COURSES IN FOREST PATHOLOGY

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Dr Overholts course in Forest Pathology.

CHAPTER I.

INTRODUCTION

1. SCOPE OF THE COURSE.

In its broadest sense Forest Pathology might be defined as the science of Forest Protection, and Forest Protection includes all of the acts of the forest owner made with a view to the safety of his investment. From this broad view point a course in Forest Pathology should include a study of all the factors which may adversely influence the normal development of a forest stand, or as recently stated by Meinecke#, "Forest Pathology deals with all factors causing loss in forest trees, either in actual or prospective values."

In the curriculum for Forestry students certain phases of this broad conception of Forest Pathology are covered in other courses. For example, according to the above definition, protection of the forest against fire becomes an item in the subject, and for students other than foresters might well receive elementary consideration; yet such a consideration would be entirely out of place before a group of Forestry students. In like manner a discussion of the subject of insect depredations would be entirely superfluous for students who are to receive a course in Forest Entomology.

Of prime importance in the course is the study of the so-called "Parasitic Diseases" that effect living trees. I refer especially to leaf-spots, such bacterial diseases as crown gall, the mildews, and the large series of canker-producing fungi such as the chestnut blight disease, white pine blister rust, etc., - diseases that unchecked often result in the death of the tree. Then there is a series of what are often termed "Physiological Diseases" or "Non-Parasitic Diseases", that take their origin, directly or indirectly, as a result of abnormal or unfavorable relations between the tree and its non-living environment. Examples of this type of diseased condition are seen in "sun scald", "winter injury", "smoke injury", and "electrical injury", as well as in the diseased condition that may result when a tree is growing in a water-logged soil, when illuminating gas is present in the soil, or in the presence of one or more of a number of other similar unfavorable conditions that may develop in isolated localities.

We must also necessarily include a study of the decay processes e.g. heart rotting, etc. that may be going on in forest trees, and since the processes and organisms concerned may be identical in standing trees and in structural timbers, it should include also a study of the deterioration of wood and how to prevent it.

Meinecke, E. P. - Jour. For. 15:215. 1917.

However, it is impossible in the time available for this course to properly dwell upon all the different phases of Forest Pathology. It will be necessary to limit our work largely to the fungous diseases of forest trees, perhaps branching off at times into other lines as opportunity offers.

2. AIMS OF THE COURSE.

Four chief aims will be kept in view thruout the course. They are as follows: (1). To obtain a knowledge of the morphology and life history of representative examples of disease-producing organisms belonging to the various sub-divisions of the plant kingdom. Such knowledge would serve as a basis for a continuation of work along the same lines. (2) To acquire a considerable degree of efficiency in determining to genus and species unknown organisms causing various types of disease. This will bring the student in touch with the literature of the subject and will enable those so inclined to go deeper into any specialphase in which they may be interested. (3) To gain a considerable amount of miscellaneous information on the subject of plant diseases in general, their symptoms and effects, and the control or preventative measures that may be applied. (4) Last but not least, to develop the powers of close observation and discrimination necessary for successful work in any line of scientific endeavor.

3. INTERRELATIONS OF FORESTRY AND PATHOLOGY

The ends it is hoped to attain thru the application of pathological principles to forestry work may be conceived to be at least three in number, related here in the order in which they must appear in the attempt to transform our virgin forests into the ideal normal forests under a scientific system of forest protection which will give an assured supply of timber on the basis of a sustained annual yield.

(1) The first end to be attained is to gain a complete and thoro knowledge of all our forest tree diseases. This can be obtained only by an intensive study of them from a purely botanical (physiological, mycological, etc.) viewpoint. The greater part of this work must deal with cataloguing and describing the casual organisms, working out their life histories, and determining their effect on the host and how these effects are brot about. Obviously this line of work is of less direct applicability than any of the others, but it is very fundamental and progress in other directions necessarily rests on its successful completion.

(2) The second end to be hoped for is that there will be instituted a system of <u>Forest Sanitation</u> and of <u>Forest Hygiene</u>. By the former of these phrases we mean that the forest shall be made a healthy place for trees to live in. If this is to be accomplished the number of breeding places for tree disease germs must be reduced to a minimum or eliminated entirely. This involves the elimination of dead and diseased tree materials, the proper disposition of brush and litter, providing for the necessary aeration and lighting of the forest cover, etc. In other words <u>sanitation</u> refers to the surrounding conditions in the forest - conditions affecting the forest as a whole, while by <u>Forest Hygiene</u> is meant those protective and preventative measures that may be applied to the individuals of a forest stand. At the present time we are far from anything but a remote beginning to these ends. But they must necessarily follow in this country as they have in Europe.

(3) Having determined the organisms responsible for the diseases of our forests trees, and after instituting necessary and proper sanitation and hygienic measures, there still remains the problem of putting this knowledge at the disposal of the forest owner and the forest or timber purchaser. For example, knowledge of the identity, life history, prevalence, etc. of the diseases present on a given timber area should enable these individuals to figure closely on the percentage cull that may be expected in logging the area. At the present time estimates of cull are guesswork, and timber owners and buyers often experience very unpleasant surprises at the outcome of our present haphazard methods of estimating that factor. Other such examples of the practical value of Forest Pathology could be easily cited.

CHAPTER II

OUTLINE HISTORY OF THE DEVELOPMENT OF FOREST PATHOLOGY

1. IN PUBLIC OPINION AND THOUGHT.

Plant Pathology is a science of recent development and it has developed simultaneous with the pathology of agricultural plants. In recent years, however, these two phases of Plant Pathology have become widely separated, tho often concerned with similar causative organisms and employing similar or identical methods inx combating disease.

On the other hand, Forest Pathology, at least in its practical applications, could develop no faster than the science of Forestry itself, and in fact the former has lagged considerably behind the latter. All systems of forest management (including at least the essential features of Forest Pathology) have been built up as a result of hardship in securing raw forest materials. In fact, every step in the progress of Forestry has had its origin in lack or loss of forest products.

Generally speaking, those countries which today manage their forests on sound principles have passed thru the following four stages of forest experience:

(1) Forests so abundant as to be in the way and so neglected or even destroyed. Written records bear evidence that this occurred when our own country was first settled, and even within the memory of living individuals large and valuable forest areas have been cut over, and the timber piled and burned in order to clear the ground for agricultural or other purposes.

(2) Due to the growth in population and the increase in agricultural pursuits the large forested areas receded and the inhabitants of earlier settled regions were forced to draw on the frontier forests for their wood products. At the same time there developed an interest in woodland protection because farsighted individuals could forsee the time when such products would be obtained only with increased difficulty. This gave birth to the "farm woodlot idea" that has received so much attention during the past twentyfive years. The wide-spread conservation movement of the past fifty years marks the close of this phase of forestry and the beginning of the next stage.

(3) With an increased demand for wood together with a better knowledge of trees and their growth, the forest began to be recognized as a crop which must not only be husbanded but must be made to grow again. So came about the first introduction of planting or seeding large forest areas. At the present time this work is being carried on by the Federal government, the states, munincipalities, corporations, and individuals. If we could prevent the ravages of fire and disease no form of investment today would offer better inducements of a remunerative nature than the work of reforestation of waste places.

(4) In the three preceding phases of forest history pathology has played a very minor part or has entirely failed of recognition. But as the various phases of industry progress, our forests will be better controlled and safeguarded so as to yield a maximum crop each year. This means that better methods of fire protection will be perfected; there must be inaugurated a constant and untiring war against fungous and insect pests; logging operations will be more closely supervised; seeding and planting operations will be extended; and every effort will be made to insure future generations a plenteous supply of forest products. In this development Forest Pathology must have an important part but it should be borne in mind that public opinion on these points has not yet been aroused and progress in the next fifty years will be slow.

2. IN THE SCIENTIFIC LITERATURE.

We may now turn our attention to a consideration of a few of the more important pieces of literature that have appeared on the subject of Forest Pathology.

The first publication worthy of note on tree diseases was by Wilkomm in 1866. It was entitled "Die Mikroscopischen Feinde des W aldes". But at that time the knowledge of the nature of fungi had not been widely dispersed and the explanations as to the causes of diseases were very defective. Hallier[1], Sorauer[2], and Frank[3], each published texts in the following twenty years, but they dwelt upon plant diseases in general and contained very little of interest to the student of Forest Pathology.

The "Father of F orest Pathology" was Robert Hartig, who published the results of his investigations partly in periodicals and partly as independent works. He was born in 18 39 and died in 1901[4]. Of his independent works the following deserve particular mention:

1. Wichtige Krankheiten des Waldbaume, 1874.
2. Die Zersetzungerscheinungen des Holzes der Nadelholzbaume und der Eiche. 1878.
3. Untersuchungen aus dem Forstbotanischen Institut zu Munchen. I, 1880; II, 1883.
4. Die echte Hausschwamm, Merulius lacrymans. 1885.
5. Textbook of the diseases of trees (Translated into English by Somerville; edited by Marshall Ward. 1894)

[1] Phytopathologia. Die Krankheiten des Culturgewachse. 1868
[2] Handbuch der Pflanzenkrankheiten. 1874.
[3] Die Krankheiten der Pflanzen. 1886.
[4] For a brief biography see: Meinecke, El P. Robert Hartig (1839-1901). (Phytopath. 5:1-3. 1915).

This last mentioned work has become the classic of Forest Pathology and is the most complete work of its kind in existence.

In 1875 appeared "A Treatise of Dry Rot in Timber", by T. A. Britton, in which are discussed as one subject the various dry rots of timber without regard to the organism causing the decay.

In 1889 Marshall Ward published a book entitled "Timber and some of its Diseases". Here are treated a very few of the most common timber decays, including those due to Polyporus sulphureus, Armillaria mellea, Merulius lacrymans, Peridermium strobi, the "Damping off" disease of seedlings, etc.

In 1897 appeared "Diseases of plants induced by Cryptogamic Parasites", by Von Tubeuf (Translated by W. G. Smith). This has proven to be a useful book with many references to the diseases of forest trees.

Another text that will be found useful is Massee's "Diseases of cultivated plants and trees", tho as the name implies it is not a Forest Pathology text book, and the treatment of the different tree diseases is more or less meager.

In America the study of tree diseases has but just begun. But one text or field manual has yet appeared in book form and the available literature is much scattered. The organization of the Forest Service Bureau with its office of Forest Pathology has several individuals who have contributed considerably to our knowledge of tree diseases. Chief among these have been T. B. Galloway, Hermann von Schrenk, Perley Spaulding, Geo. Hedgecock, Henry Graves, E. P. Meinecke, J. R. Weir, and Haven Metcalf. Others outside the Plant Bureau who have worked along Forest Pathology lines are: Arthur of Indiana Experiment Station has added considerable to our knowledge of the Rust fungi; Atkinson of Cornell University, one of the best mycologists in thecountry and with an intimate knowledge of the higher fungi so prevalent as disease and decay producers in our forests; Clinton of the Massachusetts Agricultural College has been interested in the rusts in particular; and other names that might be mentioned in this connection will be met as the course progresses.

As stated above, the American Literature on this subject is considerably scattered. No text book suitable for our use has yet appeared either in this country or abroad. A few American works that are more or less serviceable are as follows listed in the order of their importance in this course:

vonSchrenk and Spaulding - Diseases of deciduous forest trees. (Bul. U. S. Dept. Agr. Pl. Ind. 149. 1909). Obtainable from the Superintendent of Documents, U. S. Dept. Agr., Washington, D. C., for 15 cents.

Rankin, W. H. Manual of Tree Diseases. 1919. MacMillan Co.
von Schrenk - Diseases of New England Conifers. (Bul. U. S. Dept. Agr. Pl. Ind.) Obtained as above.
Meinecke, - Forest tree diseases common in California and Nevada. (U. S. Dept. Agr. Forest Service Bul. 1914). Obtained as above.
Duggar, Fungous Diseases of plants. 1909. (Ginn and Co.)
Stevens - The fungi which cause plant disease. 1913. American Book Co.
Freeman - Minnesota Plant Diseases. 1905.

A comprehensive manual of Forest Pathology is greatly needed.

The Structure and Function of the Parts of a Tree.

A disease always involves a disturbance of the structure or function of some part of the tree. In order to detect abnormalities in structure or function it is necessary that we first have an idea of the normal structure and functions of the parts of a tree.

Only casual observation is necessary to determine that an ordinary living tree is composed of three main parts, each with its own peculiar structure and performing certain definite functions. These parts are (1) roots, (2) stem or bole, and (3) crown, including branches, twigs, buds, flower, fruit and leaves. We may now proceed to a more detailed observation of these parts.

1. The Roots.

A. Function. The principal functions of roots are two in number. They serve to attach the tree to the soil and to support the stem in an upright position. In certain tropical trees (e.g. the banyan) this effect is magnified by the production of many lateral prop roots. The second function is in taking up nourishment from the soil for the use of the plant. There exists in the soil many elements such as Ca., K. Na, P, etcl, that are necessary in building up the protoplasm of living plants. These elements, in the form of their salts, are held in solution in the soil water and are carried up to the leaves in that condition. In this process the root hairs function. These hairs are outgrowths from the epidermal cells of the smallest rootlets and are found only in a region a few millimeters back of the root apex. In front of this region new root hairs are being continually produced and on the other side they are continually dying and sloughing off.

These root hairs are in close contact with the finer soil particles and through the process known as osmosis they are able to take up the water that adheres in the form of a thin film to the soil particles. They are able to do this because the cell sap within the root hair is a more concentrated solution than is the soil water on the outside. The vital structure in this process is the protoplasmic membrane, i. e. the outer limiting layer of cell protoplasm. Such a membrane allows passage through it mainly in but an inward direction and is termed a semipermeable membrane. Since solutions of different densities obey the same diffusion laws as gases of different densities it will be seen that there will be a tendency for the concentrations of the two solutions to become equal. But because the protoplasmic membrane is a semipermeable one this condition can only be realized by an inward flow of soil water, resulting in a lowering of the concentration of the cell sap. Once within the root hair the water is passed on to the cells of the root and the concentration of the cell sap is again increased, resulting in more water entering the root hairs.

It has been shown that in a large number of forest trees as well as in many other plants, there is present on the apex of the rootlets a thin covering of the mycelium of a fungus. Root hairs are often absent on such rootlets and it is supposed that the fungous mycelium performs their function, probably receiving in return certain foods necessary in its own growth. A fungus growing in such relation with a root is termed a mycorhiza.#

B. Structure. A longitudinal section through the apex of a root shows the presence of three regions. The root is covered by a root cap which acts as a buffer as the root is forced through the soil. Just underneath this root cap is the growing point. The cells of this region originate all increase in length of roots. During the growing season the cells divide rapidly, adding new elements to the root cap on the one side and to the root proper on the other. Just back of this growing point the cells become differentiated into the three regions observed in a cross section of a root. These are in the order of their appearance from outside to center; bark, woody cylinder, and pith. The function and minute structure of these parts is similar enough to that of the corresponding parts of the stem, so that a consideration of these points can be deferred to a later page.

2. The Stem

In a transverse section of a woody stem we find three well defined regions, i. e., bark, woody cylinder, and pith. The first two of these will, on closer study, be seen to be made up of several defferent kinds of tissues. It is enough for our purpose, however, to deal only with the main areas of each region.

The bark, as the term is used by the forester, consists of two regions, an outer bark, and an inner bark. The outer bark is mainly composed of dead cork cells. Hence its function is mainly for protection. The amount and position of cork (suberin) that is deposited on these cell walls determines the external markings (furrows, ridges, etc.,) of the bark. Each year a special layer of cambium, known as cork cambium, adds new cells to the outer bark. Lenticels also appear as structures of the outer bark. They are small openings to the exterior and are easily observed on cherry trees, birches, alders, etc., where they are considerably elongated in a horizontal direction. They perform a function similar to that performed by the stomata of the leaves. The inner bark is of living cells and is composed mainly of the phloem tissue. It consists for the most part of elongated cells that function chiefly in the downward conduction of the elaborated sap. Hence the phloem is in reality a part of the vascular system, but since it peels off with the bark it may be classed with the tissues of that region.

McDougall, W. B. On the mycorhizas of forest trees. (Am. Jour. Bot. 1: 51-74. 1914)

The line of cleavage between bark and woody cylinder is between the phloem and the cambium tissues. Hence the cambium may be spoken of as the outer layer of the woody cylinder, and the woody cylinder may be defined as the region between the phloem (inner bark) and the pith. It is the part of the tree that has the greater commercial value. Its outer region, the cambium, is a single layer of cells thick. It is this cylinder of cells that originates all increase in diameter of the stem, cutting off a few phloem cells on the outside and many wood cells (xylem) on the inside each year, so that the xylem or wood proper grows much faster than the phloem.

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In the woody cylinder the amount and character of the growth varies with the season. In the spring, growth is very rapid and the cells cut off are very large and few in number. This gives a more porous type of wood that is known as spring wood. In the late summer growth is much slower and the cells formed are smaller and more closely compacted, forming the summer wood. These differences are more clearly marked in some species of trees than in others. The transition from summer to spring wood is much more distinct than that from spring to summer wood, Consequently each years growth appears as a narrow band, the annual ring and by counting these rings the approximate age of the tree may be obtained. The xylem functions principally in the transport of the crude sap from the roots to the leaves.

In most of our forest trees the xylem does not remain functional for more than a few seasons after it is formed. Consequently there frequently appears a well defined central region of the stem in which the wood is darker colored than towards the outside. This color is said to be due to the accumulation of tannins, gums, etc., in this region. The cells, of this darker layer are inert and form the heart wood of the tree. The lighter colored wood outside of this is still functional in sap conduction and is called sap wood. In some trees this differentiation into sap and heart wood is not visible.

Referring again to the cross section of a mature stem, attention is called to the radial lines running from the center to the outside of the stem. These are the medullary rays. They are continuous in a vertical direction for only a few millimeters. Their chief function seems to be the transference of liquids in a lateral direction from xylem to phloem and vice versa.

In the coniferous stems the structure of the xylem is somewhat different from that in broad leaved trees. Instead of being composed for the most part of tracheal tubes and wood fibers it is made up of cells called tracheids. These differ from tracheal tubes both in origin and in structure. On their walls are scattered many small pits with overhanging borders and they are known as bordered pits.

The pith of the stem soon becomes crushed into a very small area by the growth of the woody cylinder. Thus it is soon rendered functionless and is to be considered as a part of the heart wood.

3. The Crown.

The crown of a tree is composed of the larger branches, the twigs, leaves, flowers, and fruits. The only one of the parts that needs consideration here is the leaves.

A. Leaf Structure. In structure leaves are remarkably constant. There is an outer epidermis of one or more layers of cells on all sides of the leaf. On the lower surface this is pierced by many minute openings, the stomata or breathing pores. Internally the leaf usually shows two kinds of tissue, an upper layer of elongated cells known as palisade cells, and between this and the lower epidermis are several layers of loosely arranged cells, the spongy mesophyll. The coloring matter of leaves is known as chlorophyll and is contained in small bodies known as chloroplasts. These are situated for the most part in the palisade cells.

B. Leaf Functions. The leaves have three functions to perform. The first of these is Photosynthesis. This may be defined as the manufacture of plant foods (carbohydrates) from CO_2 and water through the agency of sunlight and chlorophyll. The CO_2 is obtained from the air which is taken through the stomata, and the water is carried to the leaves from the soil. In the leaves the two substances are broken up and recombined in such a way that carbohydrates are eventually formed. The latest research points to the conclusion that the first product of photosynthesis is formaldehyde (CH_2O). By a process known in chemistry as a condensation process several molecules of this substance can be combined in such a way that carbohydrates are formed. Thus twelve molecules of formaldehyde if united would yield $C_{12}H_{24}O_{12}$. If one molecule of water were split off from this the result would be cane sugar ($C_{12}H_{22}O_{11}$). This photosynthesis activity goes on only in sunlight, and in the process CO_2 is used up and O_2 is set free.

A second function of leaves if Transpiration. This maybe defined as the giving off of water vapor by plants. The process is exactly comparable to evaporation except that it is taking place in living plants, although it does not appear to be very directly controlled by the plant. The excess of water carried up by the roots is gotten rid of by this process. Another advantage of the process is that inorganic elements such as K, Ca, and Mg are carried up to the leaves for use in food manufacture.

The third function of leaves is Respiration. Some of the foods that are built up by the leaves must be transformed by the plant into its own living substance in order to repair the continual wear and tear on the protoplasm. This is the function of respiration. In this process CO_2 is always set free and O_2 is used up. Respiration may be defined, then, as the breaking down of plant foods in such a way that CO_2 is given off and other simpler plant products are formed. Respiration goes on at all times during the life of the plant and sunlight is not necessary for its operation

CHAPTER III

The Nature and Cause of Disease

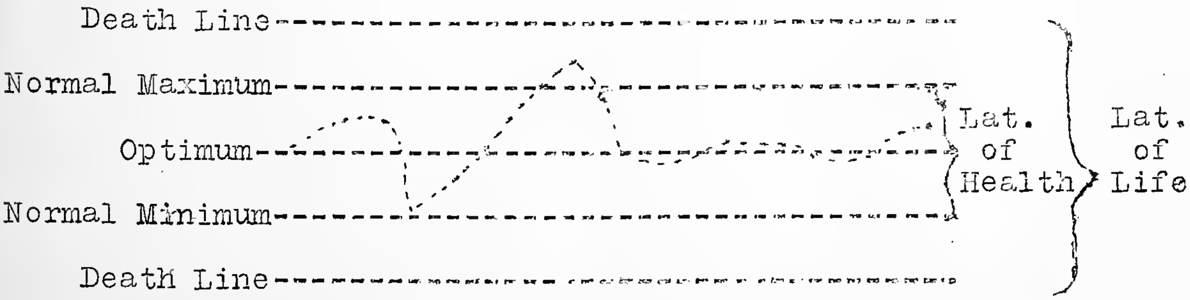
1. Disease Defined: A great many people fail to realize that plants may become diseased just as do animals. A knowledge of the subject will reveal a striking similarity between animal disease and the few but widely differing diseases mentioned in the Introduction. It needs to be pointed out however, that this similarity is greatest when we consider the causes of disease, and less when symptoms and effects are considered. From this we may infer that Bacteria and other low forms of life are capable of causing disease in plants just as in animals. In addition, as stated in the Introduction, there are a large number of plant disease for which no organism is responsible, but which consist of disturbances of one sort and another in the activities of the plant. Since these are disturbances of the physiological activities of the plant they have been called Physiological Diseases. But in all diseases there is certainly some disturbance of physiological functions, and for this reason the term Non-Parasitic is a better one to use in this connection. But regardless of which term is employed for them the salient point is that if left uncorrected they may result in increased disorder or even death, and so are rightly regarded as diseases. Such diseases in the plant world are caused by lack of oxygen in the soil; malnutrition, smoke and gas injury, etc. Parallel disturbances in the animal world could easily be cited. Among animals certain types of physiological disturbances are often referred to as Organic Diseases. Bright's disease, different forms of heart diseases, and perhaps cancer, belong in this category. It is doubtful if there are in plants any diseases that exactly parallel the organic diseases of animals. Whenever insect injury results in the production of galls or other malformations on plants, such should be regarded as diseases of a localized nature, altho the same type of injury to animals is usually not classed as a disease. In exactly the same way, the injurious effects on plants of a water-logged soil (i.e. resulting in the exclusion of oxygen from the roots) is usually classed as a disease, while asphyxiation in animals (a parallel injury) would ordinarily not be so designated.

The above brief discussion of disease paves the way for an attempt at a definition of that term. Disease may be defined as any interference with the normal structure or function of the plant or its parts; or again, as any abnormality that directly threatens the existence of the individual or the species. Both of these definitions are very general, but a more satisfactory limitation of the term seems impossible.

One example alone may be cited as representative of a large series of phenomena in plants, concerning which the question arises as to whether or not they should be classed as diseases. It is a well known fact that many cultivated plants produce what are called "double blossoms", i. e. an unusually large number of petals per flower. Ordinarily one does not regard such a case as a disease.

But an analysis of the case brings out the following facts; Doubleness is due (in many cases at least) to stamens being transformed into petals. According to the first definition above this in itself constitutes a disease, because the stamens lose entirely their normal function and in part their normal structure. According to the second definition this abnormality must threaten the existence of the individual or the species before it can be classed as a disease. Further consideration shows that such is just its tendency. For such transformed stamens do not produce pollen and noseed can be set in the ovary without the intervention of pollen. Consequently such plants unless cross-pollimated will be sterile. This condition of sterility, if long continued, certainly does threaten the existence of the species altho not of the individual. But this variation to double blossoms is especially sought after and propogated in the horticultural world, so here we have the interesting situation of the aim of cultivation directly controverting the natural tendency of the plant and striving to maintain the diseased or abnormal condition. From the standpoint of the cultivator the tendency to return to the normal is the disturbing factor altho it cannot be considered as a disease. On this basis some would divide diseases into two general classes, i.e. Absolute diseases, which directly threaten the life of the plant, and Relative diseases, which disturb the cultural aim of man.

Sorauer[1] builds up a conception of disease in the following way. We know that each life function oscillates between wide limits. When a given function is at its lowest ebb we say that it is at its minimum, and when it shows its strongest possible activity it is at its Maximum. The mean between the two is called the Optimum, and it is at this point that the normal development of the plant is most favored. The field of oscillation between



Maximum and Minimum may be termed "Latitude of Health. The whole field of oscillation between life and death may be called "Latitude of Life". The two should not be confused, for a plant may live outside the "Latitude of health" and still be within the "Latitude of life", and it is precisely this condition that may be said to donstitute disease. Now a given function may be outside the "latitude of health" for a short time, e. g. the cessation of a function because of heat or cold, but on the return of normal conditions the activity of the function may return to optimum in a few hours after its cessation. Such a condition Sorauer would describe as a "check"

[1]Sorauer, Manual of Plant Diseases. English Transl. 1:7-8.

and would regard it as probably outside the realm of disease.

Each individual plant has its own characteristic "latitude of health" both for the plant as a whole and for each of its separate functions, the latter of which may vary enormously in different plants. Let two cuttings of equal age be taken from the same geranium plant. Grow both in the same kind of soil and with equal access to water, but one in a greenhouse and the other outside. The former one will raise its minimum in regard to the amount of cold it can endure, but will lower its maximum heat limit; while the latter will lower its cold minimum and raise its maximum heat limit.

From this discussion we see that variation is a natural and normal phenomenum in the plant world, and it is often hard to draw the line between normal variation and malformation. But when variations tend to shorten the life activities of a plant they may be said to constitute a disease.

The discussion may well be concluded by attempting an answer to the question as to whether or not trees die a natural death as a result merely of old age, or do they always succomb to adverse external conditions. Undoubtedly, at least some annual plants die of old age. Wheat, oats, and similar plants have well-defined youth, maturity, and old age, and after maturing their fruit they die, and often just in the midst of the annual growing season. But in the case of shrubs and trees the cause of death is probably always an external factor, altho certain parts, such as leaves, bark, etc., may die each year. The cessation of increase in height of different species of trees must be largely ascribed to interference with nutrition, as the forces that compel the ascent of sap in trees are limited as to the height at which they can operate. As a tree becomes older the dangers thru which it must pass become more numerous, and the wounds it receives thru which parasites and saprophytes can find entrance become more numerous. The older the tree the narrower its annual increment, and the longer it takes for the cambium to cover the wounds. The nutritive processes also become more sluggish with age, in part because raw food materials may be partly exhausted from the soil. When a tree begins to be stunted it becomes more subject to disease. So when we speak of a natural age limit of trees we simply imply the usual limit of time a given species can live in spite of unfavorable external factors.

2. Resistance and Predisposition to Disease: It is a well known fact that all plants of a given species may not exercise the same measure of resistance to disease. Some become sick and soon die, others apparently living under the same conditions are only slightly affected, while still others may not contract the disease at all. Viewed from another angle we may say that some plants seem to have more of a tendency or predisposition to disease than their fellows. Just what constitutes predisposition and resistance no one can say. Apparently it is often dependent in some way upon the internal

organization of the plant, but whether it be a chemical or a physical factor or neither, we do not know. As a result we must conceive of disease as being determined by the cooperation of two factors, (a) the external cause usually easily demonstrated, and (b) the condition of the plant constituting its resistance or predisposition to the disease. No doubt predisposition and also resistance may be entirely normal, but the former at least may be at times abnormal (i.e. induced by other diseases or by injuries of some sort).

Disease resistance varies with the age of the plant. For example, a coniferous seedling may have very few powers of resistance to the disease known as "damping off", but as the seedling increases in age it soon reaches a point where it will be entirely immune from the disease. Young conifers with abundant active resin canals are well protected against infection by wood-destroying fungi, because if wounds are received they will be immediately covered over with resin. Later these resin ducts become more or less clogged and wounds are covered more slowly or not at all.

Breeding plants for disease resistance has made long forward strides in the past twenty five years. This is especially true in the agricultural world, and has been so much developed that every seed distributing house has one or more varieties of each of the common crop plants that it advertises as peculiarly resistant to one or more diseases to which the species is usually susceptibel. Along forestry lines the need of such breeding work is just as imperative but the chances of success are less because fewer varieties are available with which to experiment, and because the growing of trees is such a long time proposition that results would be extremely slow in materializing. More can be accomplished in large scale planting operations by the use of species (not varieties) or even genera for which a fewer number of destructive diseases occur in that locality.

3. The causes of Disease: The different factors that may operate to cause disease may be classified as follows:

A. External causes originating in the non-living environment, and giving rise to Non-Parasitic or Physiological diseases.
   1. In the soil.
      a. Nature and quantity of organic matter.
      b. Amount of water in the soil.
      c. Gases in the soil (Coal gas escaping from under pavements in towns; deficiency in Oxygen due to too much water)
   2. In the atmosphere.
      a. Sulphur fumes, chlorine, and other poisonous gases from factories, volcanoes, smelters, etc.
      b. Unsuitable temperatures.
      c. Amount of light.
   3. Mechanical effects of hail, snow wind, etc.
   4. Effect of fire, lightening, etc.

B. Causes originating in the living environment.
   1. Due to animals.

a. Man (Responsible for large wounds due to lumbering, pruning, and other operations)
b. Other vertebrate animals. Cattle, rabbits, mice, squirrels and birds do immense injury.
c. Invertebrates. Both acting directly as in case of chewing insects, etc. and indirectly as stinging insects producing definite galls.

2. Due to plants, and giving rise to Parasitic diseases.
a. Phanerogams or flowering plants.
1. Weeds, as crowding agents.
2. Parasitic Phanerogams, as mistletoes.
3. Climbing plants and epiphytes. Injury chiefly one of shading or of smothering.

b. Cryptogams or Flowerless plants.
(1). Classified according to type of disease.
(a). Leaf diseases.
(b). Trunk or branch diseases
(y) Sap rots
(z) Heart rots
(c). Root diseases.
(y) Sap rots.
(z) Heart rots.
(d). Nursery diseases
(2). Classified according to casual organism.
(a) Bacteria.
(b) Myxomycetes.
(c).Phycomycetes.
(d) Ascomycetes.
(e) Fungi Imperfecti.
(f) Basidiomycetes.

CHAPTER IV.

The Relation Between a Plant and its Disease-producing Organism.

1. Parasitism and Saprophytism: When a plant is preyed upon by a disease-producing organism the former is known as the host plant. Thus the white pine is one host plant for the white pine blister rust. The attacking organism is known as a Parasite if it establishes a relationship with a living part of the host, and is called a Saprophyte if the relationship is with the dead part of a host. These terms are not mutually exclusive, for an organism may be a parasite in one stage of its life history or under one set of environmental conditions and a saprophyte at another time or under changed conditions. Or it may be deriving most of its nourishment saprophytically and at the same time its line of advance may be among living cells. Consequently it becomes necessary to recognize other types of relationships in addition to strictly parasitic or strictly saprophytic ones. The following are the usual classes into which these relationships are divided:

True or Obligative Parasites, must live in every stage of their existence as parasites, and they cannot subsist on non-living organic matter.

Hemi-Parasites of Facultative Saprophytes, are those organisms which ordinarily live as parasites but at times exist as saprophytes.

True or Obligative Saprophytes, are organisms that cannot subsist on living organic matter but are restricted to a non-living substratum. Such organisms really do not come within the scope of Pathology, but they are encountered as timber decaying organisms, and, as such decays may even take place in living trees, for example in the dead heartwood, they are of considerable importance even to the grower of trees.

Hemi-saprophytes or Facultative Parasites: are organisms that usually pass their whole life as saprophytes but may at times lead a partially or wholly parasitic life.

