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FOREST PATHOLOGY[1]

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FOREST pathology is a comparatively new branch of forestry science in the United States, yet within the brief span of its development in this country and in other countries of the globe there has been an imposing amount of literature contributed on this subject. Like the science of bacteriology, forest pathology emerged from a cloudy mass of misunderstanding then known as the theory of spontaneous generation and began a comparatively rapid development leading to its present height.

It is not strange that in the period when living organisms of a low order associated with putrefaction of matter, fermentation and disease of man, beast and insect were believed to have originated spontaneously that the same theory should be applied to the lower organisms found associated with the decay of wood and with tree diseases. In 1833, Theodore Hartig, a forester and professor at Braunschweig in Germany, was the first investigator to study and record the occurrence of mycelium in wood. Under the influence of the Ungerian period he concluded that the organisms represented by these fungous threads developed by means of spontaneous generation from the rotted wood. He described this as the "breaking up of cell structure into balls or monads which later form rows and fuse to form fungus hyphae." Although an erroneous concept this was the beginning of forest pathology.

The early work in a newly occupied forest area is often given over to a survey or inventory type of inquiry which is frequently mycological in nature. This is an essential part of the knowledge of the tree-inhabiting fungi found in any forest area. Since much of the mycological ground has been broken in the earlier development of forest pathology, there remains relatively less to be done in the future, and a greater share of the pathologist's time will presumably be devoted to the pressing problems in forestry that call for pathological study.

[1] Presented before the Symposium on Forest Trees, Pacific Division of the American Association for the Advancement of Science, at Eugene, Oregon, June 19, 1930.

The introduction into this country of epidemic types of tree diseases, such as the chestnut blight and the white pine blister rust, developed for the emergency period a combat or battle front type of pathologist who gave much thought to control methods. The rapid spread and destructive action of the chestnut blight fungus left little time for long period investigations, and such work had to be deferred until emergency control measures could be put into effect. The blister rust, slower moving and presenting an easier problem on account of its heteroecism, gave more opportunity for experimentation and investigation. The data obtained from studies made on this disease in the eastern states have proved of immense value in formulating control plans to check the invasion of the rust into the white pine regions of the western forests during the years from 1921 to 1929.

The earlier developments in forest pathology, therefore, were somewhat influenced by the introduction of these two destructive diseases into our eastern forest regions, and by the field studies of the wood-rotting and bluing fungi. During this earlier period were laid the foundations for the studies in the physiology of fungi and the beginnings in wood pathology. Mycological contributions were well represented, and some excellent work on the control of seedling diseases left its mark.

The application of forest pathological principles to the forestry problems peculiar to our country was first made by Dr. E. P. Meinecke, whose "Forest Pathology in Forest Regulation"[2] sounded the keynote in forest sanitation and forest hygiene. This able analysis of our problem in tree diseases, particularly applicable to the virgin and newly logged areas of the West, was soon followed by systematic studies of the decay factor in our timber stands in various parts of the country.[3]

The general trend is in the direction of more detailed and well-controlled investigations covering all fields of forest pathology with emphasis upon the problems presented by the epidemics in our forests and the part played by pathology in the regulation and management of our federal, state and private forests. The demand for solutions to the many problems confronting the lumber industry and the need for conserving our timber supply by preventing the waste in forest products brought about by decay and stain is making itself felt, and a well-rounded investigative program is being followed by federal and other agencies.

A keener consciousness of the need to guard against the introduction to the United States of tree diseases common to foreign countries is being developed and steps are being taken by the federal agencies to obtain knowledge of the causal fungi beforehand so that epidemics similar to the chestnut blight and the white pine blister rust may be avoided. We have another potentially destructive disease recently introduced from Europe and becoming dangerously active on our native conifers in the New England states. This new menace which threatens our vast western forests as well as the eastern is the European larch canker, so destructive to European larch that this tree has almost ceased to be grown in Germany. Fortunately, quick and determined action on the part of federal and state agencies has resulted in the eradication of all the trees known to be infected in the New England region.

The earlier work in forest pathology was confined almost entirely to the etiology of a given disease and to the descriptions of causal organisms, with little or no attention given to the effect of the agency upon the tree. Later on, more attention has been directed to the effect produced on the host, but it has been largely a study of the effect upon the individual tree rather than an economic study of the losses, both present and future, occurring in the forest as a whole. Meinecke[4] has stressed this point in a discussion of forest pathological problems, and although he states that no standards exist by which the relative importance of a certain disease may be determined, yet not all forest tree diseases can be of equal importance with respect to their destructiveness.

