was rolled smooth. The fungal fruit bodies appeared in 1990. Game, set and match to the mushroom! A Canadian researcher called Reginald Buller did some experiments in the 1920s in which he put weights on the top of developing mushrooms to see how much pressure they could exert. He worked out that a single mushroom could apply a pressure of at least two thirds of an atmosphere - that is about ten pounds per square inch. It's all a matter of hydraulics, of course. The mushrooms can fill themselves with water and force their way through cracks and crevices. They are not doing it because of some perverse intention to break up paving, but because in nature they need to push through soil and plant litter in order to bring their fruit bodies to a position from which they can release their spores to the winds. Evolution has equipped them with the tools that ensure that fungi are a can-do kind of creature.

Another thing they can-do, very well indeed, is decay timber. In the two hundred years or so that Britain 'ruled the waves' with its wooden ships, fungi took on the might of the Royal Navy and seemed to win quite often. Wooden ships were expected to last a long time. Today, it's rather remarkable when a battleship is taken out of mothballs to use its big guns to pound a coastline or two, but up to about the middle of the nineteenth century vessels did not become obsolete. HMS *Royal William* lasted a hundred years, being built in 1719, taking part in the relief of Gibraltar in 1782 and being the flagship of the Port Admiral at Spithead in 1805.

The Royal Navy always preferred oak for the hulls of its ships. If the native forests had been able to supply sufficient English oak no other timber would have been used. Conservation legislation probably started with various timber preservation Acts of Parliament that were intended to remove fear of British naval supremacy being lost due to oak becoming scarce through reckless felling by controlling its use and encouraging attempts at reforestation. But wooden ships have always suffered from rotting of their timbers. Cycles of alternate wetting and drying of parts of the woodwork, poor ventilation and even the use of unseasoned wood in constructions all favor the development of the fungi to which have evolved alongside the trees to use wood as a nutrient. Unseasoned timber is bad news, or, as one of those old Acts of Parliament puts it: 'In buylding and repaireing Shippes with greene Tymber, Planck and Trennels it is apparent both by demonstration to the Shippes danger and by heate of the Houlde meeting with the greenesse and sappines thereof doth immediately putrefie the same and drawes that Shippe to the Dock agayne for reparation within the space of six or seaven yeares that would last twentie if it were seasoned as it ought.' That is, do it right first time or the damn thing will be back in dock and you'll have to do it all over again!

Samuel Pepys gave, inevitably, the best and most forthright account of the problem. Not in his Diary, but in a report to the Admiralty Board in 1684. As Inspector of the Navy he was required to carry out a survey of the fleet, especially thirty new ships. Unfortunately, his visit to Chatham docks showed only that: 'The greatest part of these thirty ships (without having yet lookt out of Harbor) were let to sink into such Distress, through Decays contracted ..., that several of them ..., lye in danger of sinking at their very Moorings. ... The planks were in many places perish'd to powder ... and the ship's sides more disguised by patching ... than has usually been seen upon the coming in of a Fleet after a Battle ... Their Holds not clear'd nor aird, but (for want of Gratings and opening their Hatches and Scuttles) suffer'd to heat and moulder, till I have with my own Hands gather'd Toadstools growing in the most considerable of them, as big as my Fists.'

In the last two quotations you have all you need to know about keeping timber constructions free of rot: use only properly seasoned timber and keep everything well ventilated. Unfortunately, their Lordships of the Admiralty did not learn their lesson. About one hundred and twenty-five years after the forthright eloquence of Samuel Pepys was delivered to them they built the *Queen Charlotte*. This was a first rate battleship of one hundred and ten guns, launched in 1810, just five years after Nelson's victory at Trafalgar. She rotted so quickly that repairs in the first six years of her life, even before she could be commissioned cost, £94,499 (more than the original cost of construction, which was £88,534!). By 1859 the total cost of repairs had risen to £287,837. She was broken up in 1892. By that time I estimate that, at today's prices, she had cost the equivalent of about two and a half billion US-dollars. That puts the cost of a nuclear submarine in context!

If use of well-seasoned timber and provision of adequate ventilation is the key to keeping your ship afloat, the same recipe will keep your house and home in safe condition. Structural timber is no different from other wood; it will decay unless kept dry. Proper building design is a key. Edgar Allen Poe understood well enough: '... I scanned more narrowly the real aspect of the building. ... Minute fungi overspread the whole exterior, hanging in a fine tangled web-work from the eaves. ...