Wound Parasites, while included in the previous classes are often treated as a group. They are parasitic organisms that are incapable of infecting a tree unless an entrance may be gained thru wounds. As a matter of fact most parasites of perennial plant parts are wound parasites.

2. Symptoms of Disease: Since disease is defined as a disturbance of the normal function or structure of plant parts, it follows that the presence of an abnormality in plants is at least evidence that such a plant may be diseased. The abnormalities caused by disease-producing factors are designated as the symptoms of the disease and the determination of the cause of these symptoms may be called Diagnosis. The chief abnormalities are classified by Heald[1] as follows:

[1]Heald, F. D. -Symptoms of disease in plants. Bull. Univ. Texas No. 135. 1-63. 1909.

1. Discoloration or change of color from the normal.
   a. Pallor. Yellowish or white instead of the normal green.
   b. Colored spots or areas on leaves or stems, the colors varying from white to yellow, red, brown, and black, the particular color produced has some, tho not a great de[al] of significance in diagnosis.
2. Shot hole: perforation of leaves, produced when the dead are[a] falls out.
3. Wilting: damping off, wilt, etc., due to failure in the water supply. This may be because of lack of water in the soil, in which the whole plant will be equally affected, or it may be due to some interference or stoppage in the conducting cells of the plant.
4. Necrosis: Death of parts, as leaves, twigs, stems, etc.
5. Reduction in size: dwarfing or atrophy, that may effect the entire tree or only certain organs of it. In the former case the cause is likely to be in the soil or concerned with the roots.
6. Increase in size: Hypertrophy due to enlargement of the cells, or hyperplasia due to the formation of new cells.
7. Change of position-Infected leaves often take an abnormal position as in case of the rosette leaves of certain plants becoming very erect when infected by a rust.
8. Destruction of organs.
9. Excrescences or Malformations.
   a. Galls: pustules, tumors, corky outgrowths, crown galls, etc. that always involve increase in size.
   b. Cankers: malformations in the bark generally resulting in an open wound.
   c. Punks or conchs or other fruits of fleshy fungi. These hardly belong in the category of symptoms, and are sometimes referred to as Signs of disease.
   d. Witches brooms, i.e. more or less dense clusters of branches due to unnatural local stimulation of grow[th] cells.
10. Exudations.
   a. Slime flux, a watery exudation from a wound or a fiss[ure] or crack, and in this exudate various bacteria and fungi may be found, causing a fermentation that may result in the decay of cell walls.
   b. Gummosis: an exudation of gum from deciduous trees, such as peaches, cherries, etc.
   c. Resinosis: an exudation of resin from coniferous trees.
11. Rotting.
   1. Root rots.
   2. Stem or trunk rots.
      (a) Heart rots
      (b) sap rots
   3. Fruits.

CHAPTER V.

The Nature and Development of Fungi

Most of the diseases of our forest trees are due to fungi, and practically all timber decays are caused by them. For our purposes the distinction usually made between Bacteria and Fungi in present-day texts need not be maintained. Consequently fungi may be said to possess two characteristics not found in combination in any other group of plants. These are that they are plants (1) without chlorophyll, and (2) reproducing by means of spores. A considerable number of flowering plants have no chlorophyll but they reproduce by means of seeds. On the other hand the Mosses and Ferns are examples of plants that reproduce by spores but they all without exception have chlorophyll.

Since fungi are without green coloring matter they are unable to manufacture carbohydrates from carbon dioxide and water, as green plants do, but they must find their food ready prepared. Such foods must be relatively complex in composition in order to supply all plant needs. In this respect fungi resemble animals and like them must obtain the bulk of their food from organic life, either plant or animal. If the food is obtained from living cells the fungus is termed a parasite, and if from dead organic remains it is termed a aprophyte, as previously mentioned.

Fungi have just as definite food requirements as do other plants, and in fact many of them have become very much specialized. along this line. Consequently we find that most of those species that live on rotten logs or on the ground cannot grow on living plants. Those that grow on living trees usually cannot grow on the ground and are often further limited to particular species of trees. Specialization may go even further and the fungus be limited to particular parts of the tree. Thus *Polyporus dryadeus* is found only on oak trees and more-over is a root rotting organism never producing its fruiting bodies much above the surface of the ground. On the other hand, *Polyporus dryophilus*, showing a similar host specialization is distinctly a trunk inhabiting form producing its fruiting bodies at considerable distances above the ground. As a further example two species of the Rhytisma tar spots are found on the leaves of different species of maples and never on any other host. Such specialization as to habitat has not been better developed in any other group of plants.

In addition to the two points already mentioned, fungi differ from green plants in their relatively simple structure and in the entire absence of any special vascular system. The life of such a plant is readily divided into two distinct parts corresponding somewhat to different stages of growth. These are : (1) Vegetative part and (2) Reproductive part.

As stated previously, fungi reproduce by means of spores. A spore may be defined, then, as a cell (or sometimes a small number of united cells), especially set apart for reproducing the plant. Consequently a spore usually marks the boundary line between the vegetative stage and the reproductive stage of the fungus. But many fungi have more than one kind of spore, and in fact some have as many as five or six different kinds produced at different stages in the life history. The different kinds of spores are in part characteristic of different groups of the fungi and consequently will not be discussed at this point.

Spores correspond womewhat in function to seeds of higher plants, in that they are the means by which the plant perpetuates itself. In origin and structure however they are very dissimilar to seeds. A seed is always multicellular and contains an embryo, that is, a small plant newly formed, ready to push out of the seed coats and establish a root connection with a substratum. No such complexity exists even in the most complex form of spore, where every cell acts independently of every other one, and each cell alone is capable of eventually producing a new plant. A spore, therefore, is a very important but quite inconspicuous part of the life history of a fungus.

Most spores require a considerable amount of moisture in order for germination to take place, and in fact, a distinct film of water is usually a necessity. Germination consists of thrusting out a short tube-like growth which soon becomes a elongated filament termed a hypha (plural hyphae). By repeated branching of this original hypha a mass of these filaments are formed. At this stage it is impossible to distinguish the original parent hypha and so any strand or filament may be called by that name, altho it must be recognized that all the hyphae of one plant may be originated from the same parent hypha and the same spore. This mass of hyphae is termed mycelium and makes up the vegetative stage of the fungus.

Ordinarily the mycelium of a fungus is within the substratum and so is invisible. The most notable exception to this is in the group of fungi known as "mildews", where the bulk of the mycelium lies on the surface of the leaves and is quite conspicuous. In the commercial world the mycelium of the common cultivated mushroom is known as spawn. Similar dense aggregations of mycelium are sometime met as white or colored strands or networks on the lower side of rotten trunks in the forest.

After the mycelium has grown within the substratum for a considerable period of time the second, or Reproductive stage in the life-history is initiated. The mycelium collects in mass at different places on the substratum, and may eventually take the form of a knob or ball. This may be preceded or accompanied by a definite sexual process or such may be entirely absent.

The different forms of fruiting bodies are too varied to take up here. The common cup fungi, mushrooms, toadstools, bracket fungi, puffballs, and the like are examples of the more advanced type of fruiting bodies. They are usually referred to as the fungus but they really represent only a portion of it. When they are mature they bear the spores in one of a variety of ways, the chief ones of which are as follows: (1) they may be collected in larger or smaller numbers in special sacs called sporangia, as represented by the common black molds: (2) they may be in smaller sacs usually clavate in shape and termed asci. The usual number of spores in an ascus is eight, and by some the ascus is regarded as a reduced sporangium. These spores are known as ascospores. This method of producing spores is constant thruout a large group of fungi known as Ascomycetes or "sac fungi". (3) they may be produced on special hyphae termed basidia, in which case they are termed basidiospores. The basidia of the most of the better developed fungi are clavate in shape and each one bears usually four spores at its apex on short stalks termed sterigmata. (4) they may be cut off singly or in succession from the ends of specialized hyphae in which case they are termed conidia or conidiospores. The hyphae from which they are produced are termed conidiophores.

In addition to these four ways of bearing spores a number of highly specialized types of spores are produced among fungi. Often times the mycelial strands will break up into a connected series of thin-walled spores of a non-resting character known as oidia. Or a series of heavy-walled spores of a resting type may be formed on the mycelium and are known as chlamydospores. Of whatever nature the various types of spores may be they all have the common functions of either serving to rapidly spread the fungus or else to tide it over unfavorable conditions.

The fruiting bodies on or in which these spores are produced are very variable as to their length of life. Some are annual, and in fact may last only a few hours, others are perennial adding new tissues from year to year. An age of seventy five to eighty years is sometimes reported for some of these fruiting bodies. Those that are strictly parasitic, such as leaf-inhabiting forms can of course live only as long as those parts remain alive.

The spores formed by a single fruiting body may vary in number from a few to many millions. It has been determined by careful analytical methods that a small spore-horn of the chestnut blight fungus may contain as many as 115,000,000 spores. Cobb states that a single head of smutted oats may contain 500,000,000 spores, or a sufficient number to give 1,000 per square foot if scattered evenly over an acre of ground. Buller estimates that a single fruiting body of Polyporus squamosus produces 11,000,000,000 spores while the giant puff ball produces 7,000,000,000,000 spores. Another estimate by the same author says that the spores of an ordinary mushroom if placed end to end would form a chain forty one miles long. When we consider the enormous numbers of spores produced by these fungi we cease to wonder at the number and frequency of these plant pests and can only express our surprise that there are not more of them.

CHAPTER VI.

The Dissemination of Fungi Causing Disease.

Observations show that fungi are disseminated in many and varied ways and often with great effectiveness.

A. The parts of fungi that may be disseminated.

1. Spores. As has been previously described spores are of various kinds and it is thru them that the largest percentage of dispersal takes place altho other methods are best suited for transportation over long distances. Many spores are thin-walled and so constituted otherwise that the distance to which they may be transported is largely dependent on the length of time they retain their vitality. This in turn is sometimes influenced by such a factor as the color of the spores, as colorless spores are more susceptible to injury than colored ones. For example, the colorless basidiospores of the white pine blister rust are believed to live only a short time, probably not more than a very few hours, consequently the percentage infection on pines from a given number of them is extremely low. Even in those spores that retain their vitality over longer periods of time a very small percentage of them finally come to rest in locations suitable for germination, or if germination occurs suitable food materials may not be on hand so that further growth can take place. In addition, small insects destroy immense numbers of spores, so than an extremely small percentages of them ever function in the normal manner.

On the other hand many fungi have spores so constructed that they are capable of functioning after long periods of inactivity. Buller relates how he was able to secure germination of spores of wood inhabiting fungi after periods as long as twenty one months, and many spores are known to retain their vitality for as long as one year. Among the rusts there is commonly developed one type of thick-walled resting spore that cannot be induced to germinate until a certain period of inactivity has elapsed.

2. Sclerotia. Sclerotia are dense aggregates of fungous tissue and not to be compared with spores except in function. They vary in size from minute masses smaller than a pinhead to organs of considerable size--sometimes a foot or more in length. Their origin is not constant. Some are simply masses of vegetative tissue closely compacted together, while others result from the sterilization of spore-producing tissue. They are often buried within the substratum but not always so. Those of larger size are often used as food, as the American "Tuckahoe" - the underground sclerotium of one or more species of Polyporus. Such structures are very effective in carrying the fungus over a period of unfavorable growth conditions.

3. Mycelium. Many notable examples could be cited of the intro-

duction of fungi into new localities, by means of their mycelium, usually thru the importation of the living hosts on or in which the fungus grows. The white pine blister rust and the chestnut blight fungus are well known instances of this sort. The strictest inspection at the point of entry is sometimes not sufficient to detect the presence of the fungus in the diseased host. In addition to examples of this sort timbers used in various enterprises may often be infected and transporting them to distant localities may easily result in introducing a fungus into hitherto unoccupied regions.

B. Manner of dissemination.

1. On seeds of Phanerogams. The fungus may be carried in either the spore, mycelium, or sclerotium stage upon or within the seeds of flowering plants. There are no well known examples of this among the fungi causing tree diseases. Our best examples are among the crop disease fungi such as those causing the smuts of cereals, anthracnose of beans, etc. Very often the infected seeds show no external sign of the presence of the fungus. Where the fungus is external on the seed it can easily be killed by the use of disinfectants and a considerable agriculture practice has been developed along those lines. If the fungus is within the seed its extermination is a more difficult manner.

2. Wind dissemination.

Wind dissemination is possible where the spores are produced in a more or less loose powdery dondition, or are formed singly from the ends of specialized hyphae from which they are easily detached. Such spores are usually so minute that no buoying apparatus is necessary to keep them afloat long enough to be transported considerable distances. Many Ascomycetes and Basidiomycetes eject their spores forcibly into the air and in this act of discharge they are easily caught up by air currents and carried away. Frequently spores are discharged in such numbers from the fruiting bodies of these fungi as to be easily visible in the form of a small cloud. These are especially noticeable in many of the cup fungi (Order Pezizales) but are not uncommon among the bracket type of fungi. In some of these forms (e.g. *Polyporus lucidus* Leyss. *Polyporus tsugae* Murrill, and *Fomes applanatus* Pers.) these spore clouds are carried upward over the surface of the pileus and many of them settle back on this upper surface, there forming a pruinose brown covering over the surface. Spores so found have often been erroneously regarded as conidia produced *in situ*. Just what factors are necessary to produce forcible spore discharge is not known exactly, but apparently it is related to the amount of water present either in the surrounding atmosphere or within the basidium.

Perhaps more exact information has accumulated concerning wind dispersal of rust spores, than of any other fungi. For example,

it is known that the spring spore of the white pine blister rust may be carried for distances of five miles or more and distances of as much as fifteen or twenty miles are not improbable. Most of the Imperfect Fungi that form leaf spots on leaves of trees are supposedly wind disseminated, altho much experimental data is necessary before we can be positive of this. The number and variety of spores that are being constantly carried in the air is surprising. Simple types of spore traps give very instructive results in this respect.

3. Water dissemination.

a. Of motile spores. Many of the lower types of fungi have motile, asexual spore bodies known as zoospores that are capable of rapidly spreading the fungus if conditions are favorable. These zoospores move about in the water by means of cilia and consequently are entirely incapable of motion if water is not present. The best example of this type of fungus among the tree parasites is in Pythium - one of the organisms causing the "damping off" disease of coniferous seedlings. When the plants are just establishing themselves this fungus may develop rapidly under proper moisture and temperature condition. Heavy rains or excessive watering supplies the proper medium for the distribution of these spores and under such conditions the disease may become very serious. Motile spores are unknown among the higher groups of the fungi.

b. Of non-motile spores. Most often water dissemination of non-motile spores acts in conjunction with wind dissemination either in initiating or completing the dispersal. For example, a spore may be carried a considerable distance by the wind and find lodgment on the rough bark of a tree. The next rain may carry such a spore into some crevice of the trunk from which it may have access to the interior of the host. It has recently been shown that the summer spores of the chestnut blight fungus are washed in enormous numbers down the trunks from the diseased portions above, and so may spread the disease to other parts of the tree.

Finally, the possibility of spore dissemination thru running water and streams, irrigation ditches, etc., must be considered. Probably spores are not usually carried long distances by such means, altho the possibility offered in case of many resting spores is considerable. The usual thin-walled spore, however, finds its best germinating medium to be water, and consequently many such spores will germinate in a few hours under such conditions. This fact undoubtedly limits to a considerable extent the radius of activity of such spores, as their mycelium may fail to find in the water the food materials necessary to continue growth, and death ensues.

4. Insect dissemination: In many cases of animal disease that are transmitted thru insects, the insects also act as intermediate hosts - that is, the disease-producing organism is parasitic on the insect as well as on the animal to which it is carried. Thus the malaria-producing organism lives both in the blood of the

mosquito and in that of man. But no plant diseases are known in which this is true. In other words insects are always passive agents in the spread of fungous spores, altho this fact does not in the least mitigate the serious effects that may follow. One of the best known examples of insect dissemination is in the case of fire-blight of fruit trees, caused by a bacterium. Winged insects, especially bees, in travelling from flower to flower and from tree to tree and very important agents in carrying the bacteria from one place to another.

Interesting experiments have been recently reported upon the relation between insects and the spread of the chestnut blight fungus. Out of 52 insects taken from diseased chestnut trees, 19 were found to be carrying the spores of the fungus. Eight individuals of the Leptostylus beetle were examined and all found to be carrying the spores of the fungus. Ants also gave positive results The number of spores so carried per insect varied from 74 in the case of one of the ants to 145,340 in case of a Leptostylus beetle.

Insect dissemination is also undoubtedly a factor in the spread of the aeciospores of the white pine blister rust. Gravatt and Posey made counts of the spores found on the bodies of the larvae of the gypsy moth that feeds on the rust blisters, and obtained numbers ranging from 1120 to 28,320 per individual. From the alimentary tract of the larvae they obtained 1740 to 48,570 spores per individual. An examination of the pellets passed by these larvae over a period of 13 hours showed that aeciospores were excreted at the rate of from 3,960 to 12,450 per pellet, or a daily average rate of 318,616 spores per larva. Collins has shown that these same larvae may be carried in air currents for distances of twenty miles. Consequently these larvae might well be important agencies in the spread of the disease.

5. Dissemination by other animals. Almost any of the higher animals are easily capable of carrying spores from place to place. All that is required is contact with a spore producing body, and the adhering spores may be carried for some time, eventually to be dropped perhaps in some hitherto uninfested locality. Experiments made on the carrying of chestnut blight spores by birds gave the following results: Thirty six birds belonging to nine different species were tested and nineteen of them were found to be carrying spores of the blight fungus. One wood pecker was estimated to be carrying 757,074 spores; another 624,341 spores; a brown creeper 254,019 spores. In the same series of tests one woodpecker was found to be carrying twenty different kinds of fungous spores.

6. Dissemination in agricultural and commercial practices.

In the same way that animals may come into contact and carry away spores of fungi, so may the tools that man uses in agricultural pursuits be important vehicles of spore transportation. In cutting out certain types of tree diseases (e.g. fire blight) it is very important that the tools used be thoroughly sterilized after each incision in order that the causal organism may not be transferred

from one part of the tree to another.

Diseased nursery stock is a frequent source of infection for hitherto uninfected plants and for that reason the present agitation over nursery inspection as well as seed certification is an important step in the right direction. The best example of introducing a new disease is the white pine blister rust situation. That disease is native in Europe and was imported into this country on white pine nursery stock. As frequently happens it has proved more destructive in this country than in Europe. Cases like this justify our Plant Quarantine laws by means of which it is possible to discriminate against nursery stock from any desired locality. Unfortunately in case of the white pine rust as well as several similar instances the quarantine laws were not established until after the introduction of the disease.

CHAPTER VII.

Abbreviated Life Histories of the Important Classes of Disease-Producing Organisms.

I. Bacteria.

(a) Size. Bacteria are the smallest of all living plants. Many of them are scarsely visible with the highest powers of the microscope and it is not impossible that there should exist forms that are too minute for detection by our present day microscopes. A few forms are large enough to be visible to the unaided eye.

(b) Structure. Bacteria are mostly one celled plants with a definite cell wall that in some cases gives the reaction for cellulose and in others contains materials similar in composition to chitin of the insect body. The cell wall is decidedly a protective membrane but at the same time it must be thin enough to allow food materials to pass thru it for it is only in that way that these plants can absorb needed nutriment from the substratum.

The bacterial cell contains no well organized nucleus as do the cells of higher plants, but in its place nuclear matter is present scattered thru the cytoplasm. No chlorophyll is contained in the cells, but at times other coloring matters are present. It is believed by some that because of the purple coloring matter present in some bacterial cells they have the power, to a slight extent, of manufacturing their own food. The entire absence of chlorophyl in other forms renders them entirely dependent on their organic substratum for the food supply.

(c) Motility. Many bacteria have a limited power of motion due to the presence of one or more minute cilia or flagellae. These cilia are lashed about or waved in much of a cork-screw fashion and so pull the organism along.

(d) Reproduction. In most forms of Bacteria but one method of reproduction is present and of the strictly asexual type. It is simply by cell division, in which the original cell becomes split or divided into two daughter cells of equal size. This process takes place rather rapidly, usually about half an hour being sufficient for the process. Immediately each of the daughter cells may divide, and so the process may go on indefinitely or until stopped by external conditions. Consequently in a few hours time enormous numbers of new plants are formed as a result of cell division in a single parent plant and its offspring.

One other feature of the bacterial cell deserves mention in this connection, altho it is not strictly a reproductive process. Many forms go thru a process of spore formation which is to be

regarded as primarily a method of tiding the plants over unfavorable conditions, or acting as a resting stage. In this process the cell content is compacted into one or more bodies of regular shape still retained within the wall of the parent cell. Such a body is termed a spore. Usually but a single spore is formed from each cell and such a case is not a method of reproduction because it does not increase the number of resulting individuals. Where two or more spores are formed per cell the actual number of individuals is increased and so such a process may be regarded as a form of reproduction. The parent cell in a case of this sort may be regarded as a sporangium. At maturity the old cell wall disintegrates, liberating the spores that are so constituted that they are capable of withstanding severe external conditions that would probably have killed the ordinary vegetative cell. On the return of favorable conditions each of these spores may return to the original condition either by a direct process of growth and enlargement, or by first throwing off the old spore wall and then growing to normal size.

(e) Classification of bacteria. The simplest method of classification of these plants is one based on a morphological character, i.e. the shape of the individual cell or plant. On this basis three groups of Bacteria are recognized as follows: (1) Spherical or Coccus forms, (2) straight Rod-shaped or Bacillus forms, and (3) Curved rod, Spiral, or Spirillum forms. These groups are then divided into genera on other characteristics. The Coccus forms are generally non-motile. Bacillus and Spirillum forms are usually motile.

(f) Importance in Forest Pathology. Conclusive proof that bacteria may cause animal diseases was not obtained until about 1875, and four years later (1879) Burrill of the University of Illinois was the first to ascribe a plant disease (fire blight of fruit trees) to these organisms. Since that time a considerable number of plant diseases have been shown to be of bacterial origin. The most important tree diseases caused by them are as follows: Crown Gall caused by Bacterium tumefaciens, Bacterial Blight of the English walnut caused by Pseudomonas juglandis, Bacterial Leaf Blight of Mulberry caused by Pseudomonas (Bacterium) mori, Bacterial Canker of Populus caused by Micrococcus populi, and several others in which the actual relationship of the bacteria to the disease has not been definitely established. Undoubtedly further research along these lines will bring to light hitherto undescribed diseases of trees that are caused by members of this group now known to number about one thousand species.

II. Myxomycetes or Slime Fungi.

The Myxomycetes are very primitive organisms near the bottom of the scale of living things. In some respects they resemble animals and in others plants. The life history is divided into two distinct phases..

Plasmodial stage, corresponding to the vegetative stage of other fungi. A plasmodium is an aggregation of nucleated myxomycetous protoplasm without walls of any sort. In consistency it is about equal to that of the white of an egg, and is composed of almost pure protoplasm. In size plasmodia vary from minute forms to those of a foot or more in diameter. The plasmodium is capable of a limited amoeboid motion in which arms are put out and the content of the plasmodium flows into them. These arms are cross-connected and in this way large net-like structures are often formed on the lower surface of rotten wood, bark, etc., for the plasmodial stage is always passed in dark and damp situations. After vegetative growth has continued for some time the plasmodium comes into the light and the second stage in the life-history is initiated.

Sporangial Stage. The protoplasm of the plasmodium collects int definite heaps of one form or another and these heaps become transformed into sporangia or spore cases. The protoplasm is cut up into numerous spores among which are often mixed numbers of distinct threads that collectively form what is known as the capillitium. These are long tubular filaments frequently with spiny or warty walls. They give support to the sporangium and probably aid to some extent in spore dispersal.

At maturity the spores are set free. They germinate in a short time, emitting a naked bit of protoplasm. A cilium is differentiated at one end and movement begins. This motile body is termed a swarm spore. After a period of motility one swarm spore serves as a center of attraction for others and a fusion begins, not however, involving the nuclei, which remain distinct. The mass of fused bodies is the plasmodium and the life cycle begins anew.

In all probability no process equivalent to sexual reproduction is found in this group.

No Myxomycetes are known at present to produce diseases in living trees altho one species was reported at one time as perhaps the cause of crown gall, now known to be caused by a bacterium. True myxomycetous parasites are not unknown among other flowering plants, however. Many species grow on wood after it has been somewhat decayed and undoubtedly they hasten the decay process somewhat, but probably not to a great extent.

III. Phycomycetes

(a) Form and Structure. This is a group very diversified in form and stmucture, and ranging from simple forms that produce no mycelium to the complex brandhing types represented by the black molds, water molds, etc. One structural feature is, however, very constant among the mycelium-forming species and that is the entire absence of cross walls except in the reproductive stage of the fungus. This feature results in long branched hyphal strands containing many nuclei unseparated by cross walls - a body that is usually termed a coenocyte.

The group contains a considerable number of obligate parasites The "damping off disease" of coniferous seedlings is sometimes caused by a fungus belonging to this group,

(b) Reproduction. Reproduction among the Phycomycetes may be of two types, asexual and sexual.

Asexual reproduction is by the production of spores that are of three general types. (a) Conidia (conidiospores) produced in succession from the tips of specialized hyphae termed conidiophores. These are non-motile spores or in some cases are essentially sporangia since on germination they give rise to zoospores. (b) From these conidia (zoosporangia) or from special sporangia there are produced spores that are motile by means of cilia and so are termed zoospores. (c) Spores of a somewhat different type may be produced in sporangia, each of these structures containing at maturity a large number of the non-motile spores that are formed by a cleavage process from the protoplasm of the sporangium.

The function of each type of spore is either directly or indirectly to reproduce the plant.

Sexual reproduction. is of two types, isogamous and heterogamous, but the process is essentially the same in both. It consists of a union of two bits of protoplasm (gametes) that to all appearances are alike (isogamy), or they may be differentiated into sperm and egg (heterogamy). In the latter case the names antheridia and oogonia are applied to the structures containing the gametes, male and female, respectively. The gametes fuse in pairs and the resulting structure is termed a zygote or gametospore. Usually the gametospore germinates to produce a new plant.

IV. Ascomycetes

The Ascomycetes comprise perhaps the largest group of the fungi. They differ from the Phycomycetes in having a septate mycelium, and an ascus produced somewhere in the life history. These asci or spore sacs may be scattered irregularly over the substratum as in certain lower members of the group (e.g.Taphrina), but more frequently they are found standing side by side and forming a

hymenium or spore producing layer. In such cases sterile threads called paraphyses are often mixed with the asci. These paraphyses are various in shape and form, and their chief function seems to be for the protection of the asci. The ascus contains the ascoepr spores and the number of spores varies but usually is eight. However, in some cases the primary ascospores may divide by a budding process and thus the number of spores is considerably increased. Such budded spores are termed secondary ascospores.

The asci with their spores are usually contained within some sort of a protective device termed an ascocarp, ascoma, or fruiting body. The form of these varies but three definite types are usually recognized. When the hymenium is uncovered thru all its development the ascoma is termed an apothecium. These are usually cup-shaped or saucer-shaped in outline and in vertical section are more or less crescent-shaped. The hymenium in such a form is the inner surface (bottom) of the cup. It is composed of asci and paraphyses and arises from a layer of underlying tissue known as the hypothecium. In addition to the hypothecium there is frequently a protective layer external to it and often extending up and over the margin of the cup. Such a layer is termed an exciple. Inx some cases the exciple is produced over the hymenium as a very thin membrane and is known as an epithecium. A different type of epithecium is formed when, as in many forms, the paraphyses are closely united at their tipe to form a protective layer. More often they are not so united.

When the hymenium is surrounded on all sides with the exception of a minute opening to the exterior the fruiting body is termed a perithecium. When the hymenium is entirely surrounded by a covering without any opening to the exterior the fruiting body is termed a cleistothecium. The fruiting bodies of the powdery milkdews are cleistothecia but the term is not in general use and such are more often designated perithecia.

It must not be forgotten that the entire fruiting body is in the last analysis composed of exactly the same elements as make up the mycelium, i.e. of hyphae that may be more or less loosely or closely united or otherwise modified to give rise to the distinctive parts of the fruiting body.

When the fruiting body is an apothecium it may have a stipe or stem, or it may be sessile, i.e. without a stem. When it is a perithecium it is nearly always sessile and may at times be buried in the substratum or occur as a cavity in a dense and compact mass of fungous tissue called a stroma. In either case it may have a long neck reaching to the exterior of the substratum or the stroma. This neck is perforate at the tip and has a canal running thru it from the perithecial cavity to the exterior. The perforation at the tip is termed an ostiole.

The above terms are applied to the perfect or ascus-producing stage of the fungus. If a sexual fusion occurs at any stage in the life history it is always in the ascus-producing stage. In fact when it occurs it always immediately precedes ascus formation. But such a sexual fusion has not been observed in all Ascomycetes and it is definitely known that ascus formation does take place in some forms without a preceding sexual stage, or with one so modified that it has not yet been recognized. When present the sexuality is always of the heterogamous type, i.e. the sexual elements are differentiated into sperms and eggs.

Ascomycetes, however, frequently have an imperfect stage, also known as a conidial stage, in which no asci are produced and no sexual process is concerned. Spore formation in this process is surprisingly uniform in all species where it is present. Essentially it consists of simply cutting off or abstricting small cells from the ends of special hyphae. A general name covering all spores so formed is conidium or conidiospore, but other names are applied to particular types of such spores. The special hyphae from which these spores are cut off are termed conidiophores. These structures may be either simple or branched and the spores may be cut off either singly or in chains.

The conidiophores are grouped in ways very similar to those that prevail for the asci in the perfect or ascus-producing stage. They may be scattered irregularly, arising directly from the mycelium. This is of course the less specialized method of producing them. More often, however, they are gathered into definite groups. When such a group is without protective covering of any sort it is called an acervulus. An acervulus with a well marked basal stroma is termed a sporodochium. If the basal stroma of such a structure is in the form of a short stem the structure is known as a coremium. If there is a well developed outer protective layer entirely surrounding a group of conidiophores the fruiting body is termed a pycnidium and the spores may be called pycnidiospores. Such a structure is sometimes erroneously called a spermagonium, a term that should be reserved to apply to similar structures that contain functionless spore-like bodies regarded as degenerate male gametes. Such structures are occasionally found in Ascomycetes and Imperfect Fungi. When spores are produced in pycnidia there is often a small opening left to the exterior and it is thru this that the spores are extruded. In some forms they are extruded in the form of long slender tendrils that are called spore horns.

If only the imperfect or asexual spore stage is present it is impossible to determine satisfactorily whether the plant belongs to the Basidiomycetes, the Ascomycetes, or whether it should be classed as an Imperfect Fungus. If thru a considerable period of observation under favorable conditions no perfect stage is developed then it is permissible to refer it to that genus of the Imperfect Fungi to which its characteristics most closely ally it.

V. Fungi Imperfecti

This group includes a heterogenous collection of forms but all agree in that the conidiospores or their equivalents are the main and in some cases the only reproductive bodies. The group may be more loosely defined as comprising all those fungi with septate mycelium, and whose entire life history is unknown but which does not include any known ascus or basidium stage.

The spores of these fungi are produced in the same ways as in the asexual or imperfect stage of the Ascomycetes. The fruiting bodies therefore are : (1) Acervuli, (2) Sporodochia, (3) Coremia and (4) Pycnidia, and the spores are either known as conidia or pycnidiospores. In addition chlamydospores may sometimes be present in the life history.

The group is not a natural one and in time its members will largely be united to other fungi of whose life-history they form at present an unknown part. The names by which they are known at present will become synonyms for the names borne by the perfect stages. Undoubtedly the larger part of the group are the asexual stages of Ascomycetes. A few, as Rhizoctonia solani, are known to be stages in the life histories of Basidiomycetes.

VI. Basidiomycetes

This group is the largest and most important one from the standpoint of Forest Pathology because it contains many virulent parasites and in addition practically all of the timber-decaying organisms. The Basidiomycetes are characterized by the production somewhere in the life history, of a basidium on which the spores are produced.

The basidium holds the same position in the life history of the Basidiomycetes that the Ascus does in the Ascomycetes. They are simple in structure, varying in the number of cells from one to four. In either case the basidium produces usually four external stalks called sterigmata, each of which bears a single spore. In typical forms the basidia are closely crowded together to form a hymenium. The basidia are usually accompanied by sterile branches that may be of two different forms: (1) paraphyses, similar to those in the Ascomycetes, and (2) cystidia which are conspicuous sterile organs in the hymenium, sometimes completely embedded, sometimes projecting prominently.