The relative importance of any particular forest disease or damage must always be measured in terms of the economic loss produced. As the factors of most weight in judging the importance of tree diseases, Meinecke lists the economic value of the species affected, the character of the injury and the aggressiveness of the agency of disease. Many of the diseases common to our forests are of no great economic importance—the actual losses over a period necessary to grow a crop of timber being very small. Such diseases may cause serious damage to individual trees only and so may be regarded in the light of pests, or diseases of minor importance.

The fact that some of these enphytotic diseases act as thinning agents in crowded stands[5] reduces to some

[2] E. P. Meinecke, "Forest Pathology in Forest Regulation," *U. S. Dept. Agr. Bul.*, 275: 1–62, 1916.

[3] J. R. Weir and E. E. Hubert, "A Study of Heart Rot in Western Hemlock," *U. S. Dept. Agr. Bul.*, 722: 1–39, illus., 1918; "A Study of the Rots of Western White Pine," *U. S. Dept. Agr. Bul.*, 799: 1–24, 1919; J. S. Boyce, "The Dry-Rot of Incense Cedar," *U. S. Dept. Agr. Bul.*, 871: 1–58, illus., 1920; "A Study of Decay in Douglas Fir in the Pacific Northwest," *U. S. Dept. Agr. Bul.*, 1163: 1–18, illus., 1923; "Decay and Other Losses in Douglas Fir," *U. S. Dept. Agr. Bul.*, (in press), 1929.

[4] E. P. Meinecke, "Basic Problems in Forest Pathology," *Jour. For.*, 15: 215–224, 1917.

[5] E. P. Meinecke, "The Evaluation of Loss from Killing Diseases in the Young Forest," *Jour. For.*, 26: 283–298, 1928.

extent the total damage they do. However, tree diseases should never be regarded as beneficial factors in a stand, for with the swift changes that are being brought about in our timbered regions due to rapid removal of timber by fire, logging and other means, there is no assurance that the particular disease in question may not, under favorable conditions, become epidemic in its nature and sweep over an entire area.

One investigator concludes that the fungus, *Cenangium abietis,* attacking the lower branches of *Pinus ponderosa* in the southwest regions acts as a pruning agent and assists the tree in clearing more rapidly the lower trunk, thus improving the value of the trunk for saw log purposes.[6] This fungus, it is stated, is weakly parasitive, attacking only those branches in the lower crown which have been weakened by drought or other causes.

A large number of leaf and twig diseases cause minor damage in a stand. There are certain needle diseases, however, which in favorable years take on the nature of an epidemic and cause sufficient economic loss to be classed as important. Forest tree rusts have been observed to increase in favorable years and to cause an increased amount of damage.

The two most important causes of native tree diseases are the mistletoes (*Phoradendron* and *Razoumofskya*) and the fungi. The latter include the parasitic leaf, twig and stem diseases; the heartrot and saprot fungi and the rust fungi. By far the greatest economic damage is produced in standing timber by the decay organisms, the heartrot and saprot fungi. Trees killed by parasitic agencies may be salvaged if cut soon enough, but there is little or no salvaging of the portion of a tree trunk infected with decay-producing fungi.

The startling fact that the enphytotic diseases are all native to this country and that the epiphytotic diseases are those which have been introduced to us from foreign countries again emphasizes the need for more careful and effective preventive methods and quarantine regulations in order to prevent these undesirable and very destructive diseases from crossing our borders.

The white pine blister rust, the chestnut blight and, potentially, the larch canker are the most important of all our tree diseases, judging them by the damage produced, the species of tree involved and the comparatively brief periods of attack. And all three of these diseases have been brought to us from foreign countries.

ECONOMIC LOSSES

It has been pointed out that there are a few tree diseases of major importance and many of minor importance in our forest areas. This distinction, although based mainly upon the relative value and accessibility of the tree attacked and upon the amount of damage produced by the disease agency, is primarily judged by the direct economic loss measured in terms of timber capital lost. Protection of forests and conserving water and game for our use and recreation also possess a distinct value, although their value in terms of merchantable products may be nil. Our present timber capital consists of 138 million acres of virgin forest, 250 million acres of second growth and 81 million acres of potential forest now classified as waste. In this remaining stand we have, in saw timber and cordwood, about 740 billion cubic feet. The drain on our forests amounts to something over 25 billion cubic feet annually, and our supply of softwood saw timber alone is being cut 8.6 times faster than we are growing it. Our annual growth of timber is approximately 6 billion cubic feet. If we are cutting our timber several times as fast as it grows[7] our timber capital will vanish rapidly.