In this there was much that reminded me of the specious totality of old wood-work which has rotted for long years in some neglected vault, with no disturbance from the breath of the external air ...' So, if the Ushers had taken Poe's pest control advice rather than dancing to his dramatic tune maybe the House would still be there.

The fungi causing the rot are those common in woodlands, and for the most part they are indifferent to the carpenter's expertise. Wood which is always dry is immune from fungal attack. If used out of doors or in humid conditions internally, all wooden structures eventually rot unless treated with some preservative. All kinds of wood are liable to attack; resistance to attack is relative. Soft woods being generally more susceptible than hard woods like oak, yew and teak.

There are three fungi which may be responsible for dry rot damage, but one called *Serpula lacrymans* is the chief culprit. When spores of this fungus fall onto damp wood they germinate and this is one reason why wet timber is prone to attack. The threadlike hyphae that emerge from the spores penetrate into the wood, releasing enzymes which extract nutrient from it to support continued growth. The fungus can get nourishment only from wood (and wood-derivatives like paper and board), but the extraction of those food materials brings about changes the chemistry and structure of the timber. The fungal hyphae may remain wholly within the wood, with no external sign of their presence until severe rotting has developed; bulging and cracking are then the signs of attack, especially evident with painted wood. The fruit-body of this fungus is not a mushroom. Rather, a flat, orange-brown or cinnamon-coloured surface-hugging fruit body that ranges in size from a centimetre or so across to a meter or more may be formed. And each square centimetre capable of producing close to a million spores. So numerous are the spores that dusty deposits of them on furniture, floors and other surfaces are often the first sign of dry rot noticed by the occupant of an infected house. But the spores are not the only way that *Serpula* can spread. Groups of hyphae join together along their length to form strands. Some of these can reach a thickness of five millimetres or more. The strands are invasive and the cells of which they are made co-operate to grow away from the food source which is already infected to find other food sources.

The strands can translocate food materials efficiently and this enables *Serpula* to spread over materials and structures from which it can derive no nutrition. Not just food. When *Serpula* grows on wood it decomposes it and eventually reduces the wood to powder (that's why it's called 'dry' rot). But when the chemicals that make up wood are digested, water is formed equivalent to half the dry weight of the wood. During active growth, therefore, the fungus can provide itself with the water it needs; so although it must have moist wood to begin its attack it can continue growth into dry timber. Indeed, when growth is luxuriant, there may be excess water produced from wood decay and this is exuded by the fungus in droplets. These are the tears suggested by the '*lacrymans*' part of the name.

In a real sense the strands are explorers and if wood is reached in a strand's wanderings it is immediately attacked and eventually destroyed. It is the strands that make *Serpula* so dangerous. Strands can penetrate through the pores in bricks, cement and stone, under tiles and other flooring, and over plaster and other ceilings; across anything that gives mechanical support. In the laboratory strands have been grown across a full meter of totally dry plaster board, and they can do this so long as the originally infected wood continues to provide nutrition to the explorer. When the English country house Haddon Hall was being renovated a large fruit-body of *Serpula* was found in a stone oven; apart from a few strands it had no visible connection with anything else. The strands of the fungus passed through the joints of nine yards of solid stone-work, all the way back to a rotting floor elsewhere in the building. That was the first the owners knew about their rotting floor! *Serpula* strands can translocate food materials in both directions (in the laboratory, it can be shown that food can flow in both directions *at the same time*). So when the strand finds newly discovered timber to attack, maybe several yards away from the original, the whole infestation is integrated into a single organism which might become the size of the whole building!

A fungus called *Phellinus megaloporus* is found as frequently as *Serpula* in parts of Europe and was responsible for serious damage to the roof of the Palace of Versailles. It requires very moist conditions and a relatively high temperature. It probably causes more rapid decay in oak than any other fungus, but it does not spread rapidly because it does not form strands. One of the other dry rot fungi, *Coniophora puteana*, is fairly common in buildings and characteristic of wood which is constantly wet. It does not extend its growth beyond the damp region. *Poria vaillantii* is not often found in buildings but was the scourge of damp mines where it rapidly reduced timber roof props to uselessness. The wet and warm environments in many mines favour rapid growth of fungi. Mine timbers five to six inches in diameter may rot completely in less than a year, and while rotting the wood the fungus produces long threads of white mycelium hanging down from the roof timbers. Like a Hollywood stage set!