The Basidiomycetes are best classified according to the following synopsis:

Basidia arising thru the germination of a chlamydospore or other resting spore (e.g.teliospore); all parasitic; never forming conspicuous fruiting bodies. Class I.HemiBasidiomycetes
Fungi producing only chlamydospores and basidiospores, the

life cycle always confined to the same host; chlamydospores usually globose, the spore mass often smut-like, sometimes hard and horny, always black----Order #1 Ustilaginales(Smuts)

Fungi usually producing other spores than chlamydospores and basidiospores, often on different host plants; chlamydospores rarely globose, the spore masses often powdery but never smut-like, often bright colored.....Order II. Uredinales(Rusts)

Basidia-arising directly from a mycelium or the hyphae of a fruiting body; only basidiospores (rarely conidiospores or chlamydospores) known: many saprophytic, often forming conspicuous fruiting bodies..........Class II.Eu-Basidiomycetes

Basidia 2-4 celled................SubClass I.ProtoBasidiomycetes

Basidia transversely 3-septate.....Order Auriculariales

Basidia longitudinally or obliquely 1-to 3-septate...... ....Order Tremellales

Basidia 1-celled.............SubClass AutoBasidiomycetes

Hymenium exposed if at all only after maturity of the spores, usually forming the lining of interior cavities; (including such forms as puffballs, stink-horns, etc.) Group 1. Gasteromycetes.

Hymenium exposed before the maturity of the spores and not forming the lining of interior cavities. Group II. Hymenomycetes

Basidia strongly bifurcate at the apex, 2-spored........ Order I.Dacromycetales

Basidia not strongly b ifurcate at the apex, usually 4-spored.

Hymenium smooth, covering the lower side of the sporophore in sessile or unbranched stipitate forms, covering all sides of the branches in upright clavarioid forms, or arising from a resupinate sporophore.....Order II.Thelephorales

Hymenium uneven, covering the surface of warts, teeth, pores, gills, etc......Order III.Agaricales

Order I. Uredinales (Rusts)

All species of this order are obligate parasites and many are important as causes of destructive tree diseases. They are a group of highly specialized forms mostly unable to grow except upon a certain host or a small group of closely related hosts. This high degree of specialization is emphasized by the fact that no one has yet succeeded in growing any of them in pure culture on an artificial medium.

Most species of rusts have several different growth stages distinguished from each other by the form and arrangements of the spores. The different kinds of spores which a species may possess vary in number from one to five. If all these spore forms are produced on one host the rust is said to be Autoecious. But a large number of rusts produce their different spore forms on two different hosts. Such rusts are said to be Heteroecious. Practically all the tree inhabiting rusts are heteroecious. The five different kinds of spores that may be present are unlike in form, have distinct names, and are produced in different ways. The names of spores and the bodies in which they are produced are: pycniospores or spermatia, produced in flask-shaped structures called pycnia or spermagonia; aeciospores or aecidiospores produced in cup-like structures called aecia, aecidia, or cluster-cups; uredospores, urediniospores, or summer spores produced in colored pustules called uredinia; teliospores, teleutospores or winter spores produced in sori called telia; and a fifth kind of spore originating from the teliospore is termed a basidiospore or sporidium. For brevity these different stages have been designated as follows: 0 stands for the pycnial stage; I stands for the aecial stage; II stands for the uredinial stage; and III stands for the telial stage.

All these different spore forms are not present in every species of rust, and in fact we may have all of them missing except the telia or winter spore stage. As many other combinations occur as are possible. If all stages are present in the life history the rust is said to be a "long cycle" rust. If either the aecial or uredinial stages are omitted it is called a "short cycle" form. In the autoecious forms of rusts the life history is comparatively simple. When all four stages are present they occur in the following order: 0,I,II, and III.

Pycnial Stage. The pycniospores have no function so far as known. They do not produce infection, altho those of some species have been made to germinate. Some believe them to be degenerate and unfunctional male gametes, hence the name spermatia that is sometimes applied to them. The pycnia are never as deeply imbedded in the tissues of the host as are often the other spore bearing structures, but most often are sub-cuticular in origin. They are nearly always flask-shaped and open by a pore. Pycnia never appear alone but are either accompanied or followed by one of the other spore forms.

Aecial Stage. Following closely the pycnial stage comes the aecial or cluster-cup stage. In this stage a multitude of yellow or orange colored spores are cut off from special hyphae that form the bottom of a cup-like structure called the aecium. Surrounding this mass of hyphae and spores on all sides is a thin firm wall called the Peridium. In some species, however, a peridium is not present, or if present, is not at all cup-shaped. The chief characteristic of the aecium is that its spores are produced in chains. The spores themselves are unicellular and mostly with an orange-colored content. The walls are variously sculptured. Aeciospores always germinate by producing a germ tube that is capable of entering thru the stoma of the leaf or stem of the proper host, and so setting up an infection. Such spores are always largely wind-disseminated.

Uredinial Stage. From infections by aeciospores uredinia bearing summer spores result. The uredinium is a simple collection of spore-bearing hyphae standing eredt and in a layer parallel with the surface of the leaf. A peridium is usually absent, but sterile clavate or capitate bodies called paraphyses are often present. The urediniospores are cut off singly (rarely in chains) from the apex of specialized hyphae, and when mature are provided with an easily detached stalk. The spores are always unicellular and the wall almost always spiny or warted. The spores are usually orange or reddish-brown in color, sometimes because of a colored cell content, and at other times because of the localization of the color in the wall. Urediniospores are wind-disseminated and always germinate by producing a germ tube that may enter through the stoma of the proper host and there set up an infection. Consequently they are well suited for rapidly propagating the fungus through the growing season. In a few cases they may rest over winter.

Telial Stage. Later from the same mycelium or from the new infections teliospores are produced. The telial sori are sometimes similar to the uredinium and in fact the two kinds of spores are often foundin the same sorus. In other cases the mature mass of teliospores from a single sorus may take the form of a slender projecting hair, or the spores may be produced singly in the epidermal cells of the host. They are usually formed singly (i.e. not in chains), usually have a permanent pedicel, and are often two-celled. Their wall is most often smooth, and is frequently much thickened. Thecolor varies from brown to nearly black. Some germinate immediatelyand always "in situ"; but more often they rest over winter. They germinate, producing a short germ tube or promycelium from either or both cells of the spore. This promycelium is the basidium. It becomes four-celled at maturity.

From each cell of the basidium is formed a tiny stalk called a sterigma and on it a sporidium or basidiospore is formed. In autoecious rusts these produce the first infection of the current year. They are small, thin-walled spores with low vitality and are wind disseminated. The mycelium developed from them gives rise

to pycnia and aecia, thus starting again the life cycle,

In heteroecious forms the process is the same as in the autoecious species except that when all spore forms are present, pycnia and aecia are produced on one host and uredinia and telia on the other. The pine blister rusts are among the most common examples of heteroecious rusts. The aecia and pycnia are always produced on the pines, the uredinia and telia on dicotyledonous hosts.

Nomenclature. A study of the complete life history of a heteroecious rust reveals the possibility of considerable confusion of the identity of different stages of the same fungus. Thus, mycologists were a long time in finding out that the pycnial and aecial stages of the white pine blister rust are only stages in a life history that included uredinial and telial stages on a very dissimilar host. The connection between the two had to be worked out by means of carefully controlled inoculation experiments. These consisted of "sowing" aeciospores from the pine on to the Ribes and so obtaining the other two stages. It also involved sowing the teliospores from the Ribes on to the branches or trunks of the white pine and so obtaining pycnia and aecia. And this could only be done after careful observations in the field showed the rather close association between the two hosts. This branch of Pathology has received earnest attention especially in the United States and Germany and as a result many such connections in other species have been made and confirmed. But a great many species yet remain of which it is not known whether they are really stages in a more complex life history or whether they are "short" cycle" forms.

Order II. Thelephorales.

This order of the Hymenomycetes is characterized by the smooth hymenium or spore bearing surface. That is, the basidia do not arise from a teliospore as in the preceding groups (Hemi Basidiomycetes) but from a layer of hyphae in a more or less complex fruiting body or sporophore (EuBasidiomycetes). These basidia are one-celled (AutoBasidiomycetes) and closely compacted to form a smooth hymenium i.e. one that does not cover the surfaces of gills, teeth, tubes, or other such structures, but is simply a plane or nearly plane surface.

There are three forms of fruiting bodies in this order. When the fruiting body has a distinct stem it is said to be stipitate. But the stem may be absent and the fruiting body attached by one side in the form of a bracket in which case it is said to be sessile. Quite as often the fruiting body is spread out flat on the substratum, without either pileus or stem, in which case it is said to be resupinate. All gradations between these three forms may be found. Thus quite frequently the fruiting body or sporophore may be spread out flat on the under surface of a limb but its more lateral margin will be reflext. Such a one is said to be effused-reflexed.

In stipitate forms the parts that may be conveniently designated are: (1) stem or stipe, (2) pileus or cap, (3) hymenium, and (4) context or inner substance of the pileus.

The hymenium is always composed of two and often of three elements; basidia, paraphyses, and sometimes cystidia or setae. The basidia are perhaps always four-spored and the spores vary in color from white to dark brown. In the family Thelephoraceae the hymenium is always on the lower side of the fruiting body or in case of resupinate fruiting bodies it is always on the lower or sometimes vertical face of the substratum--never on the top surface. In the family Clavariaceae the hymenium may completely cover all surfaces of an erect branching sporophore. This sporophore may be either simple and club-like, or much branched and with the branches directed upward.

This order contains but a few tree parasites. Its members are of most importance as producers of decay in timber. Of such forms all are sap-wood destroying forms.

Order III. Agaricales

This order of AutoBasidiomycetes differs fom the preceding one in that the hymenium is not even but covers the surfaces of various kinds of irregularities such as gills, teeth, tubes, warts, etc. The form of the hymenium divides the order into various families of which the most important are as follows;

Hymenium of gills, e.g. the common mushroom. Family Agaricaceae
Hymenium of tubes......................Family Polyporaceae
Hymenium of teeth, warts, granules, etc. Family Hydnaceae

Family 1. Agaricaceae

This is the family of the "gill fungi", including most toadstools or mushrooms. Most are saprophytes but there are a few that are at least partly parasitic.

The sporophore may be stipitate or sessile. In addition to the parts mentioned as present in the previous order, i.e. pileus, hymenium, stem, and context, there may also be present a partial veil which covers the gills at an early stage, and in mature plants either remains hanging on the margin of the pileus or else forms a ring or annulus on the stem. Some forms have also a universal veil which covers the entire sporophore when young but at maturity it usually forms a volva or death cup at the base of the stem. In this family the hymenium covers the surface of gills, that are arranged on the lower side of the pileus. A cross section of a single gill shows the arrangement of the hymenial elements to be identical with that in the Thelephorales. The tissue between the two layers of basidia on opposite faces of the gill is termed trama.

Family II. Polyporaceae

This family contains most of the fungi important as producers of timber decays. Here again the sporophore may be either stipitate, sessile, or resupinate. In vertical section thru an annual polypore of the bracket or sessile form the single layer of tubes can easily be seen joined to the lower side of the context. In the case of perennial forms a new layer of tubes is added each year.

The hymenium forms the lining of these tubes that are produced on the lower surface of the fruiting body. Paraphyses and often cystidia or setae are present in the hymenium. The tissue between the basidial layers is termed the trama.

The most important genera in the family are:

(1) Fomes which includes all perennial forms.
(2) Poria which includes all resupinate forms.
(3) Daedalea in which the hymenium is composed of tubes with labyrinthiform and elongated mouths.
(4) Lenzites in which the hymenium is lamellate or in part lamellate and of a tough and leathery consistency.
(5) Trametes in which the tubes are sunken into the context to unequal depths so that their bases do not form a continuous straight line.
(6) Polyporus which includes nearly all annual forms that are not resupinate, do not have a sinuous or lamellate hymenium, and in which the tubes are sunken into the context to equal depths.

Family III. Hydnaceae

In this family the hymenium forms the external covering of downward directed teeth or spines that project from the lower surface of the fruiting body or its branches. The fruiting body may be either resupinate, sessile, or stipitate.

Hydnum is the largest genus but contains only a few forms of interest to the forest pathologist. H. erinaceum and H. septentrionale are the most important species, growing as wound fungi on living trees.

Echinodontium tinctorium produces a serious decay disease in certain coniferous hosts of our north western forests. It is a perennial fungus and is known locally as the "Indian paint fungus".

Other genera and species are abundant as saprotting organisms on the smaller branches of dead trees but are not worth considering here.

PART II

DETAILED ACCOUNTS OF SOME IMPORTANT TREE DISEASES AND TIMBER DECAYS

In a course running thru only a single semester the number of specific diseases that can receive detailed treatment is quite limited. The number of diseases available for study is almost endless. It becomes necessary, therefore, to select for our purposes certain representative types. The selection should include the more important diseases known to be present in our forests. In addition a study should be made of a few representatives of certain other common tho less destructive parasites in order to round out the student's knowledge of the entire range of parasitic fungi. Nursery and seed bed diseases cannot be overlooked and some attention must be paid to the nonparasitic diseases, particularly that the student be able to correctly diagnose such abnormal disturbances, since often remedial measures are more easily applied to this group than to the parasitic diseases.

The following synopsis is an attempt to choose for study those diseases and disturbances that will best give the student a general idea of the field to be covered. The extent to which each one is here treated reflects partly our state of knowledge concerning the disease and in part the relative importance that they play in the forest. To some extent also the choice has been governed by accessibility of material suitable for demonstration to the student.

SYNOPSIS OF TYPICAL FOREST TREE DISEASES

1. Parasitic Diseases.
   1. Fungi producing leaf spots.
      - Phyllosticta catalpae on Catalpa
      - Phyllosticta acericola on maple
      - Cylindrosporium ochroleucum on chestnut
      - Guignardia a esculi on horse chestnut
      - Lophodermium spp. or Hypoderma deformans on conifers
   2. Fungi Inhabiting Leaves but not producing typical Leaf Spots.
      - Powdery mildews on deciduous trees
      - Taphrina coerulescems on oak
      - Rhytisma acerinum on maple
      - Rhytisma punctata on maple
      - Coleosporium solidaginis on pine
      - Melampsora abietis-canadensis on hemlock and poplar.
   3. Fungi producing Cankers.
      - Endothia parasitica on Chestnut.
      - Strumella corynoides on oaks, hickories, etc.
      - Nectria cinnabarina on deciduous trees
      - Nectria ditissima on deciduous trees.
      - Cronartium ribicola on white pine

4. Fungi producing Galls.
   Bacterium tumefaciens on various deciduous trees.
   Cronartium cerebrum on pines.
   Cronartium comptoniae on pines.

5. Fungi and Mistletoes forming Witches Brooms
   Sphaerotheca phytoptophila on hackberry
   Melampsora elatina on fir
   Phoradendron on deciduous trees.
   Razoumofskya on coniferous trees.

6. Root Rot Diseases
   Armillaria mellea on various trees.

7. Timber Staining Fungi
   Ceratostomella pilifera on coniferous timber
   Chlorosplenium aeruginosum on hardwood lumber

8. Fungi Producing Decay in Wood.
   a. Delignifying Decays
      Polyporus pargamenus and Stereum fasciatum on deciduous timbers
      Fomes igniarius and Hydnum erinaceum, heart-rotting fungi on deciduous trees.

   b. Carbonizing Decays
      Trametes malicola, sapwood decaying, on Hicoria, Quercus, etc.
      Polyporus sulphureus and Lenzites saepiaria on heartwood of deciduous and coniferous trees.

   c. Pocket Decays
      Stereum frustulosum on Quercus, Polyporus abietinus on coniferous woods, both sapwood decaying forms.
      Fomes pini on coniferous wood and Polyporus dryophilus on hardwoods, both heartwood decaying forms

9. Nursery Diseases--Damping off fungi

II. Non-Parasitic Diseases
   1. Smoke and gas injury
   2. Electrical injury
   3. Winter injury
   4. Sun-scald

CHAPTER I.

Fungi Producing True Leaf Spots.

A large series of fungi, some of which belong to the Ascomycetes and some to the Fungi Imperfecti, gain entrance to the interior of the leaf, and there produce regular or irregular but always definitely limited dead areas, usually brown in color. On these dead areas the fruiting bodies of the fungus are finally produced and usually appear either as one or more small black dots or else as a minute scurfiness. Such a disease is referred to as a "leaf spot" disease. Other cases, in which the fungi do not produce dead areas in the leaf but where only enlargement, discoloration, or other abnormality occurs are not regarded as true leaf spot diseases.

The chief differences between the many leaf spotting fungi are to be found in the spores and the manner of their production. In a considerable number of leaf spot diseases the centers of the dead areas soon drop out, giving the so-called "shot hole" effect.

Infection always starts, in these forms, from a spore which germinates and sends its germ tube into the tissues of the host. These spores are usually, perhaps always, of one of two different types, i.e. conidia or ascospores. In either case the fungus has overwintered as a spore, tho the place of overwintering is not known in all cases. It would seem that both conidia and ascospores would best retain their vitality in the structure that produced them, i.e. the pycnidia, perithedia, etc., and undoubtedly many of these fungi overwinter their spores in that way. This does not preclude the possibility, however of myceline penetration actually taking place in the bud in the late summer or fall. In at least some instances, however, this could not be true, for the spores are not matured until in the spring of the year just as the leaves begin to unfold.

The method by which each fungus enters the leaf has not been determined in all cases. But entrance may evidently be obtained in one of two different ways, either thru the stomata, or by direct penetration of the epidermal cells. In case the former part of entry is used the young germ tube grows until it strikes a stoma, whereupon it changes its course and grows thru the opening into the region of the leaf tissue. The chances for finding a stoma in short order ame rather great when one remembers that the number varies from 50 to 300 per square millimeter on the lower leaf surface. But in many instances the tip of the germ tube actually penetrates thru the leaf epidermis. The action is a chemical one however, and not a mechanical one. As the point of the hypha becomes applied to the epidermal wall certain ferments known as enzymes are secreted by the hypha. These enzymes are organic catalytic agents, and are therefore able to assist in such reactions that will result in dissolving out the substance of the epidermal cell walls, thru which opening the hypha proceeds to enter.

Of leaf inhabiting fungi two types may be recognized as regards the distribution of the mycelium. So we have <u>intercellular parasites</u>, whose mycelium is between the cells, and <u>intra-cellular parasites</u> whose mycelium penetrates the cell walls. However, in either case, there are likely to be formed specialized organs of absorption known as <u>Haustoria</u>. These are simply the inflated and bladder-like ends of the hyphae and are produced within the cell cavity. The fungi that produce haustoria are regarded as very highly specialized parasites, since they have adopted the procedure of absorbing food materials from the cells without killing them outright.

Sooner or later, however, the living cell parts begin to succumb to the attacks of the fungus. The first external symptom of a diseased condition following the attack of a leaf parasite is usually a change in color of the infected region. Internally the plant is unable longer to manufacture chlorophyll, and the chlorophyll that is present is destroyed, so that the diseased area becomes lighter in color, most often with a yellowish tinge. If this decline continues the cells die and the infected region takes on the brown color characteristic of partially oxidized plant substances. It is the appearance of these distinctly brown regions that gives to the leaf-spotting fungi their conspicuousness.

The leaf spot diseases are not regarded as destructive except in cases where they may be so prevalent that early defoliation results. This of course reduces the vitality of the tree and tends to lessen the annual increment laid down. The lessening of the vitality may result in decreasing the tree's powers of resistance to some other parasite. It would also mean that wounds heal less rapidly because of the inability of the tree to produce the necessary callus tissue. The dead tissues of the wound would be exposed for a longer period of time to many of the so-called wound fungi, among which are numbered some of the organisms most destructive as tree diseases and timber decays. In other words the chances of infection from other diseases-producing fungi would be greatly increased. The reduction in annual increment would, of course, be small when computed for a single season, but if the disease should recur year after year for a long period of time the loss in timber value would be considerable.

The most important genera of leaf spotting fungi are:

<u>Phyllosticta, Gloeosporium, Marssonia, Septoria, Cylindrosporium</u>, and <u>Cercospora in the Fungi Imperfecti</u>, and <u>Guignardia, Gnomonia, Dothidella, Hypoderma, Lophodermium,</u> etc. in the Ascomycetes.

No Basidiomycetes or Phycomycetes are known to cause true leaf spots.

The following leaf spots are to be regarded as simply representative of the very large number that are now known and have been more or less studied.

1. Phyllosticta Catalpae E. & M.

Catalpa Leaf Spot. Fungi Imperfecti

HOSTS: Different species of *Catalpa*.

SYMPTOMS: In early June or later, circular brown spots appear on the leaves. When mature these spots are 3 to 6 mm. in diameter, or larger where coalescence has occurred. They are then ashy-brown in color at the center but have a darker narrow margin, and this in turn is usually encircled by a slightly yellowish-green zone where evidently the chlorophyll is disappearing. Often the centers of the larger spots drop out, giving the so-called "shot-hole" effect.

EFFECTS: In case of light infection the functions of the leaf are probably not seriously interfered with. In severe cases defoliation may occur in July or August.

CAUSE: By an Imperfect Fungus with but one spore stage so far as known. Pycnidia are developed on the diseased spots on the upper surfaces of the leaves and are subcuticular. They do not develop until very late in the season, however, and usually are not present when the leaves fall. The conidiospores are narrow-elliptic, pointed at both ends, hyaline, one-celled, and measure 6-10x2.5-3.5 u.

SPREAD: In all probability the conidia are capable of wintering over and so provide for the primary infection the next spring. It seems doubtful if secondary infection occurrs from the first crop of pycniospores produced.

ASSOCIATED FUNGI: On either the lower or upper surface of the dead areas a minute scurfiness often occurs, that indicates the presence of the fruiting bodies (conidiophores) of another fungus, *Macrosporium catalpae* E. & M. It is generally believed that this fungus is not important in causing the Catalpa leaf disease, but is a secondary organism living on the tissue already killed by the *Phyllosticta*. This idea, however, has not yet been supported by conclusive evidence.

The conidiospores of the *Macrosporium* are ovate to elongate-pyriform, smooth, brown, 4-7 celled, usually with but one vertical wall. 27-60 x 9-12.5 u, mostly 30 - 45 u. long.

CONTROL: The commercial importance of the *Catalpa* both as an ornamental tree and as a nursery crop would perhaps warrant the raking and burning of the fallen leaves, thus insuring the destruction of the source of overwintering. The application of some standard fungicide such as Bordeaux Mixture, just after the leaves unfold and once or twice thereafter at intervals of ten days or two weeks should prevent its appearance.

LITERATURE: Report of the U. S. Commission of Agriculture, 1887, p. 364-366.

2. Phyllosticta acericola E. & M. (= P. minima)

Phyllosticta Spot of Maples — Fungi Imperfecti

HOSTS: Various species of maples ; most often on *Acer rubrum* (red maple) and *A. saccharum* (sugar maple); more rarely on *A. pennsylvanicum* (striped maple) and *A. saccharinum* (silver maple).

SYMPTOMS: The fungus makes its appearance about the middle of May or in more northern localities in June. It first appears as small dark-colored, more or less circular spots that rapidly increase in size and sometimes become irregular in shape, tho more often the circular form is maintained. When the spot has increased to nearly mature size the center dries out and becomes a lighter yellowish-brown color than the dark-brown, broad margin. On A.saccharinum the centers of these spots may eventually drop out. The dead areas are 4-15 mm. in diameter and usually abundant on the leaves.

EFFECTS: Where present at all the infection is likely to be so abundant that large areas of leaf surface are prevented from functioning properly. In severe cases the leaves may wither and die and the individual spots then become practically invisible.

CAUSE: The fruiting bodies of the fungus are small black pycnidia produced in considerable numbers on the upper surfaces of the dead areas. No other type of fruiting body is known for the fungus. The conidia are ovoid, smooth, one-celled, hyaline, and measure 8-10 x 5-6 u. The mycelium is intercellular.

SPREAD: The conidia are the only spores known to be produced and it seems probable that they retain their vitality over winter and so infect the new growth in the spring. The usual abundance of infection on the native maples points to the prevalence of secondary infections following the production of the first crop of conidia in the summer.

CONTROL: No control experiments have ever been made with this fungus. The danger of infection by over-wintered conidia would be eliminated by the burning of the leaves in the fall. The spraying of the trees or nursery stock with any standard fungicide just after the leaves open and once or twice subsequently should prevent infection of the new growth in the spring.

LITERATURE: Report U. S. Department Agriculture, 1888, p. 383-386. 1888.

3. CYLINDROSPORIUM OCHROLEUCUM (B. & C.)

Anthracnose of Chestnut — Fungi Imperfecti

HOSTS: Various species of *Castanea*, especially *C. dentata*, the American chestnut.

SYMPTOMS: In July the disease first makes its appearance as minute yellowish spots that soon become yellowish-brown at the center. The spots gradually enlarge until a diameter of about 4 mm. is reached. No further enlargement takes place unless two or more spots coalesse. Each mature spot has a large, ash-colored center surrounded by a narrow dark-brown ring. Before the leaves fall a narrow yellowish circle surrounds the brown ring on the outside.

EFFECTS: Slight infections do no serious damage and the late appearance of the disease renders it yet more harmless. Badly infected trees, especially nursery stock, may be stunted and a premature dropping of the leaves may result.

CAUSE: An Imperfect Fungus variously referred to the genera *Cylindrosporium*, *Marssonia*, *Septoria*, and *Phyllosticta*. But one kind of spore is produced. They are the conidia, contained in fruiting bodies that are formed on the lower side of the spots and are quite conspicuous. They are light colored, very small, and when mature have more the appearance of cup-shaped depressions in the lower surface of the leaf. The spore-producing layer is not covered by the wall characteristic of the pycnidium of other fungi and this type of fruiting body is known as an acervulus. The spores are crescent-shaped or only slightly curved, filifor but slightly thickest at the middle, 2-celled, hyaline, and measure 15-20 x 1,5 u.

SPREAD: The conidia live over winter and are responsible for the primary infection the following year. They are undoubtedly wind disseminated. Secondary infection has not been observed.

CONTROL: No control measures have yet been worked out. Where the disease is serious enuf to warrant it, burning of the leaves and spraying with Bordeaux should keep it in check.

4. GUIGNARDIA AESCULI (PECK) STEWART

Leaf Blotch of Horse-Chestnut — Ascomycetes

HOSTS: Aesculus hippocastanum and A. glabra.

DISTRIBUTION: Known in Europe and America, occurring to some extent wherever the horse chestnut or buckeye is found.

CLASSIFICATION: An Ascomycete belonging to the Family Mycosphaerellaceae of the Order Sphaeriales.

Several names have been proposed for a fungus found on leaves of these hosts, and the differences cited have been in sizes of the pycniospores. Stewart (1) finds that the smaller spore-sizes apply to spermatia produced in the life history of Guignardia aesculi and not heretofore known, being considered as pycniospores and the spermagonia as pycnia. Consequently he considers the following species as synonyms on for that reason: Phyllosticta sphaeropsoidea E. & E, P. aesculicola Sacc., P. aesculi E. & M., and P. aesculina Sacc. P. paviae Desm was considered identical by Ellis and Everhart, but inoculation experiments (see later) by Stewart (1) have so far shown a physiological difference and the two species are kept separate by him.

Laestedia aesculi Peck was suggested by that author as the name for the perfect stage of this fungus but that generic name is found to be preoccupied.

CAUSE: This Ascomycete has three spore-stages in its life-history, as follows: (1) Pycnidia, mostly on the upper surfaces of the leaves and producing globose or ovoid, hyaline spores, 10-16 x 6.5-10 u, tailed with a small apiculus; (2) Spermagonia on either leaf surface and sometime in the same stroma with pycnidia or perithecia, producing spores that are oblong, hyaline, 3-9 x 0.75-3 u; (3) Perithecia, appearing in late summer but not maturing until the following summer, producing spores that are sub-elliptic, hyaline, 12-18 x 7-9 u.

BIOLOGY OF THE FUNGUS: The leaves and occasionally the petioles are affected; rarely lesions appear on the immature fruit. A slight discoloration at the point of infection is the first indication of the disease. The outline of the lesion becomes irregular and newly invaded tissue appears water-soaked. The spot gradually changes to dark red or brown in the center, blending thru a yellowish margin into the green healthy tissue. The diseased spot finally dies and dries out. When the spots are large the dried area may curl up. The red or brown colored spots are striking symptoms and when the disease is severe the trees appear as if burned by fire.

Pycnidia appear soon after the lesions are apparent on the leaves, usually on the dried-out portion but occasionally on the recently infected parts that contain some chlorophyll. The pycnidium is black and globose and has a definite ostiole.

Pycniospores develop in a gelatinous matrix and extrude in a coil 2-3 mm. long. These spores germinate only with difficulty but sometimes produce a short germ-tube in 24-48 hours.

Spermagonia appear about August and are much less abundant than pycnia. When produced in the same stroma with the pycnium the thin dividing wall may break and spermatia and pycniospores be found mixed in the same fruiting structure. Attempts to germinate spermatia in tap and rain water failed.

Perithecia develop slowly from August 15 to the next spring or late winter. The spores are discharged forcibly thru the wall of the ascus. They germinate with difficulty, short germ tubes and frequent appressoria being formed, even on agar media.

Sclerotia are produced in cultures on sterile petioles, bean pods, or on eat agar.

The incubation period in infected leaves is from 10-20 days. The mycelium is both inter- and intra-cellular, hyaline, septate, 2-4.5 u diameter. No haustoria have been found in the host.

Inoculation experiments were run and all inoculated plants developed the disease while all the checks remained healthy, when the cross inoculations were from A. glabra to A. hippocastanum and vice versa. But all attempts to infect A. parviflora from these two species failed. The form on A. parviflora has been described as a distinct species (viz. P. paviae) but reduced to synonymy by Ellis and Everhart (2). Stewart (1) prefers to consider that this fungus is at least physiologically distinct from the species on the other two hosts, altho morphologically indistinguishable.

In the Eastern United States the disease is frequent and often a large percent of the foliage of mature trees is affected by mid-August and by mid-September the trees are nearly or quite leafless. It is particularly destructive to nursery plantings. Very often by midsummer the seedling beds are completely defoliated. Growth is slower and the trees apparently less able to endure severe winter, hence twigs and branches are killed back.

CONTROL: Dusting with sulphur or spraying with lime-sulphur or Bordeaux is effective in control. Dusting is preferred as the leaves can be covered better and there is no danger of burning. A mixture of finely ground sulfur (90 parts) and powdered lead arsenate (10 parts) dusted on three or four times at intervals of 3 or 4 weeks is very effective.

LITERATURE CITED: 1. Stewart, V. B. The leaf blotch disease of horse-chestnut. (Phytopath. 6:5-20. 1916)
2. Ellis, J. B. & Everhart, B. M. The North American Phyllostictas p 41. 1900.

5. Needle Cast of Conifers

Needle cast of conifers is a disease quite prevalent on many species of conifers, particularly pines, but occasionally on hemlocks, firs, larches and spruces, and appears to be common wherever these trees are grown. In the eastern United States the disease is most important on the white pine and the balsam fir, and in the Northwest on the white fir, western yellow pine, and western larch. The disease is characterized by the gradual browning of the leaves, followed by their premature casting. Trees heavily infected may at a distance present a decidedly browned appearance. The disease is caused by one of several fungi belonging to the Ascomycetes, and mostly to the genera Hypoderma and Lophodermium. These genera are closely related and distinguished by the fact that in Lophodermium the spores are much elongated and very narrow, while in Hypoderma they are 1 or 2-celled, and short cylindric.

These diseases primarily affect the needles. The first symptom of infection is the appearance of small yellowish spots that gradually enlarge and finally become brown in color. This discoloration may begin at the tip, but more often at some other point, finally killing back the needle until half or more of the entire needle is dead. Other needles in the same bundle may remain healthy or may contract the disease at a later date. On the white pine the color may eventually become of a grayish cast with the needles presenting the appearance of being somewhat curled. On the pitch pine the disease is usually not so severe but widely present and the leaves are more apt to be of a yellowish color. A peculiar banded appearance with alternating brown and yellow bands is often a marked characteristic of the disease on this host. At times, on this host a dwarfing of the needles and the death of the spur shoots has been noted. In some species only needles of the current season are susceptible to attack, but in others it appears that the older needles may also become infected. In case of seedling trees up to 5 years old death usually results so rapidly that the trees retain their needles.

Nearly all of the fungi causing leaf cast are known also to be able at times to penetrate into the woody tissues of the stem, at first into the cortex but finally penetrating into the medullary rays and the tracheids. As a result, a twig blight results, in which the terminal twigs are killed or the dwarf spurs alone may be affected. In more severe cases of parasitism as for example Hypoderma deformans on western yellow pine in the Northwest, marked enlargement follows penetration of the woody tissues. Lateral and adventitious buds on the terminal nodes are stimulated to growth, resulting in the production of witches brooms that may become so heavy as to eventually break off.