The once magnificent stands of virgin softwood timber east of the Rocky Mountains have been removed. Waste land and second-growth timber have taken their place. What has been the history of the forest areas in the Atlantic states and the Lake states is in progress of fulfilment in the southern hardwood and pine belt now largely coming into second-growth timber. The Pacific Northwest holds the bulk of the nation's timber capital, mostly virgin timber, much of it overmature and deteriorating rapidly as heartrot fungi and other disease agencies take their yearly toll. Since the risk of loss through diseases is cumulative, and decay in a mature stand increases with increase in age of the stand, it follows that our virgin stands of timber—our principal timber capital—must suffer much greater loss through disease than the young growth which is as yet of somewhat uncertain value.

However true this may be, as foresters we can not overlook the responsibility of keeping the future stands of timber healthy and producing a maximum yield of sound timber. The passing of the veteran stand often leaves to the oncoming crop of young timber a legacy of disease and injury which affects the future productivity of residual and reproduction stands. But the danger of any great loss due to decay in young stands is considerably lessened by the shorter cutting cycle, for the future generations will cut their timber long before the age attained by our present virgin stands. To offset this, such diseases as the white pine blister rust are particularly destructive to young growth, and protection must be given

[6] W. H. Long, "Self Pruning of Western Yellow Pine," *Phytopath.*, 14: 336–337, 1924.

[7] Forest Service, "Wood Waste Prevention," pp. 1–29, illus., National Conference on Utilization of Forest Products, 1924.

the reproduction areas in order to insure our future timber capital.

The two main divisions of loss evaluation due to disease agencies are the losses in standing timber and the losses in wood products. The compilation of loss figures is therefore complicated on one hand by the great differences in complexity of forest conditions for the various forest regions and by the multiplicity of products produced from wood, and on the other hand, by the large number and variety of destructive agencies responsible for these losses.

RELATION OF LOSSES TO FOREST DEPLETION

In summarizing the evaluations for both the forest losses and the losses in wood products, it is found that the annual loss equivalent in cubic feet of standing timber is as follows:

Loss in timber stands, including losses due to diseases, decay, fire and insects	2.4 billion
Loss in wood products due to decay of wood in service and in storage	4.0 billion

We are faced, therefore, with a total annual drain on our forests of over 6 billion cubic feet. The replacement of this wasted material necessitates the cutting of additional timber from our forests and in some cases causes premature harvesting of stock which would better have been left to develop for a future cutting. Every rotted tree that is cut down and culled means that another sound tree of the same board feet content must be felled to take its place in terms of wood products. In Idaho alone the loss by decay in the standing timber is estimated at approximately thirteen million board feet annually. The thousands of board feet of sapwood lumber which are annually degraded on account of sap stain must be replaced by clear lumber to supply the demand for high-grade clear stock. This means that more trees need to be cut in order to obtain the proper proportion of these grades. To the bluing of sapwood, therefore, may be laid a certain overproduction of lower-grade stock and a considerable portion of the annual cut of timber which could otherwise be reserved for future use.

The losses through improper storage of wood or through improper handling or poor design and use in building construction, losses through deterioration of stored pulp or through degrade due to sap stain, and losses due to failure to use wood preservatives all tend to hasten the exhaustion of the nation's supply of raw material.

To a progressive nation, and to the maintenance of that nation's high standards of living, the prevention of such losses and the husbanding of our forest capital are imperative. By means of present known improved practices and methods applied to wood products alone, two ninths of this loss could be prevented and the drain on our forest raw material would be lessened by approximately one and a half billion cubic feet, representing an annual saving of about 195 million dollars.

The elimination of this preventable waste in the woods, the mills and in service can best be brought about by the development of preventive methods through a study of the agencies causing these losses. As our methods of treating wood to prevent decay improve in proportion to our knowledge of the decay-producing fungi, so will our methods of preventing diseases in the forest improve as our knowledge of the disease-producing agencies increases.

Most foresters would place fire prevention first on the protection list, with insect control second and fungous diseases third. The more spectacular and more readily observed damage is usually impressed the deepest on the memory. While fire eats its way rapidly through a stand and in its wake leaves an annual loss of startling proportions, yet the control of fire is primarily concerned with keeping the loss at a minimum and, unlike certain tree diseases, there is little danger of the complete destruction of a species of valuable timber over its entire range. If, on the other hand, blister rust should gain the upper hand in the struggle for forest protection, our western white pine forests would virtually be doomed. Insect damage resembles, in many ways, the attack by fungi. With insect epidemics, however, we have balancing factors which bring the damage to a low ebb and frequently bring about almost normal conditions. On the other hand, we occasionally have a species of tree almost obliterated by an insect attack. The larch saw fly nearly wiped out the eastern larch in the Lake states some years ago, but in doing so it apparently sawed off the limb upon which it depended, for no recurrence of the epidemic is on record.

