Wood-decay by non-hymenomycetous organisms

Timber, which is subject to decay by microorganisms while in the standing tree and subsequently when in use, were separated (Savory, 1954 A and B) into four groups - the bacteria, the wood-rotting Basidiomycetes, the sap-stain fungi and the wood-rotting micro-organisms. In the process of the succession (Shigo and Sharon, 1968) and close associations (Blanchette and Shaw, 1978) of micro-organisms, discolouration and decay of the wood resulting in (a) chemical changes initiated by micro-organisms (b) further changes by organisms other than Hymenomycetes and (c) decay by bacteria, non-hymenomycetous and hymenomycetous fungi were observed. Succession as well as association do not follow a general sequence. Shigo (1972) recorded succession of great variety of bacteria, Actinomycetes, nematodes, non-hymenomycetous fungi and some hymenomycetous fungi as well as Phycomycetes and slime molds in the discolouration and decay of Red-oak and White oak.

Close associations of bacteria, yeasts and mycelia were also observed (Blanchette and Shaw 1978) in logs naturally infected by four Basidiomycetes - Coriolus.
versicolor, Hirchiopurus abietinus, Cryptoporus volvatus and Fomitopsis pinicola. Associations among the colonizers of Pine stumps were observed by Meredith (1959) which contained as many as 21 species of Basidiomycetes, 5 of Ascomycetes, 2 of Phycomycetes and 12 of Fungi Imperfecti.

Succession of bacteria and non-hymenomycetous fungi have also been recorded (Shortle and Cowling 1978 B) in discoloured sapwood of sweet-gum and yellow-poplar trees with decay causing Hymenomycetes becoming abundant in latter stages. The coloured zones or the "pseudoslerotial plates" were the sheets of mycelia (on the non-decayed wood) around the decayed wood as referred to by Lopez-Real (1975) and also by Shigo (1965). From the columns of such "discoloured" wood surrounding the decayed wood three organisms commonly were isolated: a hymenocete from the decay, a non-hymenomycetous fungus (usually an ascomycete or a deuteromycete) and bacteria from the cells surrounding the decay.

Decay and discolouration of northern hardwoods usually involves organisms other than hymenomycetes and tissues, infected with these pioneer organisms, are discoloured. When conditions remain favourable, Hymenomycetes invade these tissues and cause decay (Shigo, 1967).
of succession and association were not delimited to
creation of the coloured zones but Kistler and Merrill
(1960) found \textit{Strumella coryneoidea} to behave like a
typical white-rotting fungus and appear to be more active
decay organism than species of Xylariaceae but not as
active as \textit{Polyporus versicolor}. Merrill \textit{et al} (1964)
found that the members of Xylariacea were as good as
the members of Basidiomycetes, but the action of the
former group were slower.

Soft-rot fungi (Ascomycetes and Fungi Imperfecti)
were prevalent in situations of extreme wetness or
frequent dryness - conditions that retard or inhibit
development of more aggressive wood-destroying Basidiomycetes
and were able to digest secondary walls of trachieds and
fibers (Duncum and Eslyn, 1966).

Although no general conclusion had yet been made
in support of utilization of cellulose and lignin, Merrill
and French (1966) found that the weight loss of wood
caused by \textit{Sporotrichium pruinosum} was comparable to those
by \textit{Lenzites trabea} (a wood-rotting Basidiomycetes); and
in ability to digest cellulose and lignin similar to
white rotting fungi.

The wood of \textit{Pinus ponderosa} buried in soil were
found (Merrill and French, 1966) to be colonized by *Fusarium solani*, *Trichoderma viride*, *Aspergillus ustus* and species of *Penicillium* upto 12 weeks. Shortle and Cowling (1978 A) recorded *Ceratocystis coerulescens*, *Fusarium oxysporum* and *F. moniliforme* as early colonizers of discolored wood and were replaced by decay fungi. Weight loss of wood although regarded as basic action of Basidiomycetes, Merrill and French (1964) recorded significant reductions in holocellulose with about one per cent weight loss by *Alternaria* and *Penicillium* and the latter species were found to cause substantial reduction of holocellulose and alpha-cellulose with about 13% weight loss. Boyce (1961) opined that the processes that lead to decay in living trees are usually thought to start with infection by a hymenocete only in spite of various records of succession of micro-organisms. However, Shain (1971) found no evidence to indicate that a succession of micro-organisms was necessary before invasion of *Picea abies* by *Fomes annonous*.

Shigo (1972) in a later stage opined that although there is little doubt that successions of micro-organisms occur during wood-decay, it was unwise to state that they occur always in the same manner.
Although Shortle and Cowling (1978 A) was in support of the view that succession of micro-organisms takes place in the process of decay and discolouration of wood, differed in that some of the decay-fungi cause wood discolouration independent of pioneer organisms and induce host response, and temporarily allows pioneer fungi and bacteria to flourish.