In the spring following infections of the previous summer or rarely in the same season, there are produced on the dead portions of the needles the characteristic black apothecia, n nearly rounded to linear in shape, black in color, and at maturity opening by a longitudinal fissure. Apothecia are never produced on infected sheaths or twigs. Spores are matured and liberated from these apothecia for a period of time that may extend over several months, the hygroscopic nature of the lip of the apothecium facilitating their discharge. The spores retain their vitality for some time in case of Hypoderma deformans, Weir reporting spores viable from dry material kept in the laboratory for a year.

The continued killing off of the needles undoubtedly affects the annual increment laid down even in the milder cases of infection. In more severe cases young trees may be killed outright. Where witches brooms are formed these never produce cones and the normal parts of the supporting branch are usually sterile.

While the parasitism of these forms has been experimentally proved in most cases, yet in case of some of the species the evidence shows that they are often only weak leaf parasites, and seem to come in only on the older weakened needles. The disease does not appear to be highly infectious, as trees heavily infected are often found entirely surrounded by trees of the same species with little or no infection.

In nurseries this disease is frequently reported as killing off 2-3 year old seedlings in definite local areas, and while fruiting bodies of some of these fungi can always be found on leaves of plants so infected, this is not sufficient evidence of the parasitism of the fungi in these cases.

Two spore stages are known for some of these fungi. The conidial stage referable to the genus Leptostroma may precede the formation of ascospores. The conidia are not known to be functional.

The ascospores are produced in modified apothecia. The species all belong to genera of the family Hypodermataceae of the Order Hysteriales. They comprise the following group of species as now known: Hypoderma deformans on western yellow pine and perhaps other species in the far West and the Northwest; Hypoderma strobicola on white pine, scrub pine, and pitch pine in the eastern United States; Hypoderma lineare on white pine in the eastern United States; Lophodermium nervisequum on balsam fir in the eastern United States and on fir in the West, and Lophodermium pinastri on different pines in the eastern states.

Little has ever been attempted in the way of control of this disease. In logging operations care should be taken to mark for cutting all heavily infected trees that come under the regulation diameter. This is particularly important if it should prove, as observations indicate, that trees once heavily infected seldom recover. Successful control of the disease in nurseries has been reported for the use of a copper sulphate spray but due to the prolonged period of spore discharge this means a minimum of 8-10 applications per season, although this would vary with the season.

CHAPTER II

Fungi Inhabiting Leaves but not Producing Definite Leaf Spot Diseases.

There is a considerable number of leaf inhabiting fungi whose presence is not associated with definite dead areas in the leaf. Most of them are definitely parasitic, and indeed are probably to be regarded as more highly specialized parasites than are those forms previously considered as leaf spotting organisms. That is, a parasite that, as it were, can hold in check its feeding propensities so that the host is not killed but can continue to furnish enough food materials to support the fungus, must probably be regarded as a more specialized parasite than the other type. Other symptoms of a diseased condition may or may not be present, depending partially on the severity of the attack. In fact, the range of injury produced by this group of organisms varies from no more than a long drawn out smothering effect or perhaps no visible effect at all, to cases of atrophy and finally to death, the latter more particularly involving all or a large part of a leaf and not a definite spot.

Discolored areas may well result from this type of injury, but in most if not all cases the discoloration is not of the host tissue but is produced by some stage of growth of the fungus itself; or if tissue discoloration is present it is masked by the fungous tissue.

This group of disease-producing organisms may be conveniently divided into two series. The first of these is characterized by having practically all parts of the fungus, i.e. both mycelium and fruiting bodies, external on the host. The second group comprises those forms with the mycelium and in some cases the fruiting bodies internal. In the first group belong the powdery mildews and their kin, and to the sedond group certain leaf inhabiting rusts and in addition the tar-spot fungi and their relatives.

1. Powdery Mildews.

This is a group of highly specialized parasites mostly confined to the leaves of their host plants. They are not to be confused with the "downy mildews" belonging to the Phycomycetes which often have a similar habitat but are readily distinguishable under the microscope. Under the hand lens the powdery mildews are easily recognized when in fruiting condition as described below. In general, the powdery mildews are characterized as being leaf inhabiting parasites with the white mycelium and the black perithecia produced on the surface of the leaf. In some species they are on the upper side of the leaf, in others on the lower side, and some species are to be found on both sides of the same leaf. Nearly all broad leaved trees may be attacked by one or more species of these fungi, a total of only about 10- or 11 species being foung on our principal trees and a few others on certain less valuable

timber species, such as alder, willow, cherry, apple, etc. The host range of these species is therefore quite large, one species being known to occur on at least 12 common species of forest trees and another on 11 species.

In addition to the superficial white mycelium present on the leaves these fungi send short haustoria into the cells of the host. In all cases entrance is gained by a direct penetration through the cuticle and the cell wall, presumably by means of enzymes. The haustoria are in most cases confined to the epidermal cells of the host, but in two genera they are known to penetrate the mesophyll cells and it is not impossible that some haustoria in all species may penetrate into the subepidermal cells. Otherwise it is difficult to explain how such highly parasitic species could exist on the very limited nourishment to be obtained from the epidermal cells alone, aided perhaps by the small supply that, thru osmosis, might be drawn into the epidermal cells.

As is the usual case with highly parasitic fungi the materials absorbed from the host are probably the final products of metabolism, consisting in part, therefore, of proteins, and other nitrogenous substances as well as organic acids and other materials in the cell sap, and showing little preference for the carbohydrate content of the cells.

Powdery mildews as they usually occur on forest trees do not cause serious injury. Occasionally on young shoots of oak or other woody plants as cherry, rose, or apple, when the young growth is heavily infected a distinct dwarfing of the shoot occurs, the leaves being small and with somewhat of a tendency to curl unnaturally. Other visible effects are usually lacking, though it has been shown by experiment that grass leaves heavily infected with powdery mildew show as little as one-half the amount of photosynthetic activity as measured by reducing sugars formed, as do uninfected leaves under similar conditions.

The powdery mildews are Ascomycetes belonging to the Order Perisporiales and family Erysiphaceae. But five genera are known on forest trees and they are to be separated only on microscopic characters. As the generic or specific identity of the fungus is not necessary in this case to provide intelligent means of control this separation is of little practical importance. Two types of spores are present in the life history, i.e. conidia and ascospores. Conidia are produced rather early in the season and are cut off in chains from the tips of undifferentiated conidiophores. The conidia do not differ materially in the different species. They function in spreading the fungus to other host plants or to other parts of the same plant. They probably are incapable of wintering over. It is their abundance that first suggested the name "powdery mildews" for this group of parasites. Later in the season, often as late

as September or October, perithecia are formed, at first pale waxy yellow in color, later becoming brown and finally black. They are found distributed irregularly over the mycelium and in some cases are large enough to be visible to the unaided eye. They are globose in form, with a black, cellular wall to which are attached special radiating hyphae termed "appendages". The tips of these appendages are variously formed, sometimes dichotomously branched, sometimes straight, sometimes coiled, and these variations are made use of in recognizing genera. It is supposed that their function may be to help anchor the perithecium at an early stage, and later by special torsions to elevate it slightly above the surface of the host so that it may be more easily torn off and distributed. Each perithecium contains one or more asci, each ascus with 2 to 8 spores. The numbers here are of importance in taxonomic work. The spores in the asci winter over within the perithecium and in the spring are set free by a yielding of the perithecial wall to the pressure within. They provide the means, therefore, of primary infection in the spring.

Unlike most plant diseases where the parasite is internal, the powdery mildews can be eradicated after infection has taken place, due to the fact that practically the entire fungus is external. Hence toxic substances applied to this mycelium will kill it and so rid the leaf of the infection. Flowers of sulphur dusted over the foliage or in case of large trees applied with a blower, gives good control. Bordeaux mixture is not highly efficient but lime-sulphur has been used with good success. Raking and burning the leaves will of course reduce the amount of primary infection in the spring.

2. Sooty Molds and Brown Felt Fungi

Closely related to the previous group of parasites is another group embracing a number of species of similar habit but with usually a much more extensive development of a black or brown mycelium that may cover both leaves and branches. The true sooty molds are saprophytic and sometimes develop in connection with aphid attacks, these organisms excreting a sweet liquid, known as "honey dew" on which the fungus thrives. The damage done by these is insignificant and except for occasional cases of profuse mycelial development followed by a smothering effect on the host, may be disregarded.

In case of the brown felt fungi the case is different. Three species of these fungi are known, two occurring in Europe as well as in America. Neopeckia coulteri is found only on species of the genus Pinus, and Herpotrichia nigra on Abies, Juniperus, Picea, Libocedrus, or Tsuga. A third species

H. quinqueseptata was described on Abies from the Northwest in 1915. These are all indistinguishable from habit alone.

All three of these species are Alpine, found growing over needles and twigs of the host at elevations of 5000 to 11000 feet above sea level, both in Europe and in America.

They form brown or black felt-like masses over leaves and twigs so that the needles become completely matted together and buried in the mycelial mass. Later when the leaves have died the entire mass can be readily lifted from the twigs. The growth of this mat is rapid, branches of Alpine fir two feet in length being entirely covered by the mycelium by fall following infection in the spring. Considerable damage is caused by these fungi, particularly on young trees, although old trees may also be killed. Ninety-five per cent infection of an even aged Alpine fir stand has been reported by Weir. The mycelium of the fungus penetrates the leaf tissues throughout, causing more damage to the mesophyll cells than to the epidermal cells. The fungus usually develops best on the lower branches of older trees, especially where these have been buried in the snow over winter.

As a result of severe attacks by these fungi entire branches are often killed and the width of the annual ring is materially lessened. The effects of this fungus have been described as due in part to the action of the internal mycelium and in part to the smothering effect of the external mat, shutting off light and air from the enclosed host tissue.

3. The Tar Spot Fungi

A small series of fungi, widely distributed and quite common, are to be recognized in part by the black tar-like spots formed on the upper surfaces of the leaves. The spots contain the fruiting bodies of the fungi and usually are not produced on dead areas of the leaf tissue. The fungi belong to the genus Rhytisma and are classed in the Order Phacidiales, family Phacidiaceae of the Ascomycetes. Two species are common on maple, R. acerinum forming large black blotches sometimes nearly 1 cm in diameter, and with the surface of the black mass thrown into corrugated folds. Sections thru these areas show a white internal stromatic structure in which are imbedded numerous apothecia. Further examination shows that this stromatic layer is superimposed on the external leaf surface, neither entirely replacing nor destroying the leaf tissue at this point, although the mycelium is internal. This species is common on Acer rubrum on which host large areas are prevented from functioning properly, and it is believed that this fungus is largely responsible for the slow growth of the red maple in many regions. On A. saccharinum it is often equally severe but on A. saccharum and other species it is of less importance.

R. punctata, the dotted tar spot, is also an inhabitant of maples, being most severe on _A. pennsylvanica_ and _A. spicatum,_ though occasionally found on _A. saccharum._ This fungus presents quite a difference to the preceding species, the difference being such as would be present if the large black stromatic mass of _A. acerinum_ would break up into as many separate and isolated masses as there are apothecia imbedded in it. The appearance, therefore, is of many smaller black dots, 0.5 - 1 mm. in diameter though usually somewhat longer in one direction than the other. Each spot contains a single apothecium. Many of these spots are scattered on the infected area which may be 1-3.5 cm. broad. At first these spots are indefinite and green in color and the perithecia may be developed while this color still prevails. These spots finally begin to turn brown late in the season, and the browning progresses outward, so that if the development of the disease is not stopped by normal leaf fall extensive dead areas may result. More frequently, however, before this stage has progressed far the leaves begin to wane in vitality and become yellowish in color. It is at this time that the disease is most striking. The chlorophyll persists in a wide band on the margin of the infected area until long after the uninfected leaf tissue has lost its green. Consequently the brown of the dead area contrasts strongly with the green of the marginal band and the yellow of the leaf. This coloration is best developed in _A pennsylvanica_ but is shown also by the other hosts of this parasite.

Other species of this genus are parasitic on other woody plants, such as the willows, hollies, various heaths such as blueberries, Andromeda, etc.

Inoculation experiments tend to show that as far as the maples are concerned distinct races of these parasites exist, for neither of these species on one host is able to infect another species of host.

The spots formed by these fungi appear as small yellowish areas in early or mid-summer, soon becoming black, however, as the stromatic tissue begins its development. Within the cavities of the stroma a conidial stage is first produced with minute oblong spores whose part in the life history is unknown. The diseased leaves fall to the ground where they lie until the following spring when the ascospores are produced. These are not matured until about the time the host begins to leaf out. They are discharged by the rupturing of the stromatic tissue along the corrugated margins and so provide for the primary infection of the season. Secondary infection probably does not occur. The spores are long needle-shaped and colorless, measuring 60-80 x 1.5-2.5 u.

Preventive measures, where possible of application, consist in raking and burning the leaves and spraying with Bordeaux mixture as for other types of leaf parasites.

4. Leaf Rust Diseases of Trees.

A large number of highly parasitic fungi, included in the group of the plant Rusts, are found on the leaves of trees, both deciduous and coniferous. With three or four unimportant exceptions these rusts all have a similar life history that includes the four usual spore forms (O,I,II,III), and with the same exceptions all are heteroecious. Practically all species of coniferous trees (except the cedars) are hosts for one or more species of these leaf rusts, but among the important deciduous forest trees only the oak, the ash, the poplars, and the birches suffer from their attacks, altho there are several unimportant shrubs on which certain species are known to occur. Among the coniferous hosts the leaves always bear the pycnia and the aecia. On the ash tree the same is true but on the oaks and the poplars the uredinia and telia are produced.

A. Coniferous Leaf Rusts.

The Alternate Hosts: The alternate hosts for the coniferous leaf rusts present a wide variety of relationships such as ferns, poplars, birches, willows, Hydrangea, a number of different genera and species in the heath Family (E ricaceae) such as Azalea, Vaccinium, Rhodora, Gaylussacia, Ledum, Chamaedaphne, etc., and in addition to these woody hosts, a considerable number of herbaceous genera and species. Of these latter, among all the multitudinous families of flowering plants but 7 contain species that harbor the alternate stages of these leaf rusts. The composite family leads in this respect, with at least 11 species of heteroecious rusts, the chickweed family has two and the other families, as shown on the chart of relationships, have but one each. A study of this chart reveals the relationships of all these various rusts in a way more graphic than can be described in words. For example, all needle rusts of pines, of which there are 14 species, are found in their alternate stages on herbaceous hosts, mostly in the composite (sunflower) family. On the other hand all leaf rusts on Larix, Pseudotsuga, and Tsuga go for their alternate stages to broadleaved woody plants, more than 2/3 of them to the low families Salicaceae and Betulaceae, a single species to the rather high family Ericaceae, and one species to the intermediate Family Hydrangeaceae. In contrast to these conditions the leaf rusts on Picea go partially to herbaceous hosts in the Chickweed Family and the Heath Family, and partially to the woody members of the heath family. Perhaps the leaf rusts of Abies, as a group, show more diversity in choice of hosts, than do any others. The five known species go to five separate families and 2 different divisions of the plant Kingdom. Two species (perhaps both are composite species as here treated) go to various members of the Fern Division; one to the Salicaceae (Willows), one to the chickweed family (Carophyllaceae), one to the evening primrose family (Onagraceae), and one to the woody members of the Heath Family.

The Number of Species and their Classification: These heteroecious leaf rusts represent a total of 32 species of which 14 are on the leaves of Pinus, 6 on Abies and 5 on Picea, 3 each on Tsuga and Larix, and one on Pseudotsuga. These 32 species are distributed among 8 genera all of which are full cycle rusts except the one alternating between Abies and the heaths (Calyptospora columnaris), in which the uredinia are lacking. This species is further characterized by being the only one that, on the alternate host, is not a leaf parasite, but instead causes the formation of a witches broom, attacking therefore the woody tissue and producing the teliospores within the epidermal cells of the host.

Morphologically these rusts can be separated into two groups on the nature of the aecial cluster cup. The genera Coleosporium, Pucciniastrum, Melampsoridium, Melampsorella, Melampsoropsis, and Calyptospora have a distinct peridium, projecting, and more or less prominent, while the genus Melampsora entirely lacks such peridium and except for color is quite similar to the uredinial stage. Aecial stages lacking a peridium are referable to the form genus Caeoma, and aecial stages with a peridium are often classed as in the form genus Peridermium.

Independence of the Uredinial and Telial Stages: While these rusts are long cycle heteroecious forms yet peculiarly enough the fungus may actually be independent of the aecial stage for its propagation. This is because the plant is able to winter over in the perennial parts of the alternate host either as mycelium or as viable urediniospores. At least a dozen such instances are known among the leaf rusts. This results sometimes in the uredinial and telial stages being self perpetuating to the extent that they may spread to distances of hundreds or even thousands of miles from any known source of aecial infection. Consequently in many species of leaf rusts, the geographical range of the uredinial and telial stages is much more extended than for the aecial and pycnial stages. These latter stages will of course follow the former as far as the range of their hosts permits but quite frequently the range of the uredinial hosts is much greater than of the aecial hosts.

The Life Cycle: On the coniferous hosts, the pycnia are always produced first, either in late fall or in early summer, depending upon whether infection has occurred in the fall or in the spring. They occur as small yellowish dots on the leaf surface and at maturity ooze out a small pale viscous drop in which the pycniospores are suspended. These spores are, so far as known, functionless in the life history.

The aecia follow the production of pycnia. In case of fall-infected leaves the aecial stage appears in late spring, usually in May or June on the leaves of the previous season. Hartig states that leaves once infected may produce aecia for more than one season. Where infection occurs in the spring they do not appear until later, usually running well into July, and always on the new leaves of the current seasons growth. Usually the aecia are formed in two parallel rows, one on either side of the midrib, in such leaves as spruces and hemlocks, but irregularly on the needles of pines. The most conspicuous aecial stages are found in those species in which the peridium is present as a part of the cluster cup. This structure is yellow or orange in color and may project as much as 2.5 mm. from the leaf surface. At first it forms a continuous covering over the spore mass, but at maturity it ruptures at the apex or elsewhere and allows the yellow or orange spores to escape. In case of the so-called Caeoma forms (i.e. aecial stages lacking a peridium) the spores are formed beneath the epidermis of the host thru which they burst out at maturity. All aeciospores are primarily wind disseminated, although this does not preclude the possibility of other agencies acting in this capacity.

The spores of the aecial stages of these various leaf rusts are quite similar in appearance and the different species are in many cases indistinguishable on this basis. All show spores with distinctly roughened walls, the roughening usually being in the form of tubercular spines that are more or less deciduous and easily crushed off when mounted in water under a cover glass.

Infection of pine leaves does not necessarily result in their death, as Hartig states that the infection may live over in the needle a second season and produce another crop of aecia. In the other genera the teliospores rest over winter, germinating the next spring resulting in infection on the new growth of the season followed by the pycnia and aecia during the same summer, often as late as July. In these cases the rust fruits on the needles but once, usually resulting in the death of the leaf the same season, but if the needles are not killed the infection apparently dies out.

On the alternate host these rusts are confined to the lower leaf surfaces. They are not particularly conspicuous at any stage of their development. The uredinia, present in all species except the Vaccinium-Abies rust, appear as small cushion shaped pustules smaller than a pinhead., yellow or orange in color, and before rupturing the epidermis are more or less waxy in appearance. A uredinial sorus consists of a compact mass of fertile hyphae, originating beneath the epidermis of the host. A peridial covering is present in some genera and absent or nearly so in others. Where a peridium is present dehiscence is through a central pore but in its absence they burst irregularly through the epidermis. Sterile clavate or knob-like organs known as paraphyses may be mixed with the fertile hyphae or form an imperfect marginal band to the sorus.

More variation exists among the telial stages of these species than among either of the others, and gives basis for distinguishing several genera of somewhat doubtful taxonomic value. The most common condition, present throughout the genera Coleosporium, Melampsora, Melampsoridium, and some species of Pucciniastrum, is a cushion-shaped telial mass similar to the uredinial sorus but usually more waxy in appearance and deeper colored. This is composed of oblong unstalked teliospores, covered at first by the epidermis, and compacted side by side into a palisade layer just beneath the epidermis. In some species of Pucciniastrum, in Calyptospora and Melampsorella the spores are produced within the epidermal cells of the host. In Urediniopsis they are scattered through the mesophyll tissue of the leaf (but not within the cells). In the genera Coleosporium, Melampsora, Melampsoridium, Melampsorella and Melampsoropsis the teliospores are one-celled at maturity though in the genus Coleosporium they become 4-celled by the early division of the cell content. In Pucciniastrum, Calyptospore and Uredinopsis they are 1-4 celled or occasionally more.

No provision is made for the discharge and dissemination of the teliospores and in all cases they can be released only by the rupture of the epidermis or by the weathering away of the overlying leaf tissue; In Coleosporium, Melampsorella and a species of Uredinopsis (as reported by Weir) the spores germinate as soon as mature in the fall, while the species of Melampsora, Melampsoridium, Pucciniastrum, Calyptospora and most species of Uredinopsis overwinter in the teliospore stage and germinate the following spring. In all genera but Coleosporium germination is by means of a typical germ tube that becomes the basidium and produces one basidiospore from each of the four cells into which it becomes divided. In Coleosporium the mature teliospore divides into 4 superimposed cells which constitute the basidium, and from each cell a long sterigma bearing a basidiospore is produced.

Effects on the Host: The effects of coniferous leaf rusts on their hosts is usually not serious. In case of hemlocks, spruces, and firs infection means the quick death of the needle and while bearing the aecial stage, only a few weeks after infection, these leaves can be detected at a glance by the yellowed color of the upper leaf surface. Only rarely, however, is infection followed by so heavy a leaf cast that the life processes of the tree are interferred with. The needle of pines are not so quickly killed and infection of them always comes late in the season after the bulk of the summer's work is over. Next spring a new crop of healthy leaves will be produced that will again remain free from infection until later in summer. Melampsora abietis-canadensis is perhaps the most destructive of this entire series, as in addition to its effects on the leaves of hemlock, the entire years growth may be killed outright. The infected stems become curiously twisted and contorted during the time the aecia are produced and by late summer these twigs are always dead. The mycelium does not

live over in the stems, however, so that trees heavily diseased one year may be entirely free from it the next season.

Control: Control measures, if desirable and practicable, consist solely in the eradication of the alternating hosts. Additional protection can be afforded nurseries by so locating the seed beds that they are far enough removed from any danger of infection from the alternate host.

No mention has so far been made of three species of coniferous tree rusts with different life histories than those above described. These species are a s follows: Gallowaya pini, a short cycle autoecious form on the leaves of Pinus virginiana on which telia alone are known to be produced; Necium farlowii a form with a similar life history but found on the leaves of Tsuga canadensis in the epidermal cells of which the teliospores are produced; Chrysomyxa weirii, again with a similar life-history including, so far as known, only telia on Picea englemannii.

The number of coniferous leaf rusts will be augmented in the future as the life histories of all forms are cleared up. In several instances uredinial and telial stages are known on herbaceous hosts for which no alternate stage on coniferous leaves has yet been found. Also the number of European species not represented in our flora is considerable and some of these will undoubtedly eventually be introduced.

B. Leaf Rusts on Broadleaved Forest Trees.

The number of these rusts that need consideration here is limited, partly because their life histories in many cases have already been considered above, where broad-leaved trees are the alternate hosts for coniferous leaf rust fungi, partly because some of them will be considered when the alternate stages of certain stem inhabiting rusts are discussed, and partly because of the actually smaller number of described species.

Concerning broadleaved tree rusts that have not previously been considered, there are but two that need mentioning here. They are as follows: (1) Puccinia fraxinata with pycnia and aecia on Fraxinus; the alternate host is a species of Spartina (2) Cronartium cerebrum, with uredinia and telia on various species of oaks; the species will be discussed under a later heading. A number of species of Crataegus harbor heteroecious leaf rusts but the host is unimportant as a forest tree.

The actual damage ordinarily inflicted on broadleaved trees by these leaf rusts is negligible in most cases, through Hartig states that in the dase of the poplar - Larix rust, the disease may be so severe as to cause early defoliation. The Vaccinium Abies (Pucciniastrum myrtilli) on the high-bush huckleberry produces a witches broom type of injury that will be considered later.

5. Oak Leaf Blister - *Taphrina coerulescens* (D.&M) Tulasne.

Oak Leaf Blister — Ascomycete

HOSTS: Various species of Quercus (oaks).

SYMPTOMS: There appear in June or July small blister-like spots that usually develop first on the lower side of the leaf but are easily visible from above. These spots vary in size up to a centimeter of more in diameter. At maturity they become concave below and convex above, and may appear more or less powdery and with a slight bluish tinge. Other discoloration is not marked and the areas do not die.

EFFECTS: The disease is essentially one effecting nursery stock and young trees. It is not necessarily serious except in case of severe infection or where present year after year. Some defoliation may occur at times.

CAUSE: The fungus causing leaf blister is one of the lowest of the Ascomycetes and is closely related to the fungus causing the common peach leaf curl disease. The asci are not collected into a definite hymenium but are scattered irregularly over the surface of the blisters. Each ascus at first contains eight spores, but very soon these divide by a budding process until the ascus is completely filled with a mass of these secondary spores.

SPREAD: The ascospores undoubtedly live over winter and infect the new growth in the spring. Whether or not a secondary infection takes place in the summer is not known.

CONTROL: Control methods have not been worked out, but there is no reason to suppose that the methods employed for peach leaf curl should not be effective here. They consist in applying a dormant spray of concentrated lime-sulphur before the buds unfold, in order to prevent infection from the spores that lodge in the bud scales.

Chapter III

Canker-Producing Fungi

Canker-producing fungi are typically stem parasites, and to this group of organisms belong the most destructive of all tree diseases. The injurious effects vary from the destruction of occasional twigs to the entire girdling of the trunk of a mature tree resulting in its death. These fungi usually produce their effects by destruction, in one way or another, of the living tissues of the inner bark, including the cambium. The destruction of the cambium alone is not sufficient to cause, in short order, the death of the tree. In most cases it is the destruction of the phloem region that interferes with the conduction of elaborated foods to the roots, resulting in their starvation, that causes the tree to succumb. More rarely the wood itself is attacked, as in the Strumella disease, with a consequent interference with the upward conduction of water to the leaves, causing the death of all parts of the tree above the infected region.

In any event the diseased region is referred to as a canker, provided that it does not involve any considerable overgrowth resulting in the formation of distinct swellings or galls. A canker is not necessarily an open wound tho cankers of the best developed type may have such an appearance. In the other extreme it may simply consist of a region of dead or diseased tissue marked off from the uninfected tissue by some sort of a visible, tho not necessarily definite, circumscribing boundary.

1. STRUMELLA CORYNOIDEA SACC. & WINT.

Strumella Disease of Oaks and Chestnuts   Fungi Imperfecti.

HISTORICAL: Heald and Studhalter, working for the Pennsylvania Chestnut Blight Commission were the first to describe this disease in detail in 1914. Prior to that time Dr. Buckhout, Professor of Botany at The Pennsylvania State College, had noted (1899) a similar disease on oaks, but he ascribed it as possibly due to Nectria ditissima. In view of the fact that both these fungi are now known to produce conspicuous cankers on oaks in the vicinity of State College, the conclusion of Heald and Studhalter that Dr. Buckhout had in mind the Strumella disease, seems open to question. Or as seems more probable, cankers from both fungi may have been under observations without a distinction being made between them. That the disease is not new is proved by the large cankers of many years standing found on mature trees of oak in central Pennsylvania.

HOSTS AND GEOGRAPHICAL DISTRIBUTION: The following are the known hosts of this fungus at the present time.

American Chestnut................	Castanea dentata.
Chestnut Oak.....................	Quercus prinus.
Black Oak........................	" velutina.
Red Oak..........................	" rubra
Scarlet Oak......................	" Coccinea.
White Oak........................	" alba.
Pignut Hickory...................	Hickoria globra.

Other species of hickory are also probably to be included in the above list.

In addition to these hosts on which the fungus is parasitic, there has been found on the dead bark of trees of Juniperus virginianus in Missouri and Pennsylvania a fungus that morphologically is indistinguishable from the species in question. Attempts at cros inoculations have so far failed.

The disease appears to be most severe on red, black, and chestnut oak, and forms more pronounced cankers on these species. Well developed cankers have not been found on white oak, but the natural roughness of the normal bark renders the lesions more inconspicuous. On chestnut the cankers are often not conspicuous. On hickory well developed cankers are usually formed, but it seems to occur less rarely on that host than on any other.

The first recorded collection of this fungus was made in Missouri. It has since been collected in Ontario, Canada, in Massachusetts, and in Pennsylvania. Present indications are that it is native to the northeastern United States and Canada. It has been considerably studied in central Pennsylvania where it is found that as high as 20 percent of black and red oaks in mixed stands may be so badly cankered as to render a considerable part of the trunk valueless for lumber.

<u>SYMPTOMS AND EFFECTS:</u> Infections are practically always found on the main trunk of the tree and often at a distance of 10 to 20 feet above ground. Young infections on smooth-barked trunks can be easily recognized by the presence of yellowish or yellowish-brown patches, slightly raised, and contrasting sharply with the darker colored normal bark. Such diseased areas are to be distinguished from lesions of the chestnut blight fungus by the presence of small black sterile nodules scattered over the area. Under the bark the whitish mycelium is easily visible but it does not occur in fan-shaped masses as does the buff or orange-colored mycelium of the chestnut blight fungus.

As the disease advances two types of lesions may be recognized. In the <u>Diffuse</u> type no well defined canker is formed, but the fungus quickly girdles the trunk before the latter has time to produce a calus. Such cases probably represent less resistant trees, and on such, often the only evidence of the fungus is the formation of the black fruiting bodies described below. In the <u>Canker</u> type of infection there is formed an elongated or elliptical dead area from which the bark finally disappears. As the mycelium yearly invades new tissues the host attempts to check the spread of the disease by the formation of a ridge of callus, but is usually unsuccessful. Consequently, old cankers are conspicuously marked with alternating ridges and furrows in the exposed wood or showing through the bark. The growth of the fungus on such trees is slow and 6 to 10 years or more may elapse before a tree 6 inches in diameter will be completely girdled. As long as the bark covers the lesion the sterile nodules referred to above will be found present. After the bark disappears the cankers are to be recognized by their elliptical shape and the markings of the concentric ridges.

After the younger trees are completely girdled there often appear numerous sprouts from just below the girdled areas, similar to those formed following girdling by the chestnut blight fungus.

The final result of the disease is the death of the tree. Apparently the diffuse type of infection kills more quickly than the canker type. As soonaas the trunk is girdled that part above the canker must die. But in large trees the process is long drawn out and the mycelium of the fungus is constantly decaying more of the wood of the open canker. As a result the tree may be so weakened that it will not be able to withstand the force of the wind.

<u>THE FUNGUS:</u> As soon as the trunk has been girdled the fruiting bodies are produced abundantly on the dead areas, especially on the branches. These bodies are termed sporodochia and consist of a compact fascicle of branched conidiophores that cut off spores at their tips and along the sides. The sporodochia are black or nearly so and 1-3 mm. in diameter. The abundance of spores gives them a powdery appearance when mature and the spore

mass readily rubs off on the fingers when handled. The conidiophores are smooth or more often with undulating walls and more or less minutely spiny. The spores are globose to pyriform or somewhat irregular and measure 7-12 x 4-7 u. The wall is minutely spiny and brown or dark brown in color.

Undoubtedly the spores are wind disseminated. Observations show that infection takes place either through a branch axil or through the tissues of a dead branch as a dead stub is practically always the center of a canker. Whether or not infection can take place thru open wounds is a question not yet settled.

<u>CONTROL:</u> Under a well regulated system of Forest Sanitation such a disease would be a negligible factor. A prompt removal of dead and diseased trees would greatly decrease the chances for infection.

<u>LITERATURE:</u> Heald, F. D. and Studhalter, R. A. - The strumella Disease of Oak and Chestnut Trees. (Penn. Dept. Forestry Bul. 10 p. 1-15. 1914).

2. ENDOTHIA PARASITICA (MURRILL) ANDERSON & ANDERSON.

Chestnut Blight or Chestnut Bark Disease. Ascomycete.

I. INTRODUCTION: The Chestnut Bark disease is caused by a fungus belonging to the group Ascomycetes, Order Sphaeriales, and is one of that group commonly referred to as Pyrenomycetes. The fungus is parasitic in the bark of the chestnut tree and very soon causes the death of the host. Two types of fruiting bodies and spores are found in the life history: Pycnia, producing pycniospores, and later followed by Perithecia, producing ascospores in asci.