Fungous attacks are slow but steady in their advance upon our forests, and the effect is at times the least spectacular of all forest damages.

THE CONTROL OF DISEASE IN TREES AND THEIR PRODUCTS

Fortunately, under present-day extensive forest management, the economically important forest tree diseases are not very numerous. As soon, however, as intensive forest practice becomes general and in step with the rapidly disappearing virgin stands, we will find the list increasing. Diseases which are of minor importance in our present timber stands may be found more harmful in the intensely managed forests of the future. There is also the possibility that changed conditions due to logging and to artificial control of the forest area in efforts to favor a maximum stocking of particular tree species may encourage the spread and development of some disease organism now obscure.

The prevention or reduction of the tremendous losses in the field of forest pathology and in the field of wood pathology is a difficult task, since forestry is yet in the extensive stage of its development.

The uniform and universal application of intensive control methods to the vast areas of timberland in the United States in an effort to ward off the more important tree diseases is beyond the limits of practicability under present economic conditions. The areas of inaccessible and low-value timber are too great, and even in the more accessible areas containing valuable timber the cost of an intensive job of control in many cases is prohibitive. We are, nevertheless, not justified in making a sweeping statement that the control of forest tree diseases is impracticable or impossible. The rapid depletion of our forests by fire, decay, disease and insects and through the steady and increasing toll of the annual cut will soon cause attention to be centered on the more accessible second-growth timber and potential forest areas. As wood becomes less plentiful, this reduction of forest capital will eventually call for a more intensive management of these forest areas and will result in the application of intensive rather than extensive control methods. At present, our faith in control methods leads us to hope that the damage due to the white pine blister rust in the West may be kept at a minimum by a system of local control concentrated upon the stream type where the most dangerous alternate hosts (susceptible wild currants or gooseberries) are found in greatest density. Beyond this we have ventured little or no distance in advocating intensive disease control over large areas of timber. The control of disease in a field, an orchard or in a woodlot is difficult enough, but when a heavily timbered area of several thousand acres, spread over very rough terrain, is contemplated, it is obvious that different methods are indicated for the two extremes.

The forester is faced with the triple problem of (1) preserving the present merchantable stand from further loss before harvesting; (2) providing for reproduction on all cut-over areas, and (3) the application of forest management to the stands of the future. In all three of these problems the question of protection against storm, fire, insect and disease demands an answer in practical terms. Control methods, therefore, are urgently needed to stem or check the tide of losses caused by tree diseases. Roughly, the control methods applicable in the practice of forest pathology may be classified as follows:

Exclusion—the use of quarantine and inspection measures to control the spread of diseases.

Eradication—the removal and destruction of alternate hosts or of diseased trees or parts.

Protection—sanitary measures, spraying, protective treatment, injections, etc.

Immunization—developing immunity by tree breeding, selection or other means.

Further divisions under each heading are, of course, indicated. In the control of white pine blister rust quarantine and inspection activities play their part along with eradication by means of pulling and uprooting the alternate host plants and the spraying of such plants with a killing chemical. Too frequently the difficulties confronting a control program of this kind in a terrain such as the Coeur d'Alene Mountains of northern Idaho are not fully realized by foresters and timber owners. To me it is startling, the progress that has been made in methods and efficiency of control, and in the rapid reduction of cost per acre. The splendid work is continuing, and we shall see in the near future the development of more effective chemical sprays and a greater reduction in cost of control.

Protection methods applicable to our present forestry practice are rather limited. Several sound principles, however, have been developed in the past few years mainly by western pathologists who strove to find methods which could be applied to the current practices. Pathological marking rules, sanitation clauses in timber sale contracts, disposal of infected slash on the logging areas and pathological cutting ages are all devices for reducing the spread of infection in our forests. I believe I am safe in stating that future forestry will pay more heed to the pathological type of cutting age as forestry intensifies.