Wooden ships, buildings and mine shafts are not the only ways we have of feeding fungi. Soon after railroads began to spread across the world’s continents it was realized that the wooden cross-ties (sleepers), being half buried in the ground, decay rapidly. In the US, a particularly troublesome mushroom proved to be one with the scientific name *Lentinus lepideus* but which became known as the ‘Train Wrecker’. It grew even on ties made from evergreen timber treated with creosote and some train derailments were blamed on the decomposition of crossties by this fungus. The US Department of Agriculture was so concerned that for several years it banned the import of the related shiitake mushroom for fear of the damage it might also cause. Because shiitake is not especially destructive, the USDA has since relented.

Not all wood deterioration results in destruction of the timber. There are other fungi (sap-stain fungi) that cause serious losses to the lumber industry by discolouring wood. Although the timber is not weakened, the discoloration renders the wood unfit for most purposes and so is value is downgraded. The sap-stain fungi are divided into two groups on the basis of whether or not they penetrate the wood. Where the fungus growth is superficial the stain does not penetrate the wood and may be removed by planing; but when the fungus penetrates into the wood the blemishes are too deep-seated to be removed. Stained lumber cannot be used when the wood is to be used with a natural finish, which is what reduces its value. Staining develops while the lumber is being stored. Sap-stain fungi develop most rapidly when the wood has a high moisture content and the weather is warm weather. So the oft-repeated preventatives apply - use well-seasoned (i.e. dried) timber and keep it well-ventilated. Some staining is actually sought-after for special cabinet work. The fungus *Chlorociboria aeruginascens*, produces a characteristic bright blue-green colour in oak and other deciduous trees and wood stained in this way has been used for ornament, usually marquetry, in products called Tunbridge ware. There is even a British patent issued in the early years of the twentieth century covering the artificial infection of trees with *C. aeruginascens* to generate stained timber. Wood turners appreciate the pleasing colour patterns that may result from discoloration in wood caused by the early stages of rotting. Dark lines are often found in infested wood. They are due to interactions between different fungi growing in the timber and to the effect of fungus growth on the chemical structure of the wood. It is called ‘spalted’ wood and the apparently random lines create natural decorative designs for bowls and vases. If rotting has gone too far the wood is unworkable, so finding a log in the right condition can be a challenge.

Attempts at wood preservation date back a long time. The most authoritative instructions were those given to Noah: ‘... Make thee an ark of gopher wood; rooms shalt thou make in the ark; and shalt pitch it within and without with pitch.’ Other ancient texts record the preservative properties of the oils expressed from olive, cedar, larch, juniper, valerian and so on. The Romans knew well that, ironically, wood kept continually wet is less liable to rot. According to Pliny: '... The pine, the pitch-tree, and the alder are employed for making hollow pipes for the conveyance of water, and when buried in the earth will last for many years...' And according to Christopher Wren: '...Venice and Amsterdam being both founded on wooden piles immersed in water, would fall if the constancy of the situation of those piles in the same element and temperature did not prevent the timber from rotting...' The fact is, that fungal decay of wood requires moisture *and* air. Whilst the timber is submerged it is relatively safe, maybe for hundreds of years, but if excavated without concern to its preservation it can decay in a few months. Various treatments to prevente ttehave emerged over the years. The oils of coal tar, obtained by distilling coal, that are heavier than water, are known as creosote. Although int tduced in 1838, creosote is still probably the most successful tf all wood preservatives. There are also other preservative tils in use, as well as water soluble chemicals, and chemicals dissolved in oils and non-aqueous solvents.