II. HISTORICAL ACCOUNT: The first discover of the disease was in 1904 when Dr. H. W. Merkel in charge of the trees of the New York Zoological Garden noticed it growing on several chestnut trees. He sent specimens of the diseased trees to Washington, D. C. but only the pycnial stage of the fungus was present and a determination was impossible beyond referring it to the form genus Cytospore of the Imperfect Fungi. Merkel published the first account of the trouble in January, 1906. The attention of Dr. W. A. Murrill of the New York Botanical Garden was called to the disease and he began his study of it, publishing a preliminary paper in 1906 and a second paper the same year. In these articles he has described the fungus, giving to it the name of Diaporthe parasitica Murrill.

Although these were the earliest reported observations of the disease it must have been present several years previous, for when first discovered it was rather abundant and its advance from the first point of infection must have been slow, From this we may conclude that at the time of its discovery on M Manhattan Island it was also probably pesent on Long Island, in New Jersey, and in Connecticut, for it was reported from those localities as doing considerable damage only two years later. Some are of the opinion that it was present in Virginia as early as 1903 and in Pennsylvania as early as 1905. In addition to these observations a number of persons have reported seeing what they now believe to have been the Chestnut Blight several years previous to these dates, but their claims are not substantiated by specimens and it is impossible now to establish the fact.

III. EARLY INVESTIGATIONS: After the disease had been described and the fungus named by Murrill its study was undertaken by Metcalf and Collins of the United States Department of Agriculture and they worked out in detail a control method that will be discussed later. Clinton of Connecticut worked on the identity of the fungus and originated a theory to account for its sudden virulence. Stewart and Murrill of New York and Clinton of Connecticut maintained from the first that attempts at controlling the disease would be useless. But in Pennsylvania a commission of five members was appointed by the Governor to "ascertain, determine upon, and adopt the most efficient and practical means for the prevention, control, and eradication of the disease". Also, "to conduct scientific investigations into

the nature and cause of such disease and the means of preventing its introduction, continuance, and spread; to establish, regulate, maintain, and enforce quarantine against introduction and spread of such disease". This commission was given authority to destroy any infected trees found or any uninfected trees, the destruction of which was advisable in order to control the disease. In the latter case reimbursement to the extent of the actual stumpage value of the trees was allowed. The members of this commission served without salary but were reimbursed for all expenses incurred. For that purpose, and for paying the salaries of a scientific staff for the investigation and control of the disease a total appropriation of $275,000 was made available. This commission continued in existance until 1913 when it was dissolved, but not until a rather complete corps of investigators under the direction of F. D. Heald had cleared up many obscure questions concerning the disease.

IV IDENTITY OF THE FUNGUS: Up to the present time the fungus has been placed in three different genera and referred to three species and varieties by different investigators.

Murrill originally described it as *Diaporthe parasitica* Murrill. Rhem, a European botanist, in 1907 transferred the species to the genus *Valsonectria.* After the fungus had been studied by Clinton, Farlow, and Anderson it was transferred by the latter to the genus *Endothia.* The fungus has since remained within that genus. Clinton finally decided that the plant was worthy of varietal rank and he accordingly called it *E. gyrosa var. parasitica* (Murrill) Clinton. The last paper dealing with the taxonomy of the fungus is by Shear and Stevens in 1917, where they have monographed the entire genus *Endothia,* retaining the name *E. parasitica* (Murrill) Anderson and Anderson. Three other species and one variety are listed as occurring on the mainland of the United States.

V. HOSTS AND HOST RESISTANCE: It is not a matter of general knowledge that this fungus ever attacks any tree other than the American chestnut, *Castanea dentata,* and it is true that on no other species of host is it a virulent parasite. The following is a list of the genera and species of forest trees on which the fungus has been found occurring naturally:

Castanea dentata, the common American chestnut
C. pumila; the Chinquapin
C. sativa, the European chestnut
C. mollissima, a Chinese chestnut
C. japonica (- *C. crenata*), a Japanese chestnut
Quercus velutina, the black or yellow-bark oak
Q. alba, the white oak
Q. rubra, the red oak
Q. prinus, the chestnut oak
Rhus typhina, the staghorn sumac
Acer rubrum, the red maple
Liriodendron tulipifera, yellow poplar
Carya ovata, shagbark hickory

Of these hosts none outside the genus Castanea and the one case of Quercus alba give any evidence that the fungus was a true parasite although in a few cases typical mycelial fans were produced.

In addition the fungus has been successfully inoculated into the following hosts, although making little or no progress beyond attacking the dead tissue formed around the inoculation wound:

Quercus coccinea, the Scarlet oak
Carpinus caroliniana, Ironwood
Ostrya virginiana, hop-horn-beam

Within the genus Castanea a considerable variation as to susceptibility exists. Often within the common species C. dentata some individuals are apparently more susceptible than others, notwithstanding the results of Shear and Stevens where in a total of 1280 inoculations none failed to take. It has been more recently found, however, that often in heavily infected regions some trees have been somewhat resistant and the progress of the fungus has been slow, although no such thing as an immune tree has so far been found. An idea of the amount of this resistance can be obtained from the statement that whereas the growth of the fungus averages 2.2 to 2.83 cm. per month in cases of rapidly growing infections the amount of growth in the resistant trees averaged only .6 cm. for a period of 5 to 6 weeks. On such resistant individuals there are often found cankers that have actually healed there. Such resistant trees often grow in natural groups. Indicating their source from a common parent, and it is possible that their resistance may be hereditary. These facts give hope that eventually there may be produced from such resistant individuals, trees that can be used in re-forestation work.

The earlier statements that the Japanese Chestnut (C.crenata) was more resistant than our native species has been largely disproved. Even if sufficiently immune, the nuts from this tree are generally of an inferior quality and the tree can never replace the American species. From the orchardist's viewpoint one of the most promising hybrids so far secured has been a cross between the Japanese Chestnut and the American Chinquapin (C.pumila). The result is a dwarf tree heavily bearing, with nuts of a decidedly superior quality. Another line of experience has been the inter-crossing of different varieties of Japanese and Chinese Chestnuts. Some of the (Chinese) species are said to attain heights of nearly 100 feet and it might be possible to use them to some extent in reforestation work.

VI GEOGRAPHICAL DISTRIBUTION OF THE FUNGUS AND HOSTS:

A. In America. The progress of the disease has been rapid. Centered originally on Manhattan Island, or possibly earlier on Long Island, as early as 1908 it had spread to Rhode Island, Connecticut, Southeastern New York, Southeastern Pennsylvania, New Jersey, Delaware, Maryland and Virginia. In 1913 it had

spread to Massachusetts, West Virginia, New Hampshire and Vermont, besides increasing its distribution in Pennsylvania and New York. At the present time it has been found in Maine, Western New York, Western Pennsylvania, Ohio, Missouri, Iowa, Nebraska and British Columbia, although in the two latter cases it was probably introduced on nursery stock, in the one case from Pennsylvania, and the other probably from the Orient. The chestnut has been practically exterminated in the New England States, New Jersey, Delaware, Maryland, Southern New York, and eastern Pennsylvania. South of the Ohio River the fungus has not yet crossed the Appalachain Mountains, so that at present the great chestnut areas of Kentucky, Tennessee, Alabama, and Northern Georgia are not known to be infected, and these states have always had the best and most mature of our chestnut forests.

The possibility of its extension is apparently limited only by the range of the chestnut. That range is given by Sudworth as: "Southern Maine to Northwestern Vermont, Southern Ontario to Southern shores of Lake Ontario, to Southeastern Michigan; South to Delaware and Southeastern Indiana, and on the Allegheny Mountains to Central Kentucky and Tennessee, Central Alabama and Mississippi.

B. OUTSIDE OF AMERICA. Several visits have been made to Europe by American Investigators in the interests of the fungus, but it has never been collected there, although a few inoculation experiments made in Italy showed that the European chestnut was just as susceptible as the American.

In the spring of 1913 the disease was discovered in China by F. E. Myer, explorer for the United States Department of Agriculture. The conditions under which it occurred there established beyond doubt that it is a native of that country. The Chinese host species has not yet been satisfactorily determined. Other collections of the fungus were later made by Myer in localities 300 and 500 miles apart, so probably the fungus is widely distributed there. It is not, however, particularly destructive in China.

In September, 1913 it was also found by Myer in Central Japan on trees of *Castanea crenata* and in 1915 was collected in Northern Japan. Otherwise, the fungus is not known to occur.

VII. ORIGIN AND INTRODUCTION INTO AMERICA: Prior to the discovery of the disease in the Orient there was much discussion as to the probable origin of the disease and various explanations as to its sudden epidemic nature were advanced. Some believed that the disease was native to America and had suddenly become epidemic in character. Others held that its seriousness was promoted by the severe winters from 1902 to 1904, followed by summers of protracted drought from 1907 to 1911. Consequently, the trees were greatly weakened and more easily fell a prey to this fungus that previously had been only mildly parasitic. Others claimed that the practice of repeated coppicing had so lowered the vitality of the American chestnut that the fungus

found them an easy prey. This information seemed to be borne out by the fact that in the Southern Appalachain states where coppicing had not been practiced the fungus was not found to occur.

On the other hand many investigators were of the opinion that the fungus was not native to America but was introduced, probably on nursery stock. This idea was supported by the fact that the disease appeared first in one localized area - the vicinity of New York City and from there spread gradually northward, eastward and southeastward. Other evidence that pointed to the introduction of the disease from the Orient was the fact that the vicinity of New York City is the precise locality into which Japanese chestnuts were first extensively introduced. It was learned also after the disease was found in British Columbia that most all those were imported from the Orient, some from Japan, probably some from China..

In view of all this evidence it is not to be doubted that the disease is an importation into the country, as it could have hardly existed even in a weakly parasitic state without previously having been discovered. The fact that Oriental importations have been largely of C. crenata from Japan suggests that probably that country rather than China has been in direct source.

VIII. ECONOMIC CONSIDERATIONS: The chestnut is one of the most valuable hardwood trees in the Eastern United States. Several estimates have appeared dealing with the losses caused by the Chestnut Blight fungus. A few of them are reproduced here.

The entire value of all chestnut products put on the market in 1908 has been placed at about $22,000,000. In the previous year more than 600 million broad feet of chestnut lumber was cut in the United States, and in 1910 in Connecticut alone 69 million feet were harvested. In 1909 it was estimated that the damage done by the blight in New York, New Jersey, and Pennsylvania was not less than $12,000,000. In 1911 it was estimated at $25,000,000 for the entire country and in 1916 the estimate of accumulated damage was placed at $50,000,000. When the value and loss are proportioned amongthe different states in which the fungus is present, Pennsylvania ranges highest with an estimated loss in 1912 of $40,000,000 to $70,000,000.

IX. LIFE HISTORY OF THE FUNGUS:

A. Manner, place and time of Infection. The young first year twigs are naturally somewhat immune in early summer. Aside from this, trees of any age may be attacked provided some means is present by which mycelium may gain access to the inner bark It is now generally conceded that the earlier statements that infection can take place through the uninfected bark is untrue.

Wounds and mechanical injuries are the usual places of entry. Lenticels, natural fissures in the bark and old insect tunnels are probably seldom or never used as places of entry. It seems to be well established that enough dead or badly wounded tissue must be present for a brief saprophytic growth of the fungus in order for infection to take place. If this is true, dead twigs and the exposed wood of dead branches may also offer a means of entrance.

Inoculation experiments point to the conclusion that if trees are inoculated while in a resting condition infection will not take place, or if so, only after the tree resumes growth. This means that spring and summer are the seasons when heaviest infection occurs.

B. Host Relationships. The fungus is strictly parasitic on the live tissue (inner bark and cambium) of the stem. From the published observations it would seem that the mycelium does not penetrate the cell walls to any extent, but that the disintegrating action is due to the pressure exerted by the mass of mycelium pushing its way through the tissues of the bark. The parenchyma cells of the cortex are most affected and largely destroyed. In most other types of cells the only difference to be noted is the lignification of the cell walls as a result of the presence of the fungus. The sieve tubes, phloem parenchyma and cambium cells are disintegrated and later their positions occupied by the fungus. The medullary ray cells are almost unchanged and are not penetrated. The mycelium may actually penetrate the outer rings of the wood to maximum depths of 12 mm., but the average depth is only about 4.1 mm. or 2½ rings of the wood. Some have suggested the presence of some toxic or enzymatic action upon the host cells before they are invaded by the mycelium, but attempts to detect any such substance have given negative results.

That the fungus is not an obligate parasite has been repeatedly shown. It will occur on dead bark, seasoned chestnut wood, dead chestnut leaves, burs, etc. Often on the dead wood its rate of growth is considerably faster than in the live tree. But under such conditions the mycelial fans are not developed.

C. Symptoms and Effects: After infection the fungus grows through and under the bark in all directions until the tree is completely girdled. The damage done is most apparent in May or June, but in reality the harm has been done the previous summer and first shows up when the new growth is brought out.
The following are the most notable symptoms of the blight disease:

(1) Discoloration - On smooth barked trees the blight can be easily recognized by the presence of yellowish or yellowish brown patches, slightly raised, and contrasted strongly with the olive-green of the bark. In outline these areas may be regular or irregular. On the smooth bark of older branches they are inconspicouous, but may later become depressed after the bark is dead.

On rough barked trunks or limbs the fungus may not be evident until the disease is well advanced. Often the first indication is the appearance of longitudinal splits or fissures, and associated with them the bark may become sunken or broken up into logitudinal shreds. The bark over cankers of this kind has a hollow sound when tapped because the inner bark has been destroyed by the fungus.

(2) Hypertrophy - This type of enlargement is not often present, but may appear on vigorous shoots. Usually, the bark over such enlargements is longitudinally split or fissured.

(3) Mycelial Fans - Perhaps the most reliable evidence useful as a field character for distinguishing the presence of the fungus beneath the bark is the yellow or buff, fan-shaped mats of mycelium. These may be several centimeters in width and are composed of radiating hyphae closely pressed into a continuous membrane.

(4) Development of Sprouts - As soon as a branch of trunk has been girdled a number of rapidly growing shoots are produced just below the girdled area. These are usually soon killed and remain for some time attached to the trunk.

(5) Stagheads - In trees which have suffered from top infections for several years the dead branches persist above the living part of the crown. This gives rise to the so-called staghead condition and is most notable on the more mature trees.

(6) Withered Leaves. - If the branch is not completely girdled until late fall the leaves will be shed normally. The next spring such branches remain small, the leaves are of a yellowish color and soon wither and die. More frequently girdling is completed after the trees leaf out in the spring. They first turn yellowish and then a reddish-brown color and may remain on the tree through the summer and most of the following winter.

(7) Hanging Burs. - Infected branches bear burs that never mature and that commonly remain on the tree during the winter and so form one of the best known symptoms of the disease.

(8) Fruiting Bodies. - The development of the characteristic fruiting bodies of the fungus is, of course, one of the best signs of the disease. These bodies are described in a later section.

After infection by either type of spore a canker begins to make its appearance in from two to five weeks. If infection occurs on the branches the girdling that results will affect only the distal part of such branch and in the absence of new infection it will be several years before the mycelium of this infection reaches and girdles the trunk. Trees less than one-half inch in diameter may be girdled in four to six weeks. More mature trees may be girdled in a single season, and the older succumb much more slowly. The average rate of growth of vigorous infections varies from 1.84 cm. to 2.83 cm. every four weeks during the summer. At this rate a total growth of about 12 cm. in diameter might be expected per season, and at this rate it would require about eight years for a canker to girdle a tree one foot in diameter. Growth on more resistant trees is slower, averaging about 6 cm. for a period of five to six weeks.

D. <u>Fruiting Stages of the Fungus.</u> Two fruiting stages are present in the life history of the fungus, the spores from both serving to spread the fungus to other trees or other parts of the same tree. In the order of their appearance they are: <u>Pycnidia</u>, producing pycnidiospores, and <u>Perithecia</u>, producing ascospores.

(1) <u>Pycnidial Stage:</u>

(a) <u>The pycnidium and its contents:</u> In most cases pycnidia are formed the same summer in which infection takes place, and usually within one or two months after exposure to infection. In case infection takes place late in the season they may not be formed until the following spring. They usually protrude through the bark covering the canker, but at times occur on the exposed wood, on dead leaves, and on burs and nuts lying on the ground or stored under damp conditions. In form, they are minute raised papillae, yellowish or orange in color, and measure 2-4 mm. in diameter and 1-2 mm. high.

Within each pustule there is a single cavity or in some cases a number of isolated cavities in which the spores are produced. Each cavity is lined with the conidiophores from the apex of which a single spore is cut off. The spores accumulate in the pycnidium and ooze out through the osticle in the form of long slender coils known as "spore horns". These coils are coral red to orange-colored and when dry they are quite hard and brittle. A single spore horn has been estimated to contain as many as 115 million spores. The spores are minute, oblong or cylindric, and measure 3-5 x 1.25-2u.

(b) Dissemination and Longevity of the Pycnidiospores. The agents of most importance in spreading the spores are: rain, wind, insects, and birds. Of these probably rain is of most importance in spreading the disease to other parts of the same tree. The horns are easily dissolved in water and so carried down the trunks or branches, lodging in every available crack, wound, crotch, etc. This manner of dispersal also increases the area over which the spores may be picked up by birds and insects. Wind probably plays a minor part in pycniospore dissemination, as the spore horns are not suited to this method of dispersal. It is known that many insects carry the spores on their feet and bodies and in numbers often running into the hundred thousands. Experiments designed to show this point gave as high as 336,960 viable spores per insect. Birds, especially creepers, woodpeckers, juncos, and sapsuckers frequent the blight cankers and carry enormous numbers of spores from tree to tree.

Exhaustive tests on spore longevity have not been made. That they retain their vitality thru the winter and are capable of withstanding considerable desiccation both in the pycnidium and the spore horn is easily demonstrated. Material kept dry for a year has showed little diminution in the percentage of viable spores. Spores that are separated from the spore horns are much more easily injured, especially by drying out. Where they are washed down the trunk and into the soil many remain viable for considerably more than a month. Drying under more adverse circumstances shortens their life in proportion. They may be left in water with less injurious effects.

The spores cannot be made to germinate in water. They germinate readily in decoctions of chestnut bark or on sterilized twigs of various trees.

(2) Peritheciai Stage:

(a) The Perithecium and its contents: Perithecia are not produced until the latter part of the summer even from infections in the early spring, The perithecia may be in the same stroma with the pycnidia or in different ones, and usually follow the latter, though sometimes they are produced together or in rare cases the perithecia may precede the pycnidia. The pustules are yellow to orange in color or in age may be brick red or darker. They show up best when produced in lines in the furrows of the bark. Superficially they can be easily differentiated from pycnia by the fact that each shows upon its surface a number of minute raised papillae or black dots - the openings into the perithecial cavities. Each stroma (pustule) contains a number (1 to 60) of perithecia, that are flask-shaped cavities deeply embedded and with long slender necks that lead to the outside. Each perithecium contains a number of clavate asci with eight spores each. The spores are hyalin, 2-celled, usually constricted at the cross wall, and measure 7-11 x 3.5-5u.

(b) Spore Discharge, Dissemination and Longevity: The first spores mature in November and their production continues through the next growing season in the same or other stroma. Some spore discharge takes place late in the fall but more often they are retained within the perithecium until spring. The greatest discharge occurs from March to November. The spores are forcibly ejected from the perithecium, the ascus loosening from the perithecial wall and rising to the ostiole where they explode, forcing the spores into the air. Low temperatures entirely inhibit spore expulsion, and considerable moisture is necessary for it to take place. Consequently spore discharge occurs in greatest abundance immediately following rains. The maximum distances to which ascospores are ejected in still air is reported to be 22mm. in a vertical direction and 89 mm. in a horizontal direction.

The principal means of ascospore dissemination is by the wind. As the spores are discharged they are caught up by air currents and the maximum distances to which they may be transported, in high winds at least, is probably to be measured in miles. Neither insects nor birds are thought to be responsible for any considerable amount of ascospore dissemination.

As long as the spores are retained within the perithecium they are not much effected by unfavorable environment, and probably would retain their vitality for two years or more. Ejected spores lose their vitality more quickly, depending on the type of surface on which they lodge and where they may be located.

The spores germinate readily in water, producing one or more germ tubes from each cell of the spore.

X. CULTURING THE FUNGUS: Tissue cultures are easily obtained from the inside of cankers in the early stages of their development, if proper antiseptic conditions are observed. Dilution and streak cultures from pycnidiospores or ascospores are also not difficult if proper culture media are used. Chestnut bark agar, potato agar, 3% dextrose agar, corn meal agar, beef agar, potato cylinders, sterile chestnut twigs, etc. are satisfactory media.

In pure culture the mycelium is at first pure white, changing to yellow with age. Pycnidia are produced in abundance in about 12 days, but it is impossible to induce perithecia formation. Cultures from pycnidiospores grow much more slowly than from ascospores so that it is easily possible to distinguish between the two. After 3 days at 25 degrees C. colonies from pycnidiospores are invisible while those from ascospores measure 0.5 - 3 mm.

XI CONTROL OF THE DISEASE: From the first there were those who held that it was impossible to keep the disease in check, much less eradicate it. But not all of those acquainted with the ravages of the disease were of the same opinion. As early as 1911 the state of Pennsylvania appropriated $275,000 for the purpose of combatting it, and a Commission was appointed to direct the work. Small sums of money were also appropriated by some other states.

At the present time it is conceded that the disease will never be eradicated or even controlled until the chestnut is practically exterminated. Consequently the various methods that have been tried have little more than a historic interest, and need not be detailed here, though their broad outlines may be considered.

(1) Spraying with Bordeaux Mixture was one of the first methods tried, first by Dr. Merkel the discoverer of the disease in New York City, later by the United States Department of Agriculture, and by the Pennsylvania Chestnut Blight Commission. Despite beneficial results reported by agents of the latter Commission, spraying will never be a successful means of combatting the disease except in isolated cases. For such treatments to be of any value the bark of the tree must be kept continually covered by the fungicide, and every fresh wound, however, small furnishes a means of entry for the fungus.

(2) Tree Surgery Methods: Individual infections can be effectually removed by the cutting out method, if enough of the surrounding tissue is removed so that no trace of the fungus remains. But where trees are continually exposed to infection other branches will soon contract the disease and sooner or later, if the tree is not killed outright, it will lose such a large part of its actively growing and assimilative tissue that the roots will be starved. Cankers should be cut out at least an inch beyond the infected region and should include several annual layers of wood beneath the diseased bark. All wounds should be covered with paint or tar.

(3) Cutting out Diseased Trees: In 1911 Metcalf and Collins described a method of preventing the spread of the disease by destroying all advance infections, since the disease does not move forward in a solid line but spread from isolated infections often many miles in advance of the main line. This involved continual scouting work to locate all infections, and even in the experimental plots where it was tried out it was later found to have been unsuccessful. But encouraged by the apparent good results at first obtained near Washington, D. C., the Pennsylvania Commission began large scale operations along the same line, and in 1913 reported that apparently the work was being successfully carried on. But in the same year the work in that state was terminated by the failure of the legislature to appropriate funds for its continuance.

A similar line of work was carried on in Massachusetts, where an attempt was made at checking the disease by cutting out the infected trees. Every winter the selected areas were gone over carefully and the diseased trees removed. After four successive years of cutting out it was found that the average number of trees removed per acre on the cut out plots was 65.6 while the average number of infected trees per acre on the check plots was 79.8. The cost of removing the trees varied from $5.89 to $29.00 per acre for the four years.

<u>(4) Nursery Inspection:</u> Since the symptoms of the disease usually appear within a month after infection a careful inspection of nursery stock shipped from one part of the country to another should do much to keep down the spread of the disease. However, it is an easy matter for spores to adhere to such stock and to be transported long distances then to germinate and cause infection.

<u>(5) Quarantine:</u> As far as commercial practices are concerned absolute quarantine will effectually prevent the transport of the disease from place to place. Such a quarantine must be against any and all chestnut products except the barked lumber. But because of the fact that the ascospores have great possibilities of wind dispersal, and that pycnidiospores are largely carried by birds and insects, it seems that the fungus is well equipped to scatter itself over the entire country within the range of its host, and therefore a quarantine is no insurance against the introduction of the disease from one state into another.

<u>XII Disposal of Timber killed by the Disease:</u> The wood of chestnut trees killed by the disease is in no wise damaged. Tests carried out by the Forest Service show that sound wood from dead trees is fully as strong as from healthy trees. It will not remain in this condition long, however, but soon becomes attacked by wood-destroying fungi or by insects. Sap rotting fungi begin to decay the wood usually during the second or third year after the trees die. At the end of four years all the sapwood will be rotted. Ordinarilly the heartwood is quite resistant to fungous attack, but it soon becomes badly checked, especially in smaller trees. Trees 10 inches or less in diameter are, unless badly checked, marketable after being dead four years; those 10 to 18 inches in diameter are still worth cutting after six years, though in all these cases the sapwood will be a total loss.

However, diseased or dead trees should be cut and utilized as soon after infection as possible. The chief uses to which blighted timber may be put are as follows: telephone and telegraph poles, lumber both of large and small sizes, railroad ties, cooperage, shingles, fence posts, tanning extraction, mine timbers, and cordwood.

3 Nectria cinnabarina (Tode) Fr.

Coral Spot Disease — Ascomycetes.

The coral spot fungus is primarily a canker disease of the "die-back" type tho other forms of injury are sometimes met. It is an Ascomycete fungus with two (or possibly three) spore stages in the life history. It is to be regarded as a facultative parasite.

HOSTS: A large variety of hardwoods are subject to attack. In fact the known list of hosts is so large that it seems unlikely that any can be considered immune. Among these hosts the following may be mentioned; Maples, beech, basswood, hickory, oak, birch, horse-chestnut, mulberry, elms, bladder-nut, Eleagnus and currants. In regions where it occurs abundantly on some hosts it is apparently absent on others.

DISTRIBUTION: The fungus is widely distributed in Europe and America. In the United States it is everywhere abundant tho its injurious effects are not proportionately great.

HOST RELATIONSHIPS: Much controversy has been waged as to the parasitic nature of this fungus. That it is usually not a virulent parasite must be generally conceded. From nearly one hundred inoculations made by the writer, of which about one third resulted in infection, the fungus died out after remaining alive and fruiting for one to three years, tho never making substantial progress in invading the living host tissue further than to kill off the distal part of small branches into which it was inoculated. In some cases inoculation into fresh wounds formed by cutting off branches close to the main limb resulted in the production of a few fruiting bodies on the cut surface without sign of further killing of the host tissues.

The same state of affairs seems to hold where the fungus enters the lesion formed by frost as very frequently happens. Large frost cankers, some of them a foot or more long, were under observation at State College following the severe winter of 1918. They became infected with the Nectria in the following summer and produced an abundance of fruiting bodies on the dead wood. Markings and observations on these cankers for the next few years showed that the fungus made no headway against the healthy tissue, but a good rolling callus was soon formed just as tho no fungus was present, and the cankers are on the way to healing over, altho the large size of the canker and the small size of the limb will prevent entire recovery.

In other cases, however, the fungus seems able to actively invade living tissue, particularly where it obtains entrance on stems of the current seasons growth. A weeping mulberry at State College is annually killed back in the midst of the growing season, the number of dead twigs sometimes equalling the number of living ones by the end of the season. It appears to be more or less actively parasitic also on the horse-chestnut and the bladder-nut.

On the currant the fungus is reported as actively parasitic on the cambium tho Meyer reported that in Europe it had no power of injuring the cambium or the cortex cells but the mycelium invades the wood following the vessels and plugging them so that water conduction is inhibited and the branches die.

THE FUNGUS: The fungus belongs to the Order Hypocreales of the Ascomycetes. Biologic strains are apparently not present, as the writer has successfully inoculated it from maple to currant, horse chestnut, Eleagnus and birch.

Following infection there appear small conspicuous coral red convex fruiting bodies called stromata on which are produced the conidia on branched conidiophores. These spores are small, hyaline, one-celled bodies measuring 4-6 x 1-2 u.

As these bodies age they produce as small outgrowths over the surface of the stromata a number of darker red perithecia in which are produced the 2-celled, hyaline ascospores measuring 15-24 x 5-7 u.

A third spore form, referable to the form genus Verticillium has been found by the writer in connection with this disease on Mulberry.

CONTROL: On ornamental trees attention to frost injuries, involving the painting of such wounds, may do much to lessen the disease. Infected branches should be pruned out as fast as they form and before the fruiting stages are produced.

4. Cronartium ribicola Fischer

White Pine Blister Rust Basidiomycetes.

The white pine blister rust disease is caused by a fungus belonging to the Order Uredinales of the Basidiomycetes. The fungus is a heteroecious rust with the full complement of spore forms, in one stage living in the stems of white pine, and in the other stage on the lower surfaces of leaves of wild and cultivated species of gooseberries and currants referred to the genus Ribes. The first stage fruits largely in the spring (April to June) and the second stage in summer and fall (July to October). The stage of the fungus on the pine is often referred to as the Peridermium stage, and on the Ribes as the Cronartium stage, the former having been used as the generic name for the fungus in the pine stage before it was discovered that the life history included also the stage on the Ribes.

1. Historical Account

The white pine blister rust disease is of European origin, where it was recorded on Pinus strobus in the Baltic provinces of Russia as early as 1854, this species of pine having been introduced into Europe from America about 1705. It is believed, however, that Pinus cembra was the original host of the fungus. In 1888 Klebahn demonstrated the heteroecious character of the rust by infecting Ribes leaves with aeciospores from Pinus strobus. Peridermium strobi was the name applied to the aecial stage of the fungus for a long time. The Ribes stage was observed as early as 1854 and was called Cronartium ribicola. Its place of discovery appears to have been also the Baltic provinces of Russia. Since the name C. ribicola was the first to be applied to the telial stage of the fungus it becomes the accepted name for the plant.

II Pine Hosts (in North America only).

The fungus inhabits only those pines that bear their needles in clusters of fives. On the American continent Pinus strobus is the common host, although it has been found also in Massachusetts on imported Himalayan pine (P. excelsa), in Massachusetts, Minnesota and Iowa on P. flexilis, the limber pine, and in Massachusetts on P. parviflora.

Pinus strobus is the only five leaved pine native to Eastern North America. Several other species occur in the western United States. Two of them have been widely introduced into Europe and these are hosts for this blister rust, and in all probability the other species will be just as susceptible. The following is a list of 5 - needle pines native to North America and it is well worth while to attempt to keep the western species from infection in their native habitat, since all of these except P. balfouriana and P. albicaulis have been shown by artificial inoculation to be susceptible species.

P. strobiformis, Hook pine, Southern Arizona into Mexico.

P. flexilis, Limber pine, Rocky Mountain.

P. albicaulis, White-bark pine, British Columbia, Alberta and Montana to Wyoming, Washington, Oregon, and Southern California.

P. balfouriana, Fox-tail pine, California.

P. aristata, Bristle-cone pine, High altitudes from Colorado to Utah, Nevada, Northern Arizona, and Southern California.

P. monticola, Western white pine, Montana and Southern British Columbia to Washington, Oregon and California.

P. lambertiana, Sugar pine, Oregon thru California to lower California.

P. strobus, Eastern white pine, Newfoundland to Pennsylvania, along the Appalachain Mountains to Georgia, west to eastern Iowa and Minnesota. In Canada from Lake Winnipeg to the northern shore of St. Lawrence Gulf and Newfoundland.

III Ribes Hosts (in North America only)

Various species of Ribes are the hosts for the uredinial and telial stages of this fungus. It has been claimed that the cultivated species of Ribes (gooseberries and currants) are not important hosts, but the truth is that Ribes nigrum (black currant), R. vulgare (red currant), R. oxyacanthoides, and R. grossularia (gooseberries), and R. aureum (Missouri currant), all common forms in cultivation, have been found so heavily infected as to cause premature defoliation. Of these, R. nigrum is most susceptible of all, and it is not improbable that if the cultivated species of Ribes would be removed the spread of the disease would be greatly checked.

It is true, however, that some species of Ribes are more resistant than others, but probably none can claim entire immunity. Of the cultivated species, R. nigrum, R. aureum, and R. vulgare are the most susceptible, and of the wild ones R. cynosbati is most susceptible. In the New England states the cultivated species of Ribes are particularly dangerous, because many plantations of white pine are made on deserted farms where these species have escaped from cultivation and persist along with the pines. Many different species of Ribes plants are found distributed across the continent from the Atlantic to the Pacific ocean.