Keeping in view of the succession and association of the non-hymenomycetous fungi and their differential ability to utilize various cell-wall fractions, no general consensus could be made and Kirk (1971) was of the opinion that the role of soft-rot fungi, soil fungi and bacteria, at least as regards utilization of lignin, is doubtful.
Wood-decay by Basidiomycetous fungi

The role of higher fungi, specially of the Basidiomycetes group in wood-decay have been emphasized by various workers and obviously different opinions have been put forwarded.

Husain and Kelman (1959) in a review of the disintegration of wood tissues stated that approximately 2000 species of fungi belonging to the class Basidiomycetes alone have been categorised as wood decay fungi.

The wood-destroying fungi obtain food from cellulose, lignin, pentosans and other chemical components of the wood (Bakshi, 1953). Lignin can be completely decomposed (assimilated and metabolized) by wood decay fungi of the white-rot type and probably by the closely related litter decomposing Basidiomycetes (Kirk, 1971).

The fungi are rather selective in their food requirement. Likewise, the wood-rotting fungi can attack some particular tree species and can only get established in a particular portion of a tree. Again others can attack trees either in living or dead state.

A survey (Martin and Gilbertson, 1978) of brown-rot
and butt-rot of Douglas fir (Pseudotsuga menziesii) the decay was attributed to Sparassia radicata in 30% of the trees, to Phaeolus schweinitzii in 62% of the trees and both the fungi species in 8% of the trees. The butt-rot of Sitka Spruce by Fomes annonous accounted for the loss of 33% volume and 43% of value for rejection of butt-lengths per tree (Prait, 1979). In 114 of 137 trees of Juniperus excelsa, heart-rot caused by Pyrofomes demidoffii accounted for 96% of decay volume (Zakaullah, 1978).

Reyner (1977) found that in beech, birch and oak, tree species markedly influenced both the assemblage of Basidiomycetes species and the pattern of colonization.

Fomes annonous (Fr.) Karst. causes extensive central stem rot (heart-rot) in Norway spruce (Picea abies (L) Karst.) but the invasion is limited in sapwood (Shain, 1971). The most frequently and the fastest growing species of Hymenomycetes which invade Picea abies in seasonal stem wounds were Stereum sanguinoleutum, Cylindrobasidium evolvens, Peniophora pithya and Heterobasidium annosum (Roll-Hansen and Roll-Hansen, 1980).

Tissues were decayed and black lines were formed in the roots of Macadamia integrifolia both in natural
and artificial conditions by *Kretzchmeria clavus* (Ko et al, 1977).

*Fomes caryophylli* (Racib) and *Hymenochaete* (Schrad.) Lev. cause unsoundness to *Sal* and *Hypoxylon mediterranean* de Not. var. *microspora* Miller is frequently associated with dying and dead *Sal*. (Wealth of India). The infection may be traceable to timber in use.

In a sample survey of over 700 *Sal* trees, Bakshi, Rehill and Choudhury (1959) observed that decay was present in over 70 per cent trees entailing a loss of about 10% timber.
Resistance of wood to decay

The extraneous materials in wood are defined as those non-structural constituents that can be extracted with natural organic solvents or water. These include waxes, fats, fatty acids, alkaloids, essential oils, resins, sorins, terpines, tannins, (Hillis, 1962) and other phenolic substances, pigments of various types and lot of other materials.

Gardner (1962) recorded extractive compounds like \( \beta \) - Thujaplicin, Nootkatin, Dolabrin, Thuja-plicinol, Pygmaien from 10 species of Cupressus and eight species of Juniperus.

Many of these substances are deposited in the heart-wood; certain phenols and probably some tannins inhibit wood-destroying fungi, markedly influencing the natural durability of wood (Scheffer and Cowling, 1966).

Toxic extractible substances deposited during formation of heart-wood are principal sources of decay-resistance in wood. High resin content of Pine stumps was co-related with increased resistance to infections (Meredith, 1959).

Extracts from durable heartwood are much more
toxic than those from sapwood of the same tree (Hawley et al., 1924). Decay resistance of *Shorea robusta* and *Tectona grandis* is attributed to the combined toxic effect of different extraneous materials (Puri, 1967).

Normal undamaged sapwood of *Pinus ponderosa* does not produce pinosylvin and pinosylvin monomethyl ether (two extractible compounds) but restricted to heartwood under conditions of dessication (Jorgensen, 1961) may have contributed to the decay resistance of *Pinus taeda* against *Pomes annonous* (Shain, 1971).

Nitrogen content of the wood tissue may influence its susceptibility to wood inhabiting fungi. A low nitrogen content in wood increases its resistance to decay (Merrill and Cowling, 1965).

Levi and Cowling (1968) recorded a marked decrease in the nitrogen content of sapwood in stems of *Quercus falcata* was correlated with correspondingly significant reduction of the susceptibility of the wood to decay by typical white-rot and brown-rot fungi, *Polyporus versicolor* and *Lenzites trabea* respectively.