The future control work in forest pathology, until intensive forestry arrives, will be confined mainly to the parasitic diseases such as the white pine blister rust, with special regard to measures of exclusion in an effort to prevent the introduction of new diseases. The control of heartrot diseases may in some cases rest on special methods of treatment, but as shorter cutting cycles become the rule and more and more products are made from young trees of small size, we will find that pathological cutting cycles will eventually eliminate a large amount of the heartrot losses. The crop of the future will be a cellulose crop, with short cutting ages and new methods of harvesting. The step from lumber to derived products and to synthetic products from pulp is not great, and the future will see lumber and other wood products manufactured from pulp obtained from small trees and young stands. A stand cut in its youth has developed little heartrot and no fungous fruiting bodies. It, therefore, leaves no great legacy of disease to the oncoming stand and suffers itself but slightly from cull due to decay. But a stand cut in its later years carries with it an accumulation of heartrot and of fruiting bodies which in turn spread infection to the oncoming forest. In Idaho the decay factor is an important one in the management of hemlock and white fir on the cut-over areas and represents a problem which is closely knit with the future growth of white pine.

What shall we do with our residual hemlocks and white firs which at the time of removal of the white pine show from 30 to 100 per cent. infected with heartrot? If we leave them on the cut-over area they crowd out the white pine and so greatly reduce the yield at the next cutting. If left with the expectation of harvesting the hemlock and fir for pulpwood or other products, there is the depressing forecast that in the next forty or fifty years the heartrot will be so prevalent as to render the material useless. What then shall we do? Shall we practice girdling with all its attendant disappointments, high cost and fire hazard, or shall we invest in a type of insurance by cutting and burning all infected residual trees and thus give white pine a minimum of competition and an opportunity to yield a full stand of high-priced, sound wood at the next cutting? Studies have been inaugurated which we believe will throw some light on this problem and aid us in formulating a management plan which will insure a maximum yield of sound and valuable wood.

In wood pathology, which deals with the loss-producing defects caused mainly by fungi, we have two main types of control measures: prevention and eradication. Under these are various methods of dipping in chemicals, seasoning, storage and heat sterilization, with special applications to practically each type of wood product.

In this field the activity of control work will multiply and will intensify with each decade as wood becomes scarcer and more valuable. Much of the husbanding of our timber capital may be done by preventing waste in the use of wood. The product as well as the crop must be protected, and this fact emphasizes one of the most important fields of activity in forestry science.

A new angle in the field of wood utilization which has appeared of late on the pathological horizon may develop into an important means of saving much of our wood crop. It was not so very long ago that one would have been laughed at had he suggested the use of rotted wood in the manufacture of paper pulp —yet this is a commercial possibility and we find that the so-called white rots may be utilized in the manufacture of a fair grade of sulphite pulp. The brown rots are obviously unsuited for any such use on account of their color and weakened fibers.

There are additional methods which time and investigation may bring to the aid of the forester. The one is the use of wood-rotting fungi in converting waste wood to pulp or near pulp, while the other is the search for and development of wood-inhabiting fungi which possess the ability to change the artificial food upon which they are grown into commercially valuable chemical products. The first suggestion involves a search for the fungi which most readily convert wood to cellulose. Following this much work must be done to determine the optimum conditions of growth for the organisms and the development of such a process on a commercial scale.

The second suggestion is strengthened by a considerable background of present-day commercial processes in which micro-organisms, principally fungi, are used in the manufacture of valuable products. The manufacture of such products as alcohol, cheese, linen, taka-diastase, butanol, acetone, ethanol, acetic and lactic acids, gluconic acid and pectin are all brought about by the careful use of micro-organisms.

If, therefore, we can find ways to divert the fungi, which are destroying our wood capital, into some useful activity by harnessing their enzymatic power to a process of pulp production or to the manufacture of some useful chemical, then, truly, may it be said that our research is fulfilling its destiny.

The use of micro-organisms, particularly fungi, in industrial processes, presents at once many advantages and disadvantages. In general, such a use has the advantage of an even and smooth-running process, good yields with few impurities, minimum supervision and a low labor cost. When discovered, the use of a particular fungus to produce a certain substance which has previously required costly and complicated chemical equipment and reactions, or to produce a substance found only in nature, marks a decided step forward in coordinating the factors of chemical science with those of botanical science and in welding the two groups of data into a feasible commercial process. The disadvantages lie in the nature of the organism used and its sensitivity to conditions favoring its growth. Carefully controlled temperature, moisture, air and food conditions are essential, and this entails a carefully worked out process based on research in order to insure successful production.

In some such manner forest pathology may serve not only as a preventive and protective science, but may also find expression in the development of new and profitable ways of utilizing our waste wood.