R. grossularia (common cultivated gooseberry) is usually not heavily infected, and R. lacustre (a wild cut leaved currant) is rarely found bearing the disease. On the other hand, R. prostratum, the wild skunk currant, is usually heavily infected.

In all, the fungus has been found growing naturally on 13 species of Ribes in North America, and many other infections have resulted from artificial inoculations on hosts that are not native to this country.

IV Georgraphical Distribution of the Disease.

In Europe the fungus has been reported in one or more stages from practically every country from Norway and Siberia to France and Italy. Its discovery dates back to 1854 in Russia and is as recent as 1907 in France. It was found in Japan in 1906 and was collected in China in 1900, Spain and the Balkan regions are not known to have the disease.

In America the disease has been found to date in the north-eastern United States and Southern Canada, occurring as far west as Minnesota and as far south as Virginia. It has reached the great pine regions of the north-west having been located in Washington and in British Columbia in 1921. East of the Mississippi River infection is so general, that there is no hope of eradicating it from this region. In Pennsylvania pine infections were found and eradicated in 1916 at Reading (Berks County), at Spring House (Montgomery County), and at Ben's Creek (Cambria County) - all on planted stock. In 1921 it was found to be gradually moving down from New York State into the northern tier of counties. It has been reported at present to some extent in New Jersey, Virginia, Michigan, Wisconsin, Minnesota, South Dakota, Iowa, Indiana, and Ohio, but is not known to occur in Delaware, Maryland, West Virginia, Kentucky, Illinois, Iowa, North Dakota, Missouri, Kansas, and Nebraska. In Canada the rust is not found outside the provinces of Ontario and Quebec but infection is heavy on the Niagara Peninsula in Ontario.

Discovery and Origin of Early American Infections.

The first time the disease was discovered and recognized in this country was in 1906 when it was found at Geneva, N. Y. in a plantation of Ribes. Search was made for the stage on the pine but it was not discovered in the same locality until 1913. In the meanwhile, the diseased bushes were destroyed at Geneva, and as the disease did not reappear in 1907 and 1908 it was believed that it had been successfully eradicated. But in 1909 it was found in three localities in New York State and in one in Connecticut. In 1910 it was found in Ohio, Indiana, and Vermont. In 1911 it was reported from New Jersey and Virginia and again on Ribes at Geneva. In 1912 it was found on pine in Rhode Island and in 1913 at Geneva, N. Y. on pines. By 1914 the seriousness of the disease was beginning to be recognized and in the next three years much intensive scouting was done in various states, and in some places control areas were being inaugurated. By 1916 the disease was found as far west as Michigan, Wisconsin, and Minnesota and in 1917 was discovered in Iowa and South Dakota.

The origin of the earliest infections can never be determined. Spaulding states that the evidence seems to show that this disease has been present in this country since 1898, and perhaps a few years longer. The first recorded Ribes infection (Geneva, 1906) was later traced to white pines in the vicinity, but it cannot be learned whether or not these trees were imported. That the disease is native is not at all likely, and the idea that it could have been introduced on Ribes nursery stock has no evidence to back it up. It must, therefore, have come in on white pine importations, for although the white pine is a native only of eastern North America, it had been extensively grown in Europe for two centruies, from seed imported from America. And for many years prior to 1912 white pine seedlings grown from this seed were imported into this country from various parts of Europe. Limited amounts of seedlings of *Pinus cembra* (Swiss stone pine) and possibly other species representing the original hosts of the blister rust have also been imported from Europe.

It is possible to trace, with positive results, the infections found in this country on white pine in 1909 and succeeding years. All infections located in that year are known to have been imported from the nurseries of J. Hein's Sons, Halstenbek, Germany. Since 1900 this firm has shipped to America more than four and a half million white pine trees, and it is estimated that fully 95% of all diseased stock discovered in this country has come from the same source. In 1910 the disease was also imported from France but it has been impossible to determine whether or not the French exporters raised their own stock. In 1912 it was found on pines imported from Holland.

In 1912 Congress passed the Plant Quarantine Act which created a Federal Horticultural Board of five members to administer the provisions of the act, including the power to prohibit the shipment into the country of nursery stock that might carry dangerous diseases. Immediately after the Board was organized it issued Quarantine Number One forbidding the importation of white pine into the United States.

VI. The Life History of the Fungus.

The fungus responsible for this disease is a long cycle heteroecious rust. There are five spore forms in the life-history, as follows: Pycniospores, Asciospores, Urediniospores, Teliospores, and Basidiospores. The first two are produced on the pine but only the second is capable of spreading the disease (from pine to *Ribes*). The second two are produced on Ribes leaves, and the former serves to spread the disease on that host, while the latter germinates and produces the fifth type of spore that alone is capable of infecting the pine.

A. On the Pine.

1. Infection, Incubation, and Parasitic Relations.

Infection is carried to the pine by the basidiospores that are produced in the latter part of the summer when the teliospores germinate on the Ribes leaves. Undoubtedly, wind is the chief agency active in carrying basidiospores from Ribes to pines. The spores germinate by producing short germ tubes, which, if they enter the tissues of the pine are capable of causing infection, Infection has been shown to take place, at least in part, thru the stomata of the needles of all ages. The mycelium extends into the vascular bundle of the leaf and from thence into the tissues of the twig. On the leaves characteristic yellow spots appear soon after infection. Other ports of entry may also be used at times. Successful inoculations have been made thru the dormant buds and in wounded areas on the young stems. Infection thru healthy unwounded bark probably does not take place and direct infection of bark more than three years old is probably rare. Indirect infection of older wood may arise thru the spread of the mycelium from infected branches.

After infection takes place the fungus works within the host tissue for a longer or shorter period of time during which it and its effects are entirely invisible externally. This period of time is called the "period of incubation" and apparently varies considerably in different infections, from 5 to 22 months in most cases, perhaps considerably longer (up to 6 years fide Spaulding) in exceptional ones. This is followed in more rapid succession by the appearance of such characteristic symptoms as the swelling of the stem and the production of aecia.

In the pine the mycelium is intercellular, and sends out haustoria that penetrate into practically every cell cavity in the infected region of the bark. In older infections haustoria are sent into the cells of the medullary rays and may be found inwardly for at least three annual rings of wood. The host cells do not appear to suffer greatly from the presence of the mycelium of the fungus, even tho the stem be entirely girdled. The invaded cells would remain alive indefinitely if it were not for the fact that in the production of aecia the bark is ruptured in numerous places and the interior cells dry out and die. In this drying out process resin canals are ruptured and the resin exudate stops the phloem cells. Consequently, seedlings and young trees may be killed as soon as the first aecia appear, but older trees succumb less readily. The swelling that usually precedes the formation of pycnia and aecia is not the result of a stimulus to cell division but is caused by the mycelium pushing apart the cells of the cortex. The wood cells are not affected by this enlargement, except that the annual layers formed after swelling is initiated are considerably narrower than those formed under normal conditions. It not infrequently happens that the rupturing and consequent death of the bark opens the

way for attack by other fungi, that at times quickly overrun the diseased area and become aggressively parasitic in uninfected tissues.

2. Early Symptoms.

The first symptoms to appear will depend somewhat on the age of the wood infected and on the severity of the attack. Only rarely will there by any external symptoms apparent under six months after infection, nd more often this interval will be lengthened to 18 or 20 months. Infection occurs in late summer (July to October). Through the next growing season the fungus is not apparent and it is not until the beginning of the third season that swelling usually commences. In some cases pycnia are produced this third season and aecia at the beginning of the fourth. There is evidence, however, that the swelling may occupy two seasons (third and fourth) with the production of pycnia in the fourth season and aecia at the beginning of the fifth and following seasons. In the former case we have what is termed a 4-year cycle, and in the latter a five-year cycle in the life-history.

However, swelling is not always the first symptom observable. On the smaller shoots where death of the twig results before aecia are produced swelling is usually absent, but the nature of the injury here suggests that a secondary organism is also present. The dead area of the twig is depressed and is separated from the living tissue by a narrow ridge-like construction. A yellowing of the bark over this constriction is usually taken as evidence that the rust is responsible for the injury. The dead projecting branches, often only 6 to 8 inches long, resulting from this type of infection are quite characteristic and easily distinguished from cases of winter killing which effects only the growth of the preceding season.

On the larger branches and the small trunkc (up to 2 inches diameter) the first symptom is the more or less spindle-like swelling over the infected area. A pronounced yellow discoloration of the bark usually accompanies this swelling, and these two characters are the usual diagnostic ones associated with the disease in its earlier stages. The terminal part of such a diseased branch may remain alive for several years after aecia are first produced, depending on the extent to which complete girdling is present. The leaves on such a branch are often yellowish in color but just as often they are nearly or quite their normal green color. Sooner or later it dies, and with its leaves of a dark red-brown color it forms the conspicuous "flag" or "danger signal" of the disease. After girdling is completed and aecia produced the bark becomes characteristically cracked and checked.

On the larger trunks little or no swelling occurs and there may be but a slight amount of discoloration. On such trees it is almost impossible to certainly identify the disease by superficial inspection until the fruiting bodies are formed. At times a depressed or furrowed type of canker is formed but this may be only in conjunction with other fungi.

In case the trunk is infected the results may be apparent on the whole tree. Some writers have noticed a peculiar stunted appearance in the tops of such trees but the writer has not found such a character of any value in trees of any size. The new growth is said to be only about half the length of the normal growth. In addition, a coarse yellow mottling of leaves and stems has been described as of rare occurrence in diseased trees, but it is probably due to a different cause.

3. Fruiting Stages on the Pine.

(a). Pycnial Stage.

After the swelling has taken place, and most often during the third or fourth season of infection the first crop of spores is produced in small, yellowish, round blisters, 1 to 2 mm. in diameter, on the center of the swollen area. The blisters soon break and exude their contents as a thin sweet-tasting juice in which the pycniospores are embedded. The pycnia are very simple in structure and correspond in a measure to an acervulus among lower fungi. The spores are very small, colorless, ovoid or pear-shaped bodies with no known function ascribed to them and consequently are not known to be able to infect either Ribes or pine. They are mostly produced from July to October, and the area over which they are produded one summer will be occupied by aecia the next spring. After their maturity they dry down to small blackish spots, more or less distinct, that serve as diagnostic characters in recognizing a diseased stem that has produced them.

(b). Aecial Stage.

In the spring following the first production of pycnia, the aecia are produced. They appear first in April and are mostly gone by June 1st. They are small bladdery cups that measure 2 - 6 mm. in height, 1 to 6 mm. in length, and 1 to 3 mm. in thickness; or are more nearly globose and 3 to 6 mm. in diameter. They are conspicuous because of a yellow or orange-yellow wall or peridium, within which the orange-colored mass of aeciospores is produced in chains from the bottom of the pustule. When ripe the projecting peridium bursts irregularly and the spores are liberated.

Ordinarily, aecia are produced in the spring of the fourth season of infection, making a period of about 35 months, considering infection to take place in August and aecia to be produced in the third April or May following. In cases where the swelling stage occupies two seasons instead of one, another year should be added to this, making a total of 46 or 47 months from infection until aecial production. As short an interval as 12 months has been recorded for this to take place. When once begun aecial production continues on the advancing margin of the infection year after year until the tree or the branch supporting the infection dies. Frequently, the distal part of the infected branch dies the season following the first aecial production, in which case the fungus advances only in a proximal direction.

The aeciospores are orange-yellow, ovoid to ellipsoid or sub-globose, and sharply verrucose with the exception of a smooth spot on one side. They are disseminated largely by the wind, altho insects are probably of some importance in this connection and the gypsy moth larvae have been definitely connected with spore dispersal. Fairly reliable experiments show that viable spores may be distributed by the wind for distances of 5 to 7 miles from the place of their production and distances ten times as great are not improbable. It is known that the viability of individuals in a given spore mass decreases slowly and gradually for a period of about 10 weeks, at the end of which time no further germination can usually be obtained although periods of 150 and 157 days for single spores have been reported in the literature.

The spores germinate readily in tap water, producing, as a rule, a single germ tube into which the spore content, including the yellow endochrome, flows. This germ tube is capable of entering through the stoma of a Ribes leaf and so setting up an infection. Aeciospores will not infect the pine, so far as known.

4. Economic Features of the Disease on the Pines.

The white pine blister rust is decidedly most important as a disease of nursery stock and of young trees in general. This is not to be taken to mean that it does not occur to any extent on mature trees. As a matter of fact it may infect any newly formed wood without regard to the age of the tree producing it. On large trees, therefore, it is nearly always confined to the tips of the branches, because it has not been in this country long enough to have infected our more mature trees when they were young and infection through old bark occurs rarely if at all. Moreover young trees once infected never reach mature size but are always killed within a few years. The value of mature stands of white pine will not be seriously decreased by the blister rust.

In case of immature trees, and especially trees under 25 years of age the effects are different. In such cases eventually the trees dies. Only rarely in this country are trees found with wood more than 20 years old infected, because apparently the disease has been spreading for a period of not longer than 20 years, and it is only the young wood that can be directly infected. Pine seedlings 3 to 4 years old are killed in 4 years while trees 5 to 10 feet tall succumb in 5-10 years. Trees over 20 ft. high will suffer severely in 12-to 15 years, tho if numerous infection are present it may be killed in about half that time.

The result bound to follow widespread infection is the death of the pine reproduction, and it is from this fact that the disease secures its serious aspect, and which will eventually result in abandoning white pine growing in the New England states at least. White pine reaches its best development in New England, and its value probably exceeds the combined values of all the other New England lumber trees. The value of the white pine lumber annually used is not equalled by that of any other coniferous tree and is surpassed among decidious trees only by the white oak. And while the actual timber value of the reproduction destroyed is slight, yet if it necessitates the abandonment of the white pine industry in this country and the ultimate resulting loss be proportionately distributed over the next 75 or 100 years (at the end of which time little or no white pine will remain if the disease go unchecked) the figures representing the yearly proportion of loss will be quite large. White pine products for 1908 were valued at $65,000,000. The value of the merchantable white pine timber of the United States is placed at $600,000,000. If the destruction is complete (meaning 100%) at the end of 100 years, and each years loss be equally proportioned, the percentage would be 1% per year. This means a loss of $650,000 per year for the annual loss in white pine products, and a total annual loss of $6,000,000 for timber merchantable at the present time. The acreage of young white pine in the eastern United States is placed at about twice the amount of the merchantable timber.

Moreover, if the disease be introduced into the western part of the United States, it will find the sugar pine, the western white pine, and the limber pine agreeable hosts. The value of the merchantable timber from the two former of these species is placed at $240,000,000.

B. On the Ribes.

(a). Uredinial Stage.

(1). Production, Dissemination & Reinfection.

If a viable aeciospore comes to rest on the lower side of a Ribes leaf it may, under favorable conditions of moisture, produce a germ tube that is capable of entering the leaf tissue through a stoma and so start an infection. In from 9 to 12 days after infection the uredinial sori begin to make their appearance, being usually first heralded by a slight discoloration showing on the lower leaf surface, or in case of heavy infection, visible also from above. The uredinia first appear as small glistening waxy spots of a reddish color, enlarging rapidly, and in 2 to 4 days breaking open at the summit to extrude the spores in waxy cohering masses. The average size of the sori is 0.1 to 0.4 mm. in diameter and when mature they are small rounded or cushion-shaped bodies on the surface of the leaf. They may at times occur on the upper leaf surfaces and are not uncommonly found on petioles and more rarely on stems as well.

Under natural conditions urediniospores first appear about June 1st, even in regions where aeciospore dispersal occurs in abundance as early as May 1st. The first infection is usually slight as would be expected from the erratic distribution of aeciospores and the slight chance that a spore has of coming to rest on the lower surface of a Ribes leaf. The first crop of urediniospores are called primary urediniospores and are soon disseminated. They can function only in creating new infections on the Ribes. This procedure may be repeated several times through a season and consequently urediniospores are sometimes known as "repeating spores". In this way the severity of infection may be gradually increased through the season, and at the height of their production the urediniospores may form a continuous orange colored coating on the lower surfaces of the Ribes leaves, for a spore may reinfect the same leaf on which it is produced. Where secondary infection occurs the incubation period is lengthened to 13 to 20 days as compared with the 9 to 12 days required for infection from aeciospores to become apparent. Subsequent infections always take place on the younger growing leaves, and unless such are present the production of urediniospores ceases and teliospores are formed.

The urediniospores are ellipsoidal to ovate in shape and have a spiny wall. They are one-celled, the wall being colorless and the cell content orange-colored. Unlike the aeciospores they are not powdery in mass but cohere in groups and are largely so disseminated. Consequently, they are not well fitted for wind dispersal over long distances, although a distance of half a mile is probably not impossible in exceptional dases. But where the Ribes plants are surrounded and overtopped by other forms of vegetation this distance will probably be reduced to an average maximum of a few rods. Insects and other forms of animal life may also act to some extent as agents for spore dispersal.

The spores germinate readily in water, the process often beginning in about three hours and at the end of 24 hours the germ tubes have reached their maximum development, except that it has often been observed that after developing a considerable extent of germ tube, the tube content may collect into a spore-like body which immediately or at least after a maximum of a few hours rest, produces a second germ tube. That the Ribes leaves exert a stimulating effect on spore germination here as well as in case of aeciospores has been insistently maintained by most workers, but such a conclusion is not justified by careful observation on large series of experiments.

(2) Longevity and Overwintering.

Urediniospores ordinarily retain their viability for a shorter time than aeciospores. The usual maximum is less than 30 days and after 20 days the percentage is greatly decreased unless the spores be kept at low temperatures. In the light of these facts the recent report that germination and infection were obtained from overwintered urediniospores seems incredible, and the negative results of a number of experiments of this sort show conclusively that this type of overwintering cannot be regarded as important in the spread of the disease.

The appearance of heavy primary infections on Ribes in localities considerably removed from pines bearing the aecial stage of the fungus points to the conclusion that some type of overwintering on the Ribes must be operative in the life cycle. Thus, in the White Mountains in New Hampshire, heavy infections on Ribes occur on the summits of Mts. Webster and Jackson, the vicinity of Crawford Notch, the head of Tuckerman Ravine on the side of Mt. Washington, and other similar stations where there is no white pine either infected or uninfected within a radius of at least five or six miles and in most cases considerably farther. This point has provoked a considerable controversy in recent years and conclusive evidence is yet lacking on both sides.

If the overwintering of the urediniospores be ruled out as impossible on the evidence cited above, then the only other possibility is that the mycelium might overwinter in the Ribes. There are three places where this might take place. (1) in the infected leaves that might remain alive over winter. This is known to occur in Coleosporium solidaginis, the golden-rod-pine rust, where the fungus is known to remain alive over winter on the living basal rosette leaves of the goldenrod. Repeated search for this type of overwintering on Ribes has failed to show its existence in a single case within the range of the blister rust. (2) in the stems, since stem infections are sometimes found. But no evidence has been produced to show that this actually takes place, and the few stem infections that occur would hardly be responsible for the flush of the uredinial stage often ob-

served early in the season. (3) in the bud, in which case a spore might lodge between the bud scales in late summer or fall, start an incipient infection and live over winter in that condition, resuming growth the next spring.

(b). Telial Stage.

Telia normally follow uredinia and either come from the same sorus that earlier produced urediniospores or else from new infections set up by urediniospores. This sequence is regulated by some internal condition of the leaf and not by climatic factors as formerly supposed. As long as a leaf is actively growing only uredinia will be formed but as the leaf matures telia are produced. In fact it is possible, by inoculating mature leaves with aeciospores, to induce the formation of telia without any apparent intervention of the uredinial stage. The period of heaviest telia production is during the month of August.

The telial stage is always produced on the lower surface of the leaf or rarely on the petioles or the young stems, appearing as tiny, slender, cylindrical, projecting hairs ½ to 2 mm.long. These hairs are called telial columns, and each is a compact mass of oblong spores with smooth colorless walls.

At maturity these spores germinate in situ, by producing a short cylindrical curved germ tube called a promycelium or basidium. This basidium usually becomes five-celled and from each of the four terminal cells a single globose, hyaline, smooth-walled sporidium or basidiospore is formed on a short sterigma. The teliospores remain viable for a period about equalling that for the urediniospores, altho this period can be somewhat prolonged by favorable conditions.

The basidiospores are extremely buoyant and entirely wind disseminated. Evidence points to the fact that they are extremely short-lived, their viability probably lasting not more than an hour under the most favorable conditions, and often only as long as ten or fifteen minutes. If such be the case, we have here the most pronounced natural check on the spread of this disease. The basidiospores are capable of infecting only the pine and so producing again the life cycle on that host.

It is the range of dispersal of the basidiospores that is of most direct importance in causing pine infections. In other words the question as to how far Ribes and pines must be separated to avoid transference of the disease means "what is the effective range of dispersal of the basidiospores"? If they are as short lived as indicated above their range will be less than that of any other of the rust spores. In the Ribes eradication work in most of New England 300 feet has been taken as the limiting distance and in Vermont and New York this has been increased to 500 feet. Figures based on more recent observations show that appreciable infection may occur across a Ribes-free zone of 1,000 feet, and that 1,500 feet is necessary to reduce the amount of infection to a negligible factor, while to avoid all infection a zone at least 2,300 feet wide is necessary.

C. Economic Features of the disease on the Ribes.

The effect of most primary infections on Ribes plants is almost negligible. Where extremely heavy infection has occurred following secondary infections plants have been known to drop all their leaves within 21 days particularly its seasons of droughs.. More frequently very little leaf cast is present until about the time the telial stage begins to appear. The leaf takes on a mottled appearance as viewed from the upper surface, and often early in August the bushes are defoliated. A second crop of leaves may then be produced but not in time to insure the correct ripening of the fruit, and in such cases the crop is practically a total loss. In addition, buds have developed that normally shou[l]d have remained dormant until spring. Other winter buds must be formed to take their place but cold weather is likely to arrive before they are matured and they will be winter killed. The effects vary in severity on different species of Ribes.

VII. Control of the Blister Rust.

1. Scouting and Eradication.

If both host plants are necessary for the propagation of this rust (and there is no proof that such is not the case) it follows that if one of these can be eradicated and kept out of the locality the disease will disappear as soon as it has run its course on the plants affected at the time eradication takes place. Logically, the host that is of least economic importance will be the one to be eradicated. The wild species of Ribes are seldom or never utilized in any way, and the value of the cultivated gooseberries and currants is quite insignificant when compared with the value of the white pine. Consequently, except in isolated localities where the white pine is an unimportant forest tree, the Ribes are the host plants to be destroyed. In New England and New York this eradication work has been done quite extensively and is organized along the following lines.

The Federal Government, through the office of Forest Patholo[gy] has agreed to put up an amount of money equal to that contributed by any state, these monies to be used in combatting the disease in that state. Funds from this source are now available in all the New England states and in New York, Pennsylvania, Wisconsin, and Minnesota. This fight involves two lines of work. First, extensive and intensive scouting is carried on for the purpose of finding the extent of the disease. Both pines and Ribes are inspected and the inspectors, both State and Federal, have authority to enter any premises for that purpose. In some instances these inspectors look after removal and destruction of any diseased plants in gardens.

Second, the money is used in eradication work, which consists in removing the wild and cultivated Ribes plants. An area is selected in which a considerable growth of white pine, especially young trees, is present. The area is mapped, in most instances, by a Federal Agent, in order that the eradication crew may work

the more effectively.

An eradication crew comprises a group of from 3 to 10 men with a foreman, and in case of a large crew, an assistant foreman. A crew of 4 to 5 men is regarded as more widely than a larger one. These men, with the exception of the foreman, are lined up from 5 to 15 feet apart depending on the nature of the growth on the area, and strips are run side by side across the area or some well defined part of it. The foreman follows along behind the crew, crossing the strip back and forth in order to find Ribes plants overlooked by the crew, and also to judge of the quality of the work of the individuals in the crew. The man on that end of the line next the unworked area is trail marker and he marks his line in such a way that it may easily be followed on the return tripp The most successful method of marking appears to be to scatter bits of newspaper along the ground, but various other methods are used, such as breaking of branches, blazing of trees, etc.

All Ribes bushes found are pulled up by the roots and hung in a nearby tree or otherwise disposed of in such a manner that they will not come in contact with the ground. In covering swampy areas, where the trailing "skunk currant" (Ribes prostratum) is found it is necessary for the men to work very carefully and slowly, often on hands and knees to make sure that all traces of the plants are eradicated. Where cultivated fields are encountered it is only necessary to run their boundaries. A count is usually kept of the number of Ribes plants pulled each day, the numbers varying from 0 to 20 thousand per crew.

It is not difficult to figure the approximate cost per acre of eradicating the Ribes from various types of land if the acreage is known. This cost varies greatly, depending on the nature of the land covered and the numbers of Ribes plants encountered, In 1917 Massachusetts reported the average cost for all types of land as from 7 to 10 cents per acre, while New York averaged 38 cents per acre, Rhode Island 54 cents, New Hampshire 65 cents, Connecticut 86 cents and Maine 95 cents. Figured on different types of areas, the cost may run as high as $9.00 per acre on swampyland inhabited by skunk currant. More improved methods have reduced the cost in more recent years so that the average cost in New England in 1919 was 24 cents per acre. In New Hampshire the cost dropped from 42 cents per acre in 1917 to 20 cents in 1919 and to 17½ cents in 1920. This includes only the cost of the labor actually used in pulling the bushes and does not cover preliminary surveys, mapping, etc.

Even with the greatest care a crew is able to give to the work a considerable number of Ribes plants will be overlooked in the first eradication. Consequently, in order to be sure of complete eradication, these control areas need to be gone over again within two or three years, although the cost of re-eradication probably amounts out of all proportion to the damage the remaining Ribes plants will do if left undisturbed. Along with the wild Ribes the cultivated ones must also be removed. In most states

the owners may be reimbursed for any such destroyed, at least if they be free from disease. If all the cultivated bushes could be eradicated it is probable that the presence of the wild ones would not increase the danger enough to compensate for their eradication, unless possibly where the species R. cynosbati is the prevailing wild one.

That eradication of the Ribes is possible even in large scale operations is shown that up to 1921 more than 500,000 acres have been covered in New Hampshire alone, and more than 5 million Ribes bushes destroyed.

Some experiments have been made that show that fuel oil and dip oil can be successfully used as a spray to kill Ribes where they grow in dense colonies.

2. Cutting out Pine Infections.

Several experiments have been undertaken looking to the cutting out of the diseased parts of the pine as a means of control of this disease. All such experiments have so far failed, since it is necessary to follow this up for several years in order to make sure that all developing infections are taken out. However, in small scale operations there is no reason why this cannot be done, but each year it should be done just before the blisters in the aecial stage break and scatter their spores.

3. Spraying.

Spraying, as a protection against Ribes infection, has been tried out in several instances, Bordeaux mixture and soluable sulphur being applied every two weeks throughout the summer. Infection cannot be entirely prevented but can be so much reduced that practically no damage to the Ribes results. But of course, if infection occurs at all there is danger of the spread of the fungus to other plants and so back to the pines. Moreover, to obtain results it is necessary to spend so much time in making sure that the spray thoroughly covers the lower leaf surfaces, that its practice on a commercial scale would be impossible.

4. Quarantine Measures.

The most effective measure those states and countries that have no blister rust can exercise is the quarantine restriction, especially against five-needle pines, and preferably against Ribes. Although the latter plants are always shipped in dormant condition and so have a less opportunity for carrying the disease. In 1912 the Federal Horticultural Board imposed an absolute quarantine against the shipment of the five-needle pines into the country. In addition, the following states have adopted quarantine measures, that are, however, not absolute in many cases:

A Federal quarantine, designed to protect the western forests, forbids the transfer of both Ribes and 5-needle pines to any point west of the western boundary of Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

The states of Iowa, New Hampshire, Pennsylvania, South Carolina, Vermont, and West Virginia entirely forbid the entrance of white pine, while Maine, Connecticut, Massachusetts, and Rhode Island have no quarantines on pines, altho in Maine a special permit is required.

In addition, most of the other states south of the infested areas forbid the entrance from those areas of any white pines, the quarantines being specific in each case but the details cannot be elaborated here.

The quarantines against Ribes are somewhat more varied in character. Georgia, New Hampshire, South Carolina, and West Virginia entirely prohibit the entrance of all Ribes. In addition, Maine and Massachusetts allow imports only on state permits. In Pennsylvania there is no quarantine against Ribes except that R. nigrum is entirely prohibited entrance.

Other states have certain quarantines levied against those states where infestation is most general.

VIII Summary and Outlook.

Throughout New England and New York and in Michigan and Wisconsin the disease has gained such a foothold that attempts at eradication have been given up. In this region and in the eastern United States in general the only hope for the future growing of white pine lies in the control of local areas by means of Ribes eradication. Slowly but surely the disease will sweep down from New York and Michigan into Pennsylvania and the south until the entire white pine belt east of the Mississippi River will be infested. Quarantines can only delay, not prevent, its spread. But even in these rust infested regions it will be possible to grow white pine in local areas if the Ribes be eradicated and kept at a proper distance from the pine.

West of the Federal quarantine line little of additional hope can be held out, now that the fungus is established in British Columbia and Washington. Its progress can be hindered but it seems doubtful if efforts at eradication can be successful. One redeeming feature can be seen in this situation. Cultivated Ribes are a rarity in forested lands of the north west or in close proximity to such lands. Our knowledge of these species of Ribes as hosts of the blister rust makes it possible to predict that the disease will spread with far less rapidity in their absence.

1.

5. Cedar Rusts Caused by Species of Gymnosporangium.

A number of rusts, belonging to the genus Gymnosporangium attack different species of cedars, including the red cedar and its relatives, the white cedar (Chamaecyparis) and the incense cedar (Libocedrus). All are heteroecious rusts but lack a uredinial stage. The alternate hosts are mostly members of the rose family Rosaceae, including the genera Amelanchier, Crataegus, Pyrus, Sarbus, etc.

The details of the life histories have not been followed in these fungi. The telia are produced on the Gymnosperm host and appear in April or May. They are stem parasites, not always producing pronounced cankers, sometimes only the slightest of swellings. The mycelium becomes massed beneath the cortex of the host and forms bunches of spore-bearing hyphae that break thru the cortex and appear externally as tongue-shaped or short-cylindric reddish-orange masses. On the advent of warm spring rains the spore stalks gelatinize and greatly elongate, and the sori become quite conspicuous. The teliospores germinate and produce basidiospores after the usual manner of rust teliospores, and these may carry the infection to the alternate host where pycnia and aecia are produced. The fungi are perennial on the Gymnosperm host so that new infections added to old may cause such a drain on the tree as to kill it. At seasons other than when teliospores are being produced the fungus is scarcely discernible on the stems. From the time of infection by aeciospores to the first production of telia about twenty months probably elapses.

Chapter IV

Gall-Producing Fungi

In strong contrast to the previous or canker-producing type of organisms, it frequently happens that the result of infection is a stimulation to such excessive growth that a conspicuous overgrowth or gall may be produced. When such is the case the cells of the host are usually not killed by the parasite, altho they may die as an indirect result of its presence. Overgrowths are caused by one or both of two factors (a) excessive enlargements of the cells already present in the diseased region, a process known as hypertrophy, and (b) a stimulation to cell division and the consequent formation of new cells without any abnormal cell enlargement. This last is known as hyperplasia. In some cases it may be that some enlargement may result from the massing of the hyphae between the cells of the diseased area, pushing them apart as has been described for the white pine blister rust. Probably this factor alone would never result in the formation of a typical gall.

It is evident then that the distinction between a gall and a canker is not necessarily well marked, but is one of degree rather than of quality unless some other classification of these injuries be accepted.

From the nature of the effects produced on the host it follows that gall producing fungi are less injurious as a class than are canker-producing fungi, and their effects are usually long drawn out. But this alone may not classify them as the lesser of two evils from a silvicultural stand point. A given tree, diseased by a canker-producing fungus, may die within a few weeks of infection, and it can at once be replaced, either by natural seeding or other wise. While the same tree with a gall-producing disease may continue to exist for years, occupying the space that could be utilized by a healthy tree yet itself becoming more and more unfit, because of the galls, for timber purposes.

Very few parasitic organisms outside of the heteroecious stem rusts cause gall formations on the host. One other such, crown gall, is presented here, partly because in so doing we draw upon the group of the Bacteria for a disease-producing organism, and partly because certain interesting facts have been discovered in connection with this parasite that gives us an insight into how some parasitic organisms produce their effects on the host; partly also from other considerations. In addition, such gall-forming parasites as the mistletoes will be considered under a later section.

1. Bacterium tumefaciens Smith - Townsend

Crown Gall of Deciduous Trees.