Intimate nature of association between lignin and wood-polysaccharides prevents many cellulolytic organisms from degrading wood (Pew, 1957; Pew and Weyner, 1962).
The non-decay fungi that invade the heart-wood of western red-ceder make about some chemical changes and thereby deplete the decay-inhibitory extractives. This may be a means for change in decay-resistance (Scheffer, 1957). A contradictory opinion that microorganisms sometimes may contribute to the apparent resistance of sapwood - Nectria cucurbitula inhibited the growth of Fomes annonius in vitro (Shain, 1971).

A 0.5% suspension of spruce (Picea abies) oleoresin in malt extract agar inhibited the growth of Fomes annonius by approximate 50% (Shain, 1971). Volatile components of Pinus ponderosa oleoresin inhibit the growth of F. annonius and four Ceratocystis spp. (Cobb et al, 1968). There was no significant decrease in resistance in extractive free wafers of southern yellow pine sapwood to decay by Polyporus versicolor (Pettersson and Cowling, 1964). A contradictory finding of Puri (1967) was to find a correspondingly progressive loss of decay resistance of Tectona grandis and Shorea robusta with successive extraction with cold water, hot water, petroleum ether, methanol, ethanol and acetone.

For reasons yet unknown, much more moisture must be present in wood than in other tissues before deterioration
can be initiated (Cowling, 1963). Plant tissues are protected very effectively from microbial deterioration so long as their moisture content is maintained below a critical level that is characteristic of the tissues and organisms involved (Cowling, 1966).
Role of nitrogen in wood-decay

One of the most intriguing aspects of the disintegration of plant tissues by micro-organisms is the capacity of the wood-destroying Basidiomycetes to metabolize the cellulose, hemicelluloses and lignin in xylary tissues that contain very meager amounts of nitrogen (Levi et al., 1968).

The amount of nitrogen in the wood is rarely greater than 0.3% by weight and commonly may be only 0.03% - 0.10%. Although the carbon/nitrogen ratio in common artificial media is approximately 10/1 - 20/1, in wood the ratio may vary and as low as 350/1 - 1250/1 (Merrill and Cowling, 1966).

Although the supply of nitrogen in wood is meager, the wood-destroying fungi can readily metabolize the carbon-rich constituents of wood by employing one or more of the following three mechanisms - (I) preferential allocation of nitrogen obtainable from wood, (II) reuse of nitrogen obtainable from wood by dynamic process of autolysis and reuse without significant loss and (III) utilization of nitrogen sources outside the wood itself (Cowling and Merrill, 1966).
Wood-destroying fungi conserve the meager supply of nitrogen in wood preferentially allocating available nitrogen to metabolic substances essential to the efficient utilization of wood constituents (Mevi and Cowling, 1969). However, Klingstorm and Oksbjerg (1963) found no evidence of atmospheric nitrogen fixation by Merulius lacrymans during decomposition of wood.

Pomes applanatus, Irpex mollis, Lenzites trabea, Schizophyllum commune, can parasitize the cells of Ceratocystis fimbriata and C. fagacearum and can utilize the released nitrogen from the killed cells and perhaps aid in their colonization of wood (Griffith and Barnett, 1967). L. trabea can utilize whole mycelia or cells of C. caerulescens as a source of nitrogen (Levi et al, 1968).

The role and importance of nitrogen in wood deterioration and decay resistance have been worked out by various workers. There are positive straight line correlation between nitrogen content of test blocks and their rates of decay of Populus grandidentata by L. trabea, and Polyporus versicolor (Merrill and Cowling, 1955). P. versicolor and F. applanatus adapted their mycelial nitrogen content to that of wood used as substrate (Merrill and Cowling, 1966 A).
Definite relationship was established between nitrogen content of the wood of *Populus grandidentata* and its susceptibility to decay by *Lenzites trabea* and *Polyporus versicolor* (Merrill and Cowling, 1966 B). Xylem sapwood of susceptible trees contained more nitrogen and carbohydrate and was more favourable for the growth of *Stereum gausapatum* than was the sapwood of resistant trees (Beever, 1970). Nitrogen content of sound and decayed wood indicate that there is little change in total nitrogen content of wood during decay. Nitrogen present is utilized more effectively during decay than is that added (Hungate, 1940).

Levi and Cowling (1968) observed marked decrease in nitrogen content of sapwood of *Quercus falcata* during defoliation and this decrease was correlated with significant reduction of susceptibility of the wood to decay by *P. versicolor* and *L. trabea*. Wood destroying fungi conserve the meager supply of nitrogen in the wood by preferentially allocating available nitrogen to metabolic substances essential to the efficient utilization of wood constituents (Levi and Cowling, 1969).

*P. versicolor* rapidly utilized various types of nitrogenous compounds that occur naturally in wood or
become available during autolysis of mycelium decay (Levi et al, 1968).

Addition of ammonium nitrogen increased breakdown of applewood by *Trametes versicolor* in vitro. An inverse relationship between the level of wood-decay and the level of glucose in the medium was established (Derbyshire et al, 1969).

Nitrogen source in vitro differed the dry weight production and cellulase activity of *Stereum gausapatum*, regardless of the substrate on which it was grown (Jensen, 1971); simultaneously affecting decay (weight loss) of wood.