As for treatment, the traditional eradication strategy is removal and replacement of infected timber. This inevitably involves major building work, use of considerable amounts of chemicals and a lot of inconvenience and expense. A radical alternative approach emerged in Denmark in the early 1990s. It was observed that rafters directly under a blacke tof were rarely affected by the dry rot fungus. The temperature in such locations was often quite high and the moisture content in the timber low. Then laboratory experiments showed that *Serpula lacrymans* is very sensitive to high temperatures and so the idea emerged to use heat treatment to cure dry rot. Heat treatment, that is, of the whole building, or at least those parts of it most affected. Once a building surveyor has mapped out the extent of the attackeand the details of the construction, sources of moisture are identified and eliminated. Loss of strength in load-bearing timbers must be evaluated, because there is no alternative to their replacement if theyehave been weakened too much. The final preparative step is to simulate the treatment on a computer to optimize energy usage. Temperature sensors are put in places that are difficult to heat, e.g. in the centre of walls and beams. Then the building is covered with a one hundred millimetre thickness of insulation material on scaffolding. Finally, warm air from oil or gas burners is blown into and around the insulated zone. The temperature rise is monitored twice each day until it reaches forty degrees Celsius at which it is held for at least twenty-four hours. The laboratory tests indicate that this is sufficient to kill the fungus in the wood. When the heat treatment is finished, timber repairs or replacements identified in the initial survey can be done and the building restored to normal use, though continued vigilance against reinfection is necessary. The cost of a heat treatment is ten to fifty percent less than a standard repair and results so far are good enough to encourage the technologists to look for alternative ways of raising the temperature of a building. Like microwaves!

Fungi are quite capable of growing on waxes, paints, leather goods and all forms of textiles, from the finest cotton to the heaviest canvas. Possibly the most exotic example of fungal deterioration is that which occurs, especially in tropical regions, on optical equipment such binoculars and telescopes. Although glass alone probably does not support the growth of fungi, organic material on glass lenses or prisms, even in minute quantities (flakes of skin, dead mites, fingerprints), can provide sufficient substrate for fungus growth, which may then spread over the glass surface. In the majority of cases this sort of growth can be simply wiped from the glass to clean it, but sometimes the glass is definitely etched by the fungus and a fine network of unwanted 'scratches' are left behind on the lens or mirror. Some laboratory experiments indicate that certain soil fungi will grow on silica gels, dissolving other minerals they need from the silica and extracting nitrogen and carbon from volatile gases in the atmosphere. It's life, Jim, but not as we enjoy it!

Faced with a catalogue of destructive potential such as we've just been through it's difficult to avoid the conclusion that there is some purposeful malice at work here, aimed at destruction of human habitation, transport and possessions. Of course, that's too fanciful to be true. The truth is that fungi have been evolving for many hundreds of millions of years to live in natural wilderness habitats. Those habitats include fallen timber and all sorts of plant and animal debris, leaves, fur and feathers. But it's not a uniform mixture. There may be a large piece of wood here, and another piece over there, with all sorts of dirt, soil and rocks in between. So the evolutionary strategy that works for the most efficient wood decay fungi is to grow on one piece of wood and use some of the nutrient to send out exploring filaments to grow across the soil and rock to find the next piece of wood. That's what the forest floor is like for a fungus - islands of nutrient scattered over a mineral desert. Now, imagine that some monkey-like thing comes along and builds himself a country cottage - timber beams, stone floors, wooden stairs, brick walls. Books, shoes, fabrics and fast foods scattered around. Any passing fungal spore is going to see islands of nutrient scattered over a mineral desert. Just like home! And if it's nice and moist because the monkey-like thing keeps his windows closed ... yummy!

An organism becomes a pest when it does what it normally does, but in the wrong place. A fungus that rots the wood of your roof timbers is a pest; but the same fungus in the forest is doing an essential service for you. Fungi that decay organic material are a benefit to humanity in three very important ways. First, organic debris is continuously being removed from the environment. Second, since the debris is removed by being digested, large quantities of carbon dioxide are released to the atmosphere and made available again for use by green plants in photosynthesis. Third, the stuff that's left after the decay has gone as far as it can in the short term is the humus that forms the very structure of soil.

It's been calculated that a single large broad-leaved tree has at least a million leaves. At the end of the growing season the dead leaves fall to the ground. They'll weigh about two hundred kilogram. That's every year. In five years you've got a metric tonne of dead leaves. From one tree. I don't know if anyone has ever counted how many deciduous trees there are in the world, but my guess is around a billion or so. And every five years they make a billion tonnes of dead leaves. If fungi and bacteria were not digesting those leaves then on the one hand we'd have an awful lot of leaves to wade through to get to the office, and on the other hand the atmosphere would rapidly run out of carbon dioxide. Each growing season tremendous quantities of atmospheric carbon dioxide are used by green plants in photosynthesis. As a result, the carbon is chemically bound, first in sugar and eventually in other carbohydrates, proteins, fats, and in all of the compounds of which make up living things. While they are binding the carbon, the plants break up water and release the oxygen into the atmosphere. So, continued photosynthesis is necessary to maintain atmospheric oxygen, and carbon dioxide is necessary for continued photosynthesis. We depend on those natural digesters of organic debris for continuous recirculation of carbon by returning of carbon dioxide to the atmosphere. One estimate is that about half the atmospheric carbon dioxide is bound organically every year. If decay of wastes should cease we would not have to worry about the greenhouse effect because without carbon dioxide photosynthesis would stop and there'd be no oxygen to breathe.