Bacteria

Crown gall, sometimes known as "plant cancer", is a bacterial disease that may manifest itself as a more or less conspicuous gall at one or more places on the roots, crowns, or stems of the plant, or may be present in the "hairy root" form in which tufts of fine roots are produced from a diseased region just below the crown of the plant.

HISTORICAL: The disease has been known in America for at least fifty years but was probably introduced originally from Europe where it first began to receive attention about 1885. It was not until about 1900 that attention was directed toward it in this country. Since that time a number of intensive experiments have been directed toward the disease in America. Smith and Townsend isolated and described the causal organism in 1907 and Smith has prosecuted the main inquiry into the nature of the disease and its similarity to human cancer.

HOSTS: Perhaps no other disease is found on so wide a range of host plant as is crown gall in one or more of its different forms. Its hosts are scattered thru the Dicotyledonous plants from willows to composites and include large numbers of herbaceous plants as well as some shrubs and trees. Among the latter group its presence has been confirmed on willows, poplars, walnuts, chestnut, peach, apple, apricot, cherry and pear, and since it has been found to be so easily inoculated into so many different hosts, no doubt the list of woody plants could be considerably increased by a little experimentation. A number of other hosts, particularly species of oak, often have similarly appearing galls of considerable size that may be caused by this same organism but experimental proof is yet lacking on this point. The disease is most feared as a nursery pest of fruit trees and most of the investigations to date have been directed toward its occurrence on those hosts.

DISTRIBUTION: The disease is probably present, on one or more hosts, in every state in the United States. It is also known from Canada, New Zealand, Germany, France, Holland, and from South America and Africa.

THE CAUSAL ORGANISM: Bacterium tumefaciens is a minute, white, motile, rod-shaped bacterium that reproduces only by fission. It is an intra-cellular parasite but never occurs in large numbers in the cells, and this, together with the fact that it produces unrecognizable involution forms accounts for the difficulty in isolating it from diseased tissues. It is apparently not divided into biologic races, since it is readily transferred from one host species to another.

SYMPTOMS: Crown gall is primarily a disease of parenchyma tissues, particularly those in the stem cortex, tho leaf parenchyma, pith cells, and cambium tissue may become infected. The result is a stimulation of the cells to meristematic activity, resulting in a more or less conspicuous overgrowth or gall, the surface of which is usually rough and devoid of the usual external tissue coverings. Galls due to this organism have been reported as much as four feet in circumference.

The galls produced on plants are varied in texture, but in general, herbaceous plants produce fleshy galls that at the end of the growing season rot away and in case the plant is perennial open up the way for other organisms. In case of young woody plants also, these so-called "soft galls" are sometimes produced. But on more woody hosts the galls become quite hard and woody due to the transformation of the parenchyma cells into lignified stelar cells or vessels. If such galls are situated on the roots they are likely to develop numerous fine roots that give the name of "hairy root" to one phase of the disease. "Hard galls" do not decay at the end of the season but are perennial, growing with the host.

After the formation of what may be known as primary galls as a result of inoculation from some factor of the environment, additional galls may be formed without additional inoculation. This is accomplished by the production of so-called "tumor strands", that are strands of diseased tissue originating in the primary gall. The cells divide rapidly and force their way between the normal cells of the host, the bacteria keeping pace with the growth of these cells and always to be found within them. In this way secondary tumors may originate at distances from the primary tumor, the tumor strand serving as a connection between the two. Most curious of all, the cells developed in these secondary tumors are of the types present in the primary ones, so that if the primary tumor be a stem tumor and the tumor strand develop out into a leaf, the secondary tumor there produced will be in structure a stem tumor and not a leaf tumor. These two facts, viz. the production of tumor strands and their reproduction of the same cell types in the secondary tumor shows a remarkable similarity, as first pointed out by Smith, to animal cancer, in which exactly the same thing takes place, tho after a somewhat different fashion. This has suggested that animal cancer may be a bacterial disease, and possibly due to the same causal organism as is crown gall, and while it has been possible to produce certain types of tumors in certain cold-blooded animals by injections of Bacterium tumefaciens, yet much more conclusive evidence must be obtained before such a hypothesis can be proved. But even tho the two diseases represent only somewhat parallel developments much may be gained by the study and behavior of plant cancers by medical men.

More recent studies by Smith throws some light on the underlying causes of tumor formation. That the mere presence of bacteria in the parenchyma cells is not sufficient explanation of the initiation set up and its consequences, is quite evident. Consequently the irritation must be due to some substance or chemical compound formed in the metabolism of the bacterium. Following out this line

of reasoning he was able to show that various substances in dilute solution may cause exactly the same effect when injected alone, as when the plants are inoculated with the bacteria. Many different substances may thus be injected and result in the formation of galls so that Smith came to the conclusion that "any soluble substance whatsoever, except a killing, a plasmolyzing, or an oxygen-absorbing substance, if continually liberated in excess locally in tissues would be competent to induce tumor formation." # He was also able to show that B. tumefaciens produces in its metabolism, ammonia, many acids, and some alcohol, and he believes that these substances act together to produce the result in the crown gall disease.

ULTIMATE EFFECTS ON THE HOST: Many conflicting claims concerning the importance of the disease are in the literature. The earlier workers regarded the disease as highly serious. Later, some of the experimental work, particularly that of Hedgecock, seems to cast doubt on its importance. The later more careful work has however shown that while the effects, at least on older trees are apt to be long drawn out, yet they are cumulative, year after year, altho in some cases entire recovery is known. The death of branches or of whole trees may occur, or the effect may be one of stunting, in reducing the amount of twig growth and the diameter increase of the tree. In one instance, in experiments reported from Iowa, by actual measurement, it was found that the average twig growth in one season, was reduced from a total of 937 inches for healthy trees to 620 inches for galled trees of the same age growing under the same conditions. This is a reduction of approximately one-third.

CONTROL: Concerning trees in a wild state little is known concerning the method of dissemination of the bacterium. In case of nursery infections, strict inspection at the shipping point is highly desirable, particularly in regard to fruit tree hosts. Where pruning operations are practiced, careful disinfection of the cutting tools may do much to prevent the spread of the disease from one part of the tree to another, or from tree to tree.

2. Gall Producing Rusts

A total of about 15 species of rust are now known to produce more or less distinct galls on the woody parts of their hosts. These rusts may be divided into two series, (a) a group of full cycle species inhabiting members of the pine genus and producing pycnia and aecia on these hosts, and (b) a group of short cycle species inhabiting cedars and their allies on which is produced the telial stage, uredinia being lacking. Other differences are not lacking between these two groups as will be seen later.

Smith, E. R. Mechanism of tumor growth in crown gall (Jour. agr. Res. 8: 177. 1917).

Not more than 4 species of rust produce distinct galls on these hosts in the United States. All belong to the genus Cronartium, and the pycnial and aecial stages are referable to the form genus Peridermium. The most typical member of this group of rusts is Cronartium cerebrum, known in its aecial and pycnial stage on a large series of pines, but never on the five needle pines, from the Atlantic to the Pacific and from Canada to the Gulf of Mexico. Its alternate hosts are species of the genus Quercus on the leaves of which it produces the uredinial and telial stages. The life history of this rust will be considered first and later some remarks made on the other species.

On the pine hosts the fungus causes the formation of conspicuous rounded galls. Undoubtedly entrance to the stem tissues is thru wounds altho some investigators believe direct penetration to be possible. The wounds caused by spittle bugs have been cited by Weir as of some importance in this connection. In most instances infection seems to take place on stems not more than one year old as sections thru old infections show the irregularities of gall growth to penetrate the wood to about the first annual ring.

The period of incubation is said to vary from 7 to 16 months at the end of which time the swelling begins. In shape the galls vary from globose to pear-shaped, and, by some, certain fusifrom galls are assigned to this species. On these young galls the bark is at first smooth but soon becomes roughened by rugges dead bark scales. As the galls continue to develop their external surface becomes larger and larger in both a radial and a vertical direction. Such a gall may completely encircle the stem and its surface may be vertically split or fissured. A distinct collar of dead bark is often present above and below the body of the gall, tho this is best developed in mature galls that entirely or nearly encircle the stem. The mycelium is massed between the cells of the cortex into which and into the medullary ray cells and the phloem cells haustoria are sent.

Internally the tissues of these galls contrasts sharply in its brown coloration with the light color of the normal wood. This diseased wood shows the characteristic annual rings of woody stem these rings agreeing in number with that found in the sound wood. The minute structure of the wood shows some alteration from the normal. The walls of the tracheids are more or less sinuous and instead of a single row of bordered pits in the radial walls two or three such rows may be present sometimes accompanied by other very small bordered pits only about one fourth as large as the normal ones. The tracheids are usually shorter and broader than in normal wood, and there is a gradual shading over of such elements into cells of true wood parenchyma type -- a feature normally absent from pine wood. As to the medullary rays they are about twice as numerous in the gall as in normal wood and are apt to be 2 or 3 cells thick instead of the usual one cell. Resin ducts are distinctly more numerous also than in normal wood and are sometimes arranged in concentric circles.

At the end of the period of incubation pycnia are produced (altho said to be absent in the western form of this species) and are sloughed off at the end of the season. The following spring aecia are produced over this same area. They mature in May or early June, bursting thru the cortex of the gall in orange colored masses that are arranged in cerebriform or parallel lines, giving to the gall surface the appearance of brain-like convolutions. After the maturing of the aeciospores and the weathering away of the peridium the galls are much less conspicuous. Aecia are not again produced on the same gall area the next year, but instead, pycnia are again produced. So that these two spore forms occur in alternating years on any given area of gall surface, tho one part of a gall may be producing aecia at the same time that another part of the same gall may be developing pycnia.

The pycnia are of the same effused and indeterminate type as in the white pine rust and are quite different from the definitely limited pycnia of many other rusts. The aecia and the spores are similar to those of the white pine rust except for their development in radiating or anastomosing lines.

This species as well as one to be mentioned later is peculiar in that conclusive evidence has now been offered that the pines may be directly infected by the aeciospores, a phenomenum that has been termed "facultative heteroecism", i.e. the ability of the aeciospore to infect either the oak leaf or the pine stem. This repetition of the aecial stage is a new concept in uredinology, involving as it does the entire independence of the aecial stage. This independence is further remarkable, if present ideas are correct, since the uredinial stage is self-perpetuating on the leaves of the oak and it is claimed that oaks heavily infected may grow year after year in close proximity to susceptible pines that remain, however, uninfected. This indicates either a degree of independence unparalleled in our knowledge of rusts, or else a misconception in our ideas of the relationships of these stages.

Witches brooms are reported accompanying the galls on western pines in about one third of the infections.

As a result of infection seedling pines are often killed. Older trees are stunted or deformed as may well be imagined from Meinecke's report of as many as 529 galls present on one pine tree 5 inches in diameter. Cones from infected trees are small and produce seeds of low germinative power. As much as 100% infection is reported on jack pine in swampy areas and 50% in dry sandy areas in Michigan.

The uredinial and telial stages are produced on the lower surface of the leaves of all species of Quercus, and they scarcely differ in general aspect from those of the white pine rust, the uredinia appearing as small orange-colored pustules, and the telia as slender brown hair-like columns composed of a closely packed mass of teliospores. In the east the fungus is annual on this host but on the Pacific coast it perennates in the leaves of the evergreen oaks and so is independent of the aecial stage for propagation.

Cronartium comptoniae is another stem-inhabiting rust that only in one form produces swellings that could rightly be called galls. This rust goes to the sweet fern, Comptonia asplenifolia, as its alternate host, on the lower surface of the leaves of which it occurs in sori not different from those of the oak-pine rust. The aecial galls, when developed, are smaller in size than those of C. cerebrum and are most likely to develop in clusters of two or more that individually involve less of the circumference of the trunk, a single gall rarely if ever completely encircling it. These galls are all but universally confined to the base of the trunk indicating infection at an age of 3 years or less, and are rarely seen in trees more than 6 inches in diameter, probably indicating that infected trees mostly die before reaching this diameter, altho the thickness of the bark and the vigor of the tree may combine to suppress the disease at this time. The galls are usually less than 2 inches in diameter. They are quite conspicuous because of the orange-colored spore masses that develop in the aecia in May, pycnia being produced late in summer and in fall. Both spore types appear annually in this species. Its most important pine hosts are P. ponderosa, P. resinosa, P. sylvestris, and P. echinata, and it is known only east of Minnesota and north of North Carolina.

The fungus has been reported as causing a serious nursery disease particularly on P. ponderosa, the growing of that species and P. contorta being abandoned on its account in one nursery in the east. A death rate of 5-8% annually has been found on native P. rigida which together with P. virginiana seems to be its favorite host. In Michigan, 5-year old trees in a field comprising 12 acres or more devoted to P. ponderosa and P. contorta, were found to be practically 100% infected and had to be destroyed.

More frequently infection results in this species in the production of aecia under the overlying loose and dead bark without the formation of definite galls in which case the presence of the disease would scarcely be suspected at any time aeciospores are not present. The same is true of C. commandrae, alternating between pines and species of Commandra and found on some 10 species of pines thru most of the United States except the south. P. ponderosa, P. sylvestris, and Pl contorta, are its most important pine hosts.

Cronartium fusiforme has had a varied history, by some being regarded as the fusiform gall type of C. cerebrum and with the same alternate hosts. More recently Hedgecock and Hunt have stated that the basidiospores when carried back to the pine produce a globose swelling if the telia originated from aeciospores from a globose gall, and produce a fusiform gall if originally from galls of that type. This would indicate for the fungus varietal if not specific antonomy.

C. harknessii is a western species inhabiting the pines of the California coastal mountains, including P. radiata, P. jeffreii P. contorte, P. ponderosa, etc. Originally confused with P. cerebrum whose pine hosts overlap, it has recently been shown to be distinct, going to Castilleja (paint brush) and related genera for its alternate stage. Inoculation of pines with aeciospores show that this species also is able to propogate itself on the pines in entire independence of the Castilleja stage. Pinus radiata is its most important host, on which it inflicts considerable damage, particularly in the seedling stage.

B. Producing Galls on Cedars and Related Hosts

The second group of gall-forming rusts falls in the genus Gymnosporangium, producing their telia in gelatinous columnar outgrowths on galls produced on those hosts. No uredinia are present in the life history except in case of a single species of Asiatic origin, now introduced into this country. Pycnia and aecia are formed on the leaves twigs or fruits of various members of the Rose family (Rosaceae). A total of more than 40 species of the genus are known in America but only a very few induce swellings that can be classed as galls, some growing on the stems without marked hypertrophy and some being leaf parasites. In other respects the chief variations in the life histories are connected with the annual or perennial nature of the gall or swelling and the manner and perhaps the time of infection.

The gall inducing species are represented by Gymnosporangium juniperi-virginianum and G. globosum, occurring in their telial stages chiefly on Juniperus virginiana in the eastern United States. The aecial stages of the former species occurs on the leaves and more rarely on the twigs and fruit of a few species of Pyrus including the cultivated apple, while the latter is on leaves, fruits, and twigs of Crataegus, and more rarely on the apple, pear, quince, and the mountain ash. G. kerniana and G. nelsonii are on other species of Juniperus in the west. The galls produced on these hosts are more or less globose in form and are known as "cedar apples". All of these species are native to North America. The following discussion applies mostly to the first species named above, but the essential points in the life history of all these species probably does not offer much contrast.

Infection of the cedar in most cases occurs as the aeciospores ripen in the summer, usually in July and August. The infection occurs on minute leaf scales and is first noticeable as a small green swelling that does not appear until the beginning of the following summer. These swelling enlarge rapidly and are mature galls by autumn. The entire leaf on which the gall originates is permeated by the mycelium and as the gall grows the mycelium keeps pace with its growth but never develops downward into the twig. A mature gall is thus composed largely of host tissue that has been stimulated to excessive growth (hyperplasia) and the mycelium is largely inter-cellular, sending haustoria into the living cells of the gall, The galls of <u>G. juniperi-virginianae</u> produce spores but one season, altho it requires two years for them to mature, while those of <u>G. globosum</u> are perennial on the host.

The cedar apple or gall is then a hypertrophy of the cedar leaf, and the gall structure shows only the further development of leaf tissues. The parenchyma of the leaf is stimulated to excessive growth and new vascular elements are formed to supply these tissues. There is also formed a distinct cortical layer over the external surface of the gall.

As the gall approaches maturity the fungous mycelium begins to accumulate in small isolated masses near its periphery. This stops further growth of the gall cells at this point but in the intermediate regions growth continues so that the mycelial masses come to occupy depressed spots in the surface of the gall. From this mycelium a multitude of spore-producing hyphae are sent out in clusters. Each of these hyphae bears a 2-celled teliospore at its apex, and as the spore approaches maturity the stalk becomes very greatly elongated. In this way, a compact bundle of these hyphae is forced thru the overlying tissues of the gall and is extruded in the form of a slender cylindric-pointed column, one from each of the mycelial masses in the gall tissue. It is the appearance of these horns on the sub-globular gall that gives the cedar apples their characteristic appearance in April or May when, following the warm spring rains the spore-stalks gelatinize to a remarkable extent and these horns become jelly-like in consistency and quite conspicuous.

Each cell of the teliospore germinates by producing a germ-tube or basidium that becomes 4-celled and produces 4 basidiospores that are wind disseminated and may be carried to the alternate host there to produce their pycnial and aecial stages. A uredinial stage is therefore lacking in the life history.

The extent to which these fungi injure their aecial hosts is well known, particularly in case of those that inhabit orchard trees where in severe cases the fruits are atrophied or otherwise deformed and made unfit for use, the leaves are cast prematurely and the tree goes into the winter period in a weakened condition in which it may be easily subject to winter injury, and the twigs become cankered and killed.

On the cedars, very young seedlings are killed outright but otherwise the injury is chiefly confined to a reduction of the life processes resulting in stunted trees that more easily fall a prey to other unfavorable factors.

Control methods, applicable to the cedar have not been worked out. Cutting out the galls on large ornamental trees is a perennial process as new infections occur each summer. Spraying should reduce the injury but on large trees the foliage is so thick that it is difficult to do thoro work.

CHAPTER V

FUNGI AND MISTLETOES FORMING WITCHES BROOMS.

In the minds of a great many people the mistletoe is connected with a considerable amount of tradition and legendary fancy. The fact is often lost sight of that in certain sections of this country and of Europe it at times becomes a serious menance to the health of the forest trees. These traditional surroundings really hinder the work of control in some sections and it has even been stated that in the southwestern United States it is probable that eradication could be successful because of this sentiment.

A. Taxonomic position and Geographical distribution of the Mistletoes.

The mistletoes are flowering plants belonging to the Family Loranthaceae of the Order Urticales. This order also includes the elm, nettles, and other well known plants. There are two genera of mistletoes in America. The genus Phoradendron (meaning tree thief) contains those mistletoes that are for the most part parasitic on deciduous trees and have well developed green leaves or at least green stems. Exceptions to this are P. juniperinum growing on incense cedar in the west and P. bolleanum on Abies concelor in the same region and in the north-west. This genus includes the American mistletoe, P. flavescens, the most widely distributed of all the species, and growing on a great variety of hosts. It is the common mistletoe of the market and used in Christmas decorations. It is largely southern in its range, extending northward into New Jersey, southern Pennsylvania, southern Ohio, Indiana, Illinois, Missouri, and eastern Oklahoma. From thence, its range is across Texas, southern New Mexico, and Arizona to southern California and northward in the coast regions to Oregon and Washington. The other genus of the mistletoes is Razoumofskya (or Arceuthobium), which contains a separate species for nearly every forest tree of economic importance in the north west. Its distribution is largely western, especially in the Rocky Mountain states and the far North-west, although one or more species are occasionally found in Michigan and New York. The genus differs from Phoradendron in being confined to coniferous trees and in having much smaller scale-like brownish-green or yellowish leaves.

1. Phoradendron. The Southern or True Mistletoe.

1. Distribution in local areas. The southern mistletoe is an especially severe parasite between the 96th and 97th meridians in Texas, and a detailed study has been made of it in that region by the United States Department of Agriculture.

In that region climatic factors are concerned in producing a section apparently well suited to the development of the mistletoe. The forest development of that region does not approach in luxuriance that of the Gulf region nor is it the more stunted growth of the more arid regions to the west. The mistletoe is not better developed in this region but this is the region of greatest abundance. Along the crack bottoms where forest growth is heavy the tops of the trees are the parts largely affected. In more open stands it may develop on any limb of the tree. This difference of position is due to the variation in the intensity of the light - a considerable amount of sunlight being required for its best development.

2. Nutritive Relations: The plant is an obligate parasite. It fastens itself on the tree, penetrates the host tissues, and draws nourishment from them, resulting in deforming the tree and sapping its vitality. It penetrates the host by means of roots known as "sinkers", These extend through the bark and into the xylem of the host, from which they take up crude foods in solution. The plant has green leaves - hence is able to manufacture its own food from this crude sap of the host.

3. Life History.

(a) Flowers and fruit. The flowers of the mistletoe are not conspicuous. They are produced in December and the fruits are formed in December of one year but are not ripe until December of the following year. The fruit is a small white berry less than half a centimeter in diameter.

(b) Distribution of the seeds. The seeds are enclosed in a sticky pulp covered by a transparent skin. The berries are used by certain birds for food, especially by the mocking birds, cedar birds, and robins. So the seeds are carried by them and deposited in their encrement or otherwise on the limbs of the trees. The pulp still remaining about the seeds causes them to stick to the branch and after drying they are firmly pasted there.

(c) Germination and the Establishment of the Seedling. The seeds that are placed on the living branches or the trunks of trees are the only ones that will grow and then only when the bark is thin or a wound is present. Most seeds germinate in March, April, and May. The seed coat burst and a root tip is thrust out, It bends downward and comes in contact with the limb. Pressure against the limb causes the root tip to become disk-shaped. At the center of this disk the cells continue their downward growth resulting in the formation of a point of tissue called the primary sinker. This sinker is said to secrete an enzyme that dissolves the cells of the host. It cannot, however, dissolve the cells of the older bark. The primary sinker pushes inward until the wood is reached. A water conducting system is formed in its center. In the meantime the cotyledons have withdrawn from the seed coat. Usually this is about the extent of development during the first season. In the second season's growth the primary sinker sends out lateral outgrowths into the cortex of the host. These growths are termed cortical roots. They may also develop sinkers that

penetrate to the wood. The cortical roots eventually come to lie more or less exposed on the surface of the branch because no more host tissue is developed over them, and the overlying bark soon dies and flakes off. These exposed cortical roots form adventitious buds which give rise to new shoots, especially if the primary root be destroyed.

(d) Length of Life of the parasite. The parts that are developed within the host tissue are limited in their length of life only by the life of the host. Little data is at hand to indicate how long this may be. Tubeuf states that sinkers often extend through 60 or 70 annual rings. Meinecke states that P. juniperinum is known to live on incense cedar for a period of 220 years. But the aerial parts of the parasite rarely live more than 8 or 10 years, chiefly because they become rather brittle and are easily broken off by winds and other agencies.

4. Effects on the Host. The mistletoe seldom attacks young trees and is most often found on the large branches of the more mature ones although it gains entrance mainly through the smaller branches. The immediate result of infection is the starving of the branch lying beyond the point of infection. In most cases the host branch is much enlarged at the point of union with the parasite. Sometimes witches brooms of immense dimensions are formed. Where infection does take place on the main stem of small trees it usually results in considerable deformity as the tree grows older. Heavy infections eventually result in the death of the tree.

5. Point of Attack. Heavy cutinized walls or the walls of cork cells cannot be pierced by the primary sinkers. Infections on the older parts of trees must be through cracks or fissures. The twigs of the preceding season's growth are most often the parts affected. It has been shown that to a great extent entrance is gained through the buds. The primary root forces its way between the bud scales and into the inner tissues.

6. Trees most susceptible to attack. Those trees that occur singly or in clumps or rows along streets and roads, in parks, etc., are most often attacked. The damage to trees in forest stands is negligible because infection is confined to the topmost branches. Probably no decidious tree is free from attack when growing within the range of the parasite. But in most localities some trees are more or less immune and others are very susceptible. But a species that is fairly immune in one locality may be heavily attacked in another. Hackberry and cedar elm are the ones most commonly attacked in Texas. The sycamore is rarely attacked there but in Oklahoma and Arkansas it is the most susceptible of all. The broad-leaved elms are commonly infected further northwards, as are also the water oaks. In other sections the mesquite, osage oragge, hickory, various oaks, apple, pear, Prunus (wild species), honey locust, water ash, and others are abundantly infected.

7. Methods of Control.

(a) Pruning. Careful cutting out of infected parts is practical where they are small. The cut should be made several inches back of the visible area of infection.

(b) Cutting off the sprouts. Where this has been practiced year after year it has been successful. By keeping down the leaf area of the parasite less foods will be formed and eventually it will die for lack of nourishment. If the cutting is not done regularly, however, it will only stimulate new growth and so spread the infection. The best time to do this cutting is in the winter. When done at this time the berries are also prevented from maturing and so the chances for the spread of the disease are lessened.

(c) Cutting out the sinkers. In case of old infections on large limbs a chisel can be used to cut out the sinkers down to the wood and then the hole may be filled with tar and painted over with carbolineum or asphalt paint. In case asphalt paint is used the wounded areas should be wrapped in burlap, as experiments have shown that sprouts are less apt to appear if such wrapping is kept on for a time after the cutting is done.

II. Razoumofskya or Western Mistletoes.

1. General characteristics of the group. There are in all about 15 species of this genus that are parasitic on various of the native conifers of the north-western United States. The group in general differs from the Phoradendron group in that the leaves are reduced to small scales containing very little chlorophyll, and all species are confined to coniferous hosts.

The plants vary in size from those 4 to 5 millimeters high to those 25 to 30 millimeters or more hight and are of a general yellowish brown color. The plants are dioecious, producing their flowers in June and ripening the seeds the same year. The berries are light green in color and in ripening they develop a considerable internal pressure so that the slightest disturbance is enough to make them explode and eject the seeds with some force to distances of several yards. The seeds are provided with a mucous coat as in Phoradendron, and that enables them to stick to the branches of trees. On germination the primary root is capable of penetrating the young bark of the host on which they will grow. Sinkers and cortical roots are formed as in the genus Phoradendron.

The length of life of these parasites is extremely variable and is of course dependent on the length of life of the host after infection takes place, for all species are obligate parasites and die with their host. Weir reports finding a yellow pine slightly more than 340 years old, in which the roots of the mistletoe could be traced back to the third growth ring. This means that the parasite had lived in the host tissue approximately 340 years, for the roots extend inward only to the wood ring of the growth of the season in which infection occurred. In subsequent years the parasite accommodates its growth to suit that of the host. It accomplishes this by an external growing region similar to the

cambium of the host, and the annual growth amounts to just sufficient to keep from being engulfed by the growth of the host.

2. <u>Host relationships.</u> The species of conifers attacked and the corresponding parasite species are as follows:

Abies sp		R. douglasii abietinum
Abies amabilis		R. occidentalis abietina
Abies concolor	(White fir)	R. campylopoda
		R. campylopoda abietinum
Abies grandis	(Grand fir)	R. campylopoda abietina
Abies magnifica		R. occidentalis abietina
Abies nobilis		R. occidentalis abietina
Larix occidentalis	(Western larch)	R. larcis
Picea engelmanni	(Engelmann spruce)	R. douglasii microcarpum
Pinus albicaulis	(White bark pine)	R. cyanocarpa
P. arizonica		R. cryptopoda
P. attenuata		R. attenuata
		R. campylopoda
P. banksiana	(Jack pine)	R. americana
P. contorta	(Lodgepole pine)	R. americana
		R. campylopoda
		R. laricis (Rare)
P. edulis	(Nut pine)	R. divaricata
P. flexilis	(Limber pine)	R. cyanocarpa
P. jeffreyi	(Jeffrey pine)	R. americana
		R. campylopoda
		R. oryptopoda
P. lambertiana	(Sugar pine)	R. campylopoda
P. mayriana		R. cryptopoda
P. monophylla	(Pinon pine)	R. divaricata
P. monticola	(Mountain pine)	R. cyamocarpa
P. ponderosus	(Western yellow pine)	R. americana
		R. campylopoda
		R. cryptopoda
P. strobiformis	(Mexican white pine)	R. blumeri
Pseudotsuga taxifolia	(Douglas fir)	R. douglasii
Tsuga heterophylla	(Western hemlock)	R. tsugensis
T. mertensiana		R. tsugensis

Of these, <u>R. larcis</u> on western hemlock, <u>R. campylopoda</u> on western yellow pine, <u>R. americana</u> on lodgepole pine, and <u>R. douglassii</u> on <u>Pseudotsuga taxifolia</u> are the most important, with first rank given to the one on western hemlock as the most destructive of all. Of the others a large number have been collected but a few times or are known to be of little importance as tree parasites.

3. <u>Age and manner of infection.</u> Observations by Weir indicate that infections on trees less than 3 years old are quite rare. The youngest ages at which infections were found to occur on several different hosts are as follows:

Larix occidentalis	3 years.
Pinus contorta	3 "
Pinus ponderosus	3 "
Pseudotsuga taxifolia	4 "
Tsuga heterophylla	8 "

On firs and spruces no infections on trees less than 50 years old are known at present, although trees of this age have the infections on younger branches dating back only a few years.

Infection takes place, as in species of the genus Phoradendron, by the penetration of the primary sinker into the cells of the host. Earlier observers reported such a penetration as taking place on fairly mature stems but more recent observations point to the conclusion that the ability of the sinker to penetrate the host is limited to the tender epidermis of the younger parts of the host. Those seeds that come to rest between the bud scales near the base of the terminal bud, in the axils of the leaf scales, and among the leaf sheaths are the ones most likely to cause infection. Inoculation experiments reported by Weir, in which seeds were inserted in the axils of the leaf sheaths on twigs of different ages gave infection only on one- and two-year old twigs. Whether or not this penetration is the result of the solvent action of a secreted enzymatic substance is not clear, but it seems that such a substance is secreted in small amounts, but never sufficient to enable the sinkers to penetrate the older bark. Where infections are present on older and thicker barked trees or branches they are the result of earlier infections when the bark was thinner. However, trees never become too old for infection to take place on the younger twigs, altho other factors such as the shortened annual growth, and the slowness of growth may tend to minimize infection on such trees.

4. Direct Effects on the Host.

(a) Lessening the annual increment. The primary and general effects on the host of all these mistletoes is to reduce the healthy assimilatory surface of the leaf. Even when an abnormally large number of needles is formed as a result of infection (e.g. as in witches brooms) their dimensions are much smaller than are those of healthy ones, and even though increased amounts of foods are manufactured under such conditions they are speedily used up by the parasite. As a result a less quantity of food is available for supplying the growth needs of the host, the cambial activity is reduced, and the annual increment falls below normal. In severe cases the annual growth is reduced to a single layer of tracheids. The following table shows the results obtained by Weir in studying the amount of falling off in growth in the last 40 years, In the case of several species of forest trees. The figures represent averages for 40 or more trees of each species;

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Species	Age	Height in feet	Diameter in inches	Total annual growth for all trees
Pinus ponderosa				
Infected	100 yr.	49.5	18.2	1.54 inches
Uninfected	100 "	77.2	22.2	5.33 "
Larix occidentalis				
Infected	144 "	63.0	11.5	1.28 "
Uninfected	144 "	115.0	19.5	2.15 "
Pseudotsuga taxifolia				
Infected	97 "	62.0	17.3	2.17 "
Uninfected	97 "	73.0	22.2	3.28 "

Experiments conducted by the same author on Larix occidentalis showed that the cumulative suppression in increment growth when expressed in terms of normal increments amounted to as high as 80 to 95 annual rings in cases of trees as much as 250 years old. In other words, the same tree if uninfected and otherwise normal would at that age have had a radius enlarged by as much as the width of 85 to 95 annual rings over what it actually possesses in the diseased condition. In the same way, trees 90 years old and heavily infected lacked about the width of 30 normal growth rings in coming up to the radius that they would have obtained if uninfected.

(b) Dwarfing and death of seedlings. Not only does the general slowing down of assimilatory activities effect the diameter of the trees but also the length of the season's growth. Studies made by Weir on Pinus ponderosus seedlings in Spokane County, Washington, showed that when infected seedlings are compared with uninfected ones growing under the same conditions and of the same age a difference in height becomes apparent that varies from 10 cm. in case of 4-year old trees to 35.5 cm. in trees 10 years old. In Douglas fir the average length of the last four internodes was found to be from 8 to 17 centimeters more in case of uninfected than infected trees of the same age. The terminal and lateral buds also showed a proportionate dwarfing in size when thus compared, an average difference of 4 mm. in length and 1 mm. in breadth appearing in favor of the uninfected trees.

Moreover, most seedlings of 4 to 10 years of age are likely to be infected on the main stem rather than on the branches. Such trees never recover and even if suppression lasts only to the sapling stage they will be so seriously handicapped by that time that they will form only cull timber. The actual death rate for such infected seedlings was determined by Weir from an average sample acre in Spokane County, Washington. The acre included nine semi-mature trees heavily infected and so serving as centers of dissemination for the plot. The number of seedlings under 8 feet in height in this plot was 480. Of these 245 (about 51%) were found to be infected to such an extent that few of them could ever grow up to form merchantable timber. Of the 245 infected ones 49 (20%) were dead, and a careful examination of the entire plant revealed no cause for their death other than the mistletoe.

(c) Formation of Witches Brooms. One of the first effects of mistletoe infection is the production of a fusiform swelling that may resemble those caused by certain species of Peridermium (Uredinales). This swelling represents the early stage of the formation of a witches broom. These are simply more or less conspicuous masses of adventitious branches growing from a common center. It may require several years for the brooms to form, especially in older trees that become heavily infected. But no hosts for species of this genus are without them. They are probably more conspicuous on the Douglas fir than on any other host, because of the long trailing branches of the lower part of the broom on that tree. They vary in size from those that may involve practically the entire upper crown of the tree. It is stated that in many forest regions of the northwest practically 100% infection is present on the western larch, and largely due to the brooms formed they are the chief source of injury to trees of that species. On the lodgepole pine frequently the brooms are confined to the Lower part of the crown.

The weight of these brooms of larger size especially where they are formed toward the tip of the branches, and increased as it is by the weight of rain or snow, is often enough to cause the branches to split from the trunk, This is usually the result of infections on the western larch and where the wood at the bases of the branches is more brittle than in other species. Consequently, the larch reaches mature size only after producing several generations of branches that are broken off in succession. The same result follows broom formation in Douglas fir and western yellow pine to a large extent. If the fallen broomed branches did no more than to seriously increase the fire hazard they would be a distinct menace to the forest. Added to that, however, is the deprivation of the tree of the foods that would be manufactured by at least the healthy branches, and also the exposure of the tree through wounds thus formed to serious fungous attack.

(d) Formation of Cankers and Burls. When infection occurs on the trunk during the early life of the tree it usually causes the formation of more or less conspicuous burls. These never reach the dimensions of burls, due to other causes, that are formed on our eastern trees, but are frequently only slight enlargements of the stem. Cross section through burls are of a more serious type on the western larch than on any other host. Often a large broom forms on these burls but sooner or later they die because the burl tissue soon dies. These burls with dead centers afford excellent starting places for certain types of wood decaying fungi, and in addition are sure to result in a large amount of cull in logging operations. On the western yellow pine burls also are frequent, though often they are quite inconspicuous and their presence is indicated only by a roughening of the bark. Cross sections of the trunk at this point, however, shows the curly grain of other types of burls. At other times on this host they form conspicuous barrel-shaped swellings from which pitch usually exudes in quantity. On the western larch and the mountain larch they are frequent. On the lodgepole pine they usually cause fusiform swellings or else no perceptible swelling at all, but in such cases their presence

is usually indicated by the presence of the parasite itself. On the Douglas fir they are probably of less frequent occurrence than on any other host. But in heavily infected trees large burls involving the circumference of the entire tree are often formed, though they are not at all conspicuous. Just as often a series of more or less isolated vurls will form along the trunk, each representing the seat of an original infection.

The final result of these burls is to cut off, or at least seriously intere with the transporting functions of the stem and so hasten the decline of the tree. In addition, the fantastic curling of the wood renders this part of the tree more or less unmerchantable. As soon as the burl tissue dies it usually becomes infested with wood-boring insects. Where these burls are situated considerable distances apart it is often possible in logging operations to saw out the burls and still not interfere with commercial log lengths. But in badly infected trees the burls may be so close together that little merchantable timber is left. Streaks of discolored wood and long checks often extend from burl to burl, producing a very poor grade of lumber.

(e) Formation of Stag-heads or Spike-tops. By this is meant the dying back of the crown of the tree leaving the dead leaders or main branches protruding above the healthy lower crown. Stag-head may be attributed to different causes under different conditions and it is often disputed that mistletoes are ever responsible for it. But a knowledge of the other effects of mistletoes leaves little room to doubt that this parasite is of considerable importance in this connection. In those regions where there is a large percentage of infection it is usual to find an increased number of stag-heads. In nearly all trees the first and heaviest infection is in the lower part of the tree. As these parts become more and more hypertrophied food materials are more and more appropriated to them. The result is a drain on the resources of the whole tree. Materials traveling upward from the roots are likewise utilized, with the result that the upper part of the crown starves and in case of severe infection finally dies. Of all the hosts for this group of parasites the lodgepole pine exhibits fewer stag-heads than any other species, - at least in proportion to percentage of infection.

These spiketops afford excellent portals of entry for various organ isms of decay and in addition increase the danger of fires from lightning.

5. Indirect Effects on the Host.

(a) Inviting fungous attack. Not only may fungi enter through wounds on the dead areas that these parasites are continually causing either directly or indirectly, but heavily infected trees are more susceptible to fungous attack on any part - root, trunk, or leaves. In the case of certain parasitic Ascomycetes it has been noted that the needles of the older brooms are the first to be attacked and the needles from uninfected trees are able to withstand infection for a considerable longer period of time. The same thing is true for fungi attacking other parts of the host. A tree

that is supporting a heavy growth of mistletoe may not be able to manufacture the food materials necessary for growth in the roots. Consequently the resistance of the roots to fungous infection is much lessened, and decay may set in, which if widespread enough will soon result in such a weakening of the root system that the tree becomes easily windthrown. On the other hand if the vigor of the tree is less than normal wounds will be less easily covered with resin in those species in whcih such a method of wound protection is usually present. This again opens up the way for fungous attack.

It is not unusual to find wood decaying fungi growing from mistletoe burls. Weir reports that on examining a total of 600 such burls 278 of them were inhabited by fungi of this sort among which were Fomes officinalis, Polyporus sulphureus, Fomes pini, and Lenzites saepiaria - all heart-wood inhabiting forms. In 80% of burls so infected Fomes pini was present and that fungus is regarded as by far the most destructive of all those forms that grow on wood.

(b) Inviting insect attack. In much the same way that mistletoe injuries invite fungous attack on the host they may also prepare the way for insect depredations. Certain forest tree insects prefer a host in which the sap flow is relatively weak and consequently mistletoe infected trees are soon attacked. These trees then serve as centers from which infestations may spread.

(c) Influence on seed production and vitality. As soon as broom formation begins the number of cones and the number of seeds produced per cone decreases, and when infection becomes severe no cones at all are produced. At the same time the proportion of seeds that are incapable of germination increases rapidly. Experiments reported by Weir show that seeds taken from the Brooms of infected trees of Douglas fir, larch, and lodgepole pine gave a germination that was 10% below that obtained from seeds from uninfected branches of the same (infected) trees, and the seeds from these uninfected branches gave a germination that was 15% lower than was obtained from seeds from entirely uninfected trees. The cumulative difference here, then, was 25% between the seeds produced on the brooms and those produced on healthy trees.

6. Control of the Western Mistletoes. The control of these pests especially in the large forested areas, is a difficult task, but a few fundamental facts should be kept in mind as governing all logging and planting operations in mistletoe infested regions.

(a) No infected trees of any age whatever should be selected as seed trees for natural reforestation. Such trees merely serve as centers of dissemination for the mistletoe needs and all young growth in the locality may easily become infected.

(b) Steps should be taken in all logging operations where local problems of economy do not interfere to make a beginning of the eradication of mistletoe by marking every infected tree for cutting. In most instances it would be necessary to insert such a clause into the contract applying to just this point.

(c) It is not advisable to establish in mistletoe infected regions pure stands of a species much subject to attack. Firs, spruces, cedars, arbor vitae, and junipers are the forest species less subject to attack. Where selective planting cannot be made the stand should consist of as large a number of different species as possible.

(d) Close stands should be maintained as much as possible on all exposed parts of the forest, because mistletoes are light-loving plants.

(e) Care should be exercised in choosing locations for seed plots, nurseries, and transplant beds. It has been shown that the seeds of these mistletoes may be carried by high winds to distances of at least a quarter of a mile. Since in many cases the infection is visible for a considerable period after it actually takes place, the necessity for care in this matter needs to be emphasized in order to make sure that infected nursery stock is not obtained.

(f) In planting operations the influence of the soil type on the severity of attack should receive attention. Preliminary experiments reported by Weir show that larch stands on dry exposed hills may have as high as 80 to 85% infection, while the same species in more moist situations show only 15 to 27% infection. The inference is that the higher situations should be planted to species not much subject to attack.

(g) There exists a possibility that these mistletoes may at least in a measure be controlled by natural means. As Ascomycete, Wallrothiella arceuthobii was found by Peck to be parasitic on the seed capsules of one of the eastern species of the genus. More recently Weir has found the same fungus to be not uncommon on certain of the western mistletoes. Its effect is to parasitize the developing fruits and so prevent seed formation. It has been found infecting R. pusilla on Picea mariana in the eastern states, P. douglasii on Pseudotsuga taxifolia, R. douglasii abietina on Abies grangis and A. lasiocarpa, R. douglasii microcarpa on Picea engelmanni, and R. americana on Pinus murrayana in the western states. It yet remains to be seen to what extent the services of this fungus may be utilized in combatting the mistletoes.

2 *Melampsorella elatinum* (A. & S.) Arthur

Witches Broom Rust of Abies spp. — Basidiomycetes

Various species of fir are attacked by a species of rust known under the above name, the fungus causing the formation of conspicuous witches brooms on the host. On the leaves of the diseased shoots the fungus produces its pycnial and aecial stages. The rust is a heteroecious full cycle one, herbaceous species of chickweed (*Stellaria*) serving as the alternate host. The disease is known to occur across the American continent in the range of its hosts.

The fungus usually attacks the younger lateral branches and gains entrance thru penetration of the epidermis of very young shoots or thru wounds in the bark of older ones up to five years of age. Infection occurs in the spring from newly formed teliospores produced on the alternate host.

The first pronounced evidence of infection is the appearance of a swelling at the point of infection. This enlarges with the growth of the stem and may become an ovoid or rounded gall. The fungous mycelium sets up an irritation in the stem tissues with the result that all dormant buds in the infected region are stimulated to active growth and new buds are also formed. Each of these develops into a branch and this massing of the smaller branches over the infected region produces the witches broom. The brooms may attain a total length of 3 feet and a diameter of 18 inches, tho usually their size is less than half of this, young brooms not more than 3 inches in diameter being frequently encountered.

The diseased branches have a decidedly abnormal appearance. The leaves develop very little chlorophyll and so acquire a yellowish coloration. They also spread out on all sides of the twigs instead of having the falsely opposite arrangement shown on normal lateral branches. In size they are usually less than half as large as the normal leaves, and curved backward on their own axis so that an infected twig bears a striking resemblance to a sprig of the water plant, *Elodea*. Internally there is no distinction of tissues into palisade cells and spongy mesophyll. The fungous mycelium is rather uniformly present thruout the leaf and bud tissues, frequently causing the death of the bud. As a result of bud infection the new growth on every branch of the broom is infected and the mycelium is found uniformly present in the bark of the branches. The leaves on infected branches fall yearly so that in winter the brooms are quite conspicuous. The next spring new shoots and leaves are produced again.

The pycnia appear on the upper surface of the needles of infected branches but are inconspicuous and are followed in July or August by the aecia on the lower surface, appearing in two parallel rows. A white peridium is present and conspicuous at an early stage of spore maturity but soon disappears and eventually the entire aecial sorus drops out leaving ugly pits in the lower leaf surface. The aeciospores are carried by the wind to the chickweeds where infection occurs. The fungus overwinters on this host and telia are matured early in the spring. The teliospores are not produced in definite erumpent sori but are formed within the epi-

dermal cells of the host. Germination takes place at once and may result in immediate infection of the young growth of the fir. The fungus is therefore capable of perpetuating itself year after year on both sets of hosts -- on the fir because of the perennial mycelium in the branches and the buds; in the chickweed due to its overwintering on the persistent leaves of that host and capable, therefore, of producing the repeating spores, uredinia, in the spring, followed by other uredinia thru the season.

The aecial stage is easily distinguished from the other leaf-inhabiting rusts of Abies in that it is produced only on the distorted leaves of branches forming a witches broom.

CHAPTER VII

ROOT ROT DISEASES

1. Armillaria Root Rot

Armillaria Mellea Vahl. — Basidiomycetes

Armillaria mellea is a gill fungus, i.e. of the mushroom or toadstool type, that is capable of living either as a saprophyte or parasitically on the roots of trees. It also produces a white delignifying rot of the wood. Whether or not it is ever an aggressive parasite has been questioned because in many instances it is found in connection with injuries of other types. For example, in the coke regions of Pennsylvania where in the past the death of many trees of oak, hickory, walnut, locust and other species has been attributed to smoke injury, the writer has demonstrated the almost universal occurrence of this fungus in connection with the injury. European writers are in accord as to its parasitic nature. Hartig characterizes it as one of the "most widely distributed and destructive of parasites." There seems little doubt that it is one of the most important enemies of American hardwoods. Practically all species of hardwoods are subject to attack and it is also found on conifers, tho more rarely so. In the east it seems to prefer the chestnut and oak.

In its life history the fungus undoubtedly begins existence as a saprophyte, either on decaying wood in the forest or in the dead wood of wounds in the living tree. On the germination of the spores a mycelial complex is formed which later, penetrating under the bark of the dead host or into the soil, becomes collected in long cord-like or flattened strands, black in color and frequently anastomosing. These are the so-called "shoe-strings" or rhizomorphs that in the soil continue to grow and on coming into contact with a living root of a susceptible host finds entrance by means not certainly known but by the older pathologists described as by actual penetration thru the tissues. Inside the cortex the rhizomorph spreads out again into a weft of fine white mycelium which is parasitic on the living cells of the inner cortex, causing browning and death of these tissues. At this stage it can be demonstrated between the bark tissues and the wood as a fine white membrane and its activities appear to sever all connections between the bark and the wood so that the former becomes loosened and when tapped with a hammer gives a characteristic hollow sound, especially on the trunk. Following the loosening of the bark the mycelium again collects into the rhizomorphic strands that are such a characteristic and certain evidence of damage caused by this fungus and are easily demonstrated in abundance under the bark of trees killed by this fungus.

After the death of the cortex the mycelium attacks the wood, producing a white soft watery delignifying decay.

As soon as the roots begin to suffer the trees may become strongly stagheaded due to the interference of the water supply to their tops. This symptom may occur under either of two sets of conditions: (a) it is especially liable to happen in mature isolated trees or trees not in dense stands where a larger supply of water is demanded for a greater foliage area than in case of trees in close stands where the foliage is less in amount and largely at the top of the trees: (b) it may result entirely in a reduction in the amount of water available to the tree, due to the death of a certain proportion of the roots whose tips must die as a result of infection because of the stoppage of elaborated foods supplied normally thru the phloem of the inner cortex. On the other hand a tree may be infected on the roots at so many points that practically the entire root system is destroyed in a single season and death may result without an accompanying stagheaded condition of the top.

The rhizomorphs, in connection with the roots, are not necessarily under the bark but are found at times on the external surface, from which they may enter the soil and grow until chance brings them in contact with another living root. In this way the fungus lives on year after year spreading from tree to tree.

From July to October the fruiting bodies of the fungus are produced usually from dead areas at the base of the tree or from dead roots. These sporophores are of the mushroom type and are easily recognized by the prevailingly yellowish-brown or honey-colored scaly caps, the white gills, well developed stem, and the partial veil that covers the gills in young plants and remains as a rool or ring on the stem in mature ones. The cap is 3-15 cm. broad, the stem 5-15 cm. long and the gills are decurrent on the stem and at maturity may assume a rufearent tinge. A similar fungus known as Clitocybe tabescens (= C. parasitica Wilcox, = C. monadelpha Morgan) is reported from the Mississippi Valley and the eastern states as causing the death of fruit trees and oaks. It lacks a veil of annulus, however.

As to control measures, little can be advocated for practical application to American forest conditions. In Europe the removal of infected trees is advocated, as well as the trenching of such individuals or groups of individuals to prevent spread of the rhizomorphs thru the soil. In the latter method trenches are dug around such trees and at such a distance from the base of the tree as to render it unlikely that rhizomorphs have yet progressed beyond.

CHAPTER VII

THE DAMPING OFF DISEASE OF CONIFEROUS SEEDLINGS.

1. Introduction.

The unsatisfactory and often unsuccessful results secured in attempts to grow various species of coniferous seedlings are in a large measure traceable to the presence of any one of several soil fungi that live parasitically on the seeds and very young seedlings of these conifers. The disease is known as the "damping off" disease because of the apparent relation between the disease and certain external moisture conditions. The disease is not confined to the seedlings of coniferous trees but is met as well wherever young or more or less tender plants are grown under conditions of high air humidity and warm temperatures. Little trouble has been experienced in nurseries growing broad-leafed tree seedlings, altho the disease may attack practically all such species under proper conditions of moisture and temperature. Consequently, certain types of greenhouse plants are especially susceptible to the disease as well as plants grown out of doors in seed beds.

II The Organisms Concerned.

In the United States this damping off disease is known to be caused by the following fungi: *Pythium deBaryanum* of the *Phycomycetes*, *Fusarium* spp. of the *Fungi Imperfecti*, and the imperfect (Rhizoctonia) stage of *Corticium vagum* of the *Basidiomycetes*. A few other species in other genera are suspected of being of importance, perhaps under special conditions, in causing the disease.

(1) *Pythium deBaryanum*. Hesse

This fungus, also known as *Artotrogus deBaryanum*, is the most common damping off parasite on most other plants, tho in case of coniferous seedlings it probably ranks second in destructiveness.

The mycelium is a branched non-septate complex growing between the cells of the host, tho at or near the time of fruiting it becomes, on some hosts at least, more or less superficial.

The fungus reproduces itself in several different ways.

Sexual reproduction, involves the formation of oogonia and antheridia. The former arise terminally or intercalarly and become nearly spherical bodies, each producing a centrally located egg nucleus. The antheridia arise in the neighborhood of the oogonia and are clavate organs in which the male nuclei are produced. At maturity the tip of the antheridium comes into contact with the oogonial cell. A fertilization tube is put out by the antheridum and that penetrates the original wall and comes into contact with the egg nucleus. A male nucleus passes thru the tube and fertilization, tho somewhat delayed, is finally accomplished. The gametospore then takes on a heavy wall and later, after a period of rest, germinates by producing a mycelium.

Conidia or Chlamydospores are formed in chains either terminally or intercalary. They germinate at once by producing a germ tube capable of infecting a susceptible host.

Zoospores are produced in zoosporangia that are either terminal or intercalary and formed by a swelling out of a part of a hypha. A mass of protoplasm migrates into the enlargement, and eventually the sporangia becomes spherical in shape and the content breaks up into small reniform masses with two lateral cilia. These zoospores are discharged and after swimming around for a time they settle down and germinate by producing a germ tube that under proper conditions will produce an infection.

(2) Fusarium moniliforme Sheldon, and other species.

The genus Fusarium belongs to the Order Moniliales of the Fungi Imperfecti and hence lacks definite fruiting organs in which spores are produced. The mycelium is white, septate, and 3-5 u. in diameter. There are two kinds of spores, of course both conidial, and they are termed micro-conidia and macro-conidia respectively. The former is smaller than the latter, measuring 12 x 3.5 u. The macroconidia production begins about 48 hours after the microconidia become numerous. They seem to be produced on short aerial branches. They are 1 to 5 septate, but the septae do not appear until the spore is detached from the parent branch. In shape they are cylindric or somewhat curved and measure 32 x 6 u.

In addition to the two kinds of conidia, a third type of spore is sometimes produced. They are called chlamydospores and are usually found at the ends of slender lateral hyphae, they may be formed at any point in the hypha. Their function is thot to be to carry the fungus over unfavorable conditions.

(3) Corticium vaguum B. & C.

This fungus has only been infrequantly noted as having any direct connection with the damping off disease, and it is possible that it is not usually of much importance in that connection. The mycelium is capable of living saprophytically for extended periods in the soil or on rotting wood or other vegetable remains, and even of fruiting in such locations. The sterile mycelium has bean referred to the genus Rhizoctonia. The fungus is known as a virulent parasite on other hosts, especially the potato. On the underground portions of some plants it forms on their surfaces small brownish hard bodies termed sclerotia. These represent a resting condition of the plant. In its parasitic phase the fungus forms a sheath of mycelium around the base of the parasitized stem. From this hyaline slightly brownish mycelium the basidia arise directly, each basidium bearing 4 to 6 spores that are hyaline, ovoid to narrowly ellipsoid, apiculate at one end and flattened on one side, and measure 8-14 x 4-6 u.

III. Economic Importance of the Disease.

In most nurseries a large number of seedlings are lost every year. The loss is probably heavier than nurserymen realize, partly because many young plants are killed before they appear above ground, and their death is perhaps never noticed. The most serious aspect of the disease, however, is the effect it has in inducing the nurseryman to abandon the growing of certain kinds of seedlings. This of course has its effects in discouraging forest planting of those species. In order to stimulate forest planting it is necessary to eliminate all possible cost items. The seed of some species of conifers costs three to five dollars per pound and their germinating power is usually not normally more than sixty percent. If any considerable part of this percentage fails to yield usable seedlings the reduced production is reflected in the increased cost of the seedlings. When interest on the original cost of a forest plantation is compounded for the 100 or more years that must elapse between forest planting and timber cutting, a very slight increase in the initial cost of planting becomes a heavy charge against the ultimate timber value of the plantation.

IV. Symptoms and Effects.

Several different types of injury have been reported for these fungi. The one usually recognized as the damping off disease usually appears a few days after the seedlings have come thru the soil, tho seedlings up to nearly two months old may be attacked. In this type of the disease infection first appears as a small watery spot on the hypocotyl or the tap root. The tissues shrink slightly over these areas, become soft and watery and the plant falls over. At this stage in their development the stems are dependent for support on the turgescence of cortical cells which are of course thin wall ed cells of the parenchyma type and hence are easily penetrated by the fungus. As soon as mechanical tissue is developed in the stem the resistance of the seedling begins to increase and at the end of five or six weeks little trouble will be experienced in warding off the disease. The fungus spreads rather rapidly in this type of injury usually resulting in killing off all the seedlings in small circular areas around the original point of infection.

Another phase of the disease consists of the ability of the fungus to cause the death of the radicles as soon as the seeds begin to sprout and before the hypocotyl appear above ground. The presence of this type of injury is often the cause of poor stands obtained in the seed beds and is often attributed to lack of germinating power of the seeds.

After the stems become too woody to be penetrated and decayed the roots, owing to their position in the soil, are still in a more watery condition and the fungus may occur as a root rot of such plants. This type of injury is less frequently met and is of less economic importance than the two mentioned above.

V. Control Measures.

(1) Soil Choice: Where it is possible to obtain, a sandy soil site should be selected in preference to all other soil types for the seed beds. A sandy soil will be better drained, and will contain less organic matter on which soil fungi largely subsist. If a sandy soil site cannot be obtained, it may be advisable to improve the available soil by obtaining sand to mix with it or to surface the beds with sand. A method that has proven of some value is to cover the seed with sand or a sandy soil taken from a point so far below the surface of the ground that it will likely be free of parasitic fungi. Or after germination, the beds may be surfaced with heated sand applied as hot as the hand can stand. Some experiments with this last, however, have failed to yield results that were at all beneficial.

But a sandy soil in the seed bed is no guaranty of freedom from disease. Under ordinary circumstances, however, it makes easier the regulation of certain external factors that are largely responsible for the virulence of the attack.

(2) Moisture and Drainage: To secure good drainage it is a common practice to raise the level of the beds from 2 to 3 inches above the paths. In most instances this is probably a good practice but on very sandy soils in a dry climate it is apparently unnecessary and without value. To secure aeriation the best eastern nurseries leave the beds entirely open to the wind, but on account of a lessened humidity it has been found that in the western states it is perhaps better to use light board sides for the beds. So while excessive moisture and shade must be avoided, in very sandy soil or in dry climates there is almost as much danger from too dry beds. Excessive drying, with a consequent increase in temperature is believed to be responsible for the "white spot" injury, in which the stems of the seedlings whiten and shrink in spots just above the ground line. Death usually follows, and such injury is almost always mistaken for damping-off.

(3) Fertilizers: Only a few experiments are reported as to the effects on the disease of different fertilizers. As to nitrogenous fertilizers, Hartley and Pierce report that dried blood and sodium nitrate appear to favor the disease, while Gifford reports that in Vermont tankage has given excellent results against the disease. In small quantities lime has no appreciable effect while heavier applications have had bad effects in Nebraska and in Vermont. Manure applied before it is well rotten seemed to increase "damping off" while well composted manure appears to be harmless. Green manures have not proved harmful but it is not impossible for some such crops to harbor the parasite and so cause disastrous effects.

(4) Density of Sowing: Pines suffer most from the disease when sown too closely. This is due to the ease with which the parasites spread from one seedling to another in dense stands. In general, beds sown broadcast seem to suffer less than beds sown in drills. Where beds become infested, quick transplanting to new soil is practiced in some forest nurseries.

(5) Time of Sowing: While time of sowing has a decided effect on the prevalence of the disease, yet it is impossible to give general directions on this point for the reason that the time must vary with the time of wet and dry seasons in any locality. For example, it was found in New Mexico, that July, the local rainy season, is the worst time for sowing, while in Nebraska beds seeded late in autumn were comparatively free from the disease. But several attempts in successive years are necessary before a time for sowing in any one locality can be definitely decided upon.

(6) Seed Treatment before sowing has been recommended as giving good results. Mercuric chloride, copper sulphate, and heat are mentioned in this connection but cannot be expected to suppress the disease since these fungi are soil organisms and are not carried on the seed.

(7) Soil Disinfection:

A. By steam sterilization:

Steam sterilization has been tried out at the Vermont Station but the results were not such as to make the method worth recommending. When comparative tests were run as to the difference in effect of steaming, disinfection, and no treatment at all, the best results were by the formalin method and the next best by steam sterilization. In one instance at the end of about 30 days the loss in the untreated plot was 50% in the steamed 33%, and in the formalined area 10%. In these experiments on steam sterilization a temperature of close to 212° was maintained for periods of half an hour or longer.

The steaming process, moreover, lessens the amount of moisture in the upper layers of the soil, probably by diminishing the power of the upper layers to draw up moisture from below. This may have also an adverse or at least a retarding effect on germination.

B. By Chemical Solutions.

Because of the variable characteristics of different soils it is impossible to prescribe any one treatment that will be effective at all nurseries. However, it is no doubt possible and practicable to control damping off by some method of soil treatment. At the present time there are four promising disinfectants for use on the seed beds. These are: sulphuric acid, copper sulphate, zinc chloride, and formaldehyde. At the present time not enough work has been done to show the exact relative value of each of these substances. Sulphuric acid, however, has proved successful a larger number of times than any of the others, although it cannot be used on soils that have a high carbonate content.

No one formula for treatment can be expected to give the same results under different conditions, so that the quantity of acid to be used must be determined by experiment for each nursery. These experiments should be in the nature of small scale tests carried out in the nursery at different seasons. The test plots should be of equal size, seeded with equal quantities of seed and otherwise treated just alike except in the amount of the acid applied. Results are to be measured by the number of seedlings that survive the period of susceptibility to the disease and the results of the first set of experiments should be used as a guide for further tests for more successful results or for verification of the results of the first test. It has been advised, in order to prevent chemical injury to the seedlings, to apply air slaked lime to the beds just before sowing. When the proper quantities of acid are used such a procedure should not be necessary and it destroys some of the effectiveness of the acid.

Copper sulphate, zinc chloride, and formalin have also been used with good results for soil sterilization.

The following schedul e is essentially that recommended by Hartley and Pierce, the heavier treatments in each series to be used for heavier soils and the less concentrated solutions for more sandy soils.

1. Sulphuric acid, 2 to 7 cc. per sq. ft., dissolved in 1 to 2 pints water per sq. ft. and applied immediately after seed is sown and covered.

2. Copper sulphate, 2 to 5 or 7 cc. per sq. ft. dissolved in water and applied immediately after seed is sown.

3. Formalin, 5-14 cc. per sq. ft., dissolved in water and applied 10 days before seed is sown. Keep bed well covered during these 10 days. Do not spade up beds after treatment.

4. Air-slaked lime, 1/2 oz. (av.) per sq. ft. applied dry and raked into upper 3 inches of soil before sowing. Immediately after seed is sown and covered apply 3-8 cc. sulphuric acid per sq. ft. dissolved in water.

In dissolving the disinfectants the amount of water that should be used depends on the moisture content of the soil. In general for heavy soils sufficient should be used to make from 1 to 2 pints of solution per square foot. Two pints should be used if the soil is dry, 1 pint is sufficient if the soil is wet. For sandy soils the amount of water used should be 1 pint if the soil is already wet, and 1½ pints if it is dry.

The common commercial grade of materials should be used. The sulphuric acid should be concentrated, and the formaldehyde of the usual 40% strength to start with. In dissolving the acid it should be poured into the water - never by pouring the water into it. Both sulphuric acid solution and the copper sulphate solution

1 fluid ounce = 500 c.c.

are corrosive to metal and should either be handled in wooden or earthenware containers or in metal containers coated on the inside with hot paraffin. Where any but the formaldehyde is used it is advisable, at least under test conditions, to water the beds from the time sown until a few days after germination when the root-tips have penetrated ½ inch of the soil. In ordinary spring weather the beds should be watered daily, in misty or rainy weather every other day. If the maximum daily temperature exceeds 80° F. they should be watered twice daily. In cloudy weather 1 pint of water per square foot is found sufficient for daily watering (2/10 inch of rain is equivalent to 1 pint per sq. ft.). This watering is to prevent chemical injury to the young roots.

The following are the chief points, aside from effectiveness, that may be considered in making choices of the disinfectant to be used.

Sulphuric acid is the cheapest, is highly efficient in killing weeds and often causes increased growth of the seedlings.

Copper sulphate costs about the same as the acid, is nearly or quite as effective in controlling weeds, but has not been observed to result in any marked increase in the growth of the conifers.

Zinc chloride costs considerably more than the preceding substances, but kills weeds about as well, and has not been observed to yield increased size of the seedlings.

Formaldehyde is relatively expensive and the covering of the beds after treatment is an added expense. It kills the weeds but has little effect on the growth of the seedlings. It does not require watering as the others do.

C. Secondary Effects of the Disinfecting Agents.

(1) Effect on physical composition of the soil:

As stated above, the use of steam as a sterilizing agent apparently decreases the power of the upper layers of the soil to draw up by capillary action the water from below. Consequently, such soils dry out rapidly on the surface and when water is added it appears to percolate thru these layers more rapidly. The effect of this on seed germination depends largely on climatic conditions and the frequence and ease with which it is possible to sprinkle the beds after they are seeded. Undoubtedly beds so treated require more care and consequently the cost of producing seedlings is thereby increased.

The use of the other disinfecting agents has never resulted in this change in physical composition of the soil.

(2) Stimulation to germination.

With all disinfectant solutions so far successfully used it is usual to find a higher percentage of seed germination than in the untreated plots. This is due to two reasons, and it is impossible to actually evaluate the two under field conditions. Part of it is of course due to the consequent killing of the parasites that would otherwise kill the seeds before they were well started in the germination process. Another part is due to the stimulating effect on the dormant seed, causing many to germinate that would otherwise not do so. The sum of these two factors then, results in an increased stand on the treated over the untreated plots.

(3) Increased growth and size of the seedlings.

An increased seedling growth has been reported for beds in which the treatment was by the sulphuric acid method. Immediately after the seedlings come thru the surface, if there is any difference to be noted it is that there is a decreased growth rate in the acid plots. But this effect later disappears and during the latter part of the season such seedlings grow faster than those receiving other treatment or are untreated, Measurements from Nebraska showed that an average increase in height of 37% could be ascribed to the acid treatment. Results in Kansas nurseries were even more surprising. A moderate increase in the first season's growth with western yellow pine but with jack pine larger increases were obtained for the first year, the average height of plants in treated plots being 3 times those of plants in untreated plots. The air-dry weight of the tops was 7 1/2 times as great in the acid plots as in the untreated plots. Root growth was apparently correlated with top growth. But these unusual increases have been on soil that is distinctly alkaline, and the neutralizing effect is probably more pronounced here than elsewhere and