Balance between production and decay is important; no, it's more than important, it's crucial. During that part of evolutionary time which is called the Carboniferous Period the rate of formation of organic material exceeded the rate of decay and an amount of material corresponding to four times the total carbon dioxide content of our present atmosphere accumulated. This covered a time interval of from three hundred and sixty million to two hundred and ninety million years ago, the name 'Carboniferous' originating in the United Kingdom, where it was first applied (in 1822) to the coal-bearing strata of England and Wales. Around three hundred and thirty million years ago tropical forests and swamps covered large areas of what would eventually become eastern North America and northern Europe. These areas had warm and humid climates because at that time they were situated in the tropics, immediately North of the equator. Such conditions promoted lush growth of the vegetation and marine organisms. Over the years it became our present day supply of coal (and oil and gas). If the balance were to be disturbed to that extent again, we'd be up to our ears in dead trees. Let's hear it for the wood-decay fungi!

It's not just a case of buildings and possessions being damaged by fungi, there's a little matter of food spoilage, too. If you think about an average food, say an egg salad sandwich on rye bread, you will appreciate that foods are complex and very varied ecosystems. That sandwich I've just mentioned features highly localized regions of concentrated carbohydrate, concentrated protein and concentrated fat. These regions differ drastically in chemical and physical characters and are likely to have been changed in different ways by the processing to which the different components have been subjected. Inevitably, therefore, there is a wide range of organisms that may cause food spoilage. They tend to have in common the feature that they can tolerate environmental extremes. Most foods are pretty dry. They are either genuinely dry, like bread, corn flakes, flour, or physiologically dry like molasses and brine in which the high concentration of sugar or salt make the water in the fluid difficult to access. Fungi which contaminate these sorts of food are highly specialized to dry conditions. Other extremes that food spoilage fungi might tolerate are acid (in pickled foodstuffs, for instance) and they may even survive the high temperatures used in pasteurization. Finally, some can tolerate the preservatives which are added to food to protect them. Indeed, some off-flavours and off-odours, especially those that resemble petroleum products, are caused by the contaminating fungus metabolizing the preservative. Food spoilage by fungi is sometimes a matter of public safety; remember those mycotoxins which some fungi produce. But this is relatively rare. The main issue is more likely to be consumer acceptability. Fungal food spoilage is usually fairly obvious, either to the eye (mouldy bread, for instance) or to the nose. The sense of smell is still the most widely used, and the most sensitive, detector for off-odours - the nose detecting volatile compounds produced by the fungus during growth. Even in today's microchip oriented world, the smell of a musty or mouldy grain shipment will still determine its value and acceptability after transport or storage. So spoiled products have a real image problem. Even if the spoilage is actually benign, the look and smell will make the food unacceptable. The result is that food preparation and processing industries cannot take risks. Contamination rates may be extremely low; maybe something much less that a one percent contamination frequency in a production run of one hundred thousand cans of a fruit drink, for example. But the risk of consumer resistance to the possibly contaminated product is too great, and even at that low level of contamination the product would have to be recalled and destroyed. Detection of spoilage organisms sufficiently early in the food preparation to enable them to be removed without damage to the product is the key to control. Much effort is being devoted to research aimed at developing electronic 'artificial noses' or, to give them their politically correct name, volatile compound mapping machines. However, trained people in 'sensory panels' still remain the principle analytical safeguard against contamination by food spoilage fungi. And the use of preservatives in the food products themselves is our on-going defence against the fungi. Continuous development of new approaches is needed, though, because the fungi continue to change. Common contaminants may mutate at any time to become tolerant of preservatives or more troublesome in the processing train. In addition, as commerce becomes more international, entirely new food spoilage fungi can be introduced to an industry from some other part of the world. The spoilage fungi are just as international as the industry they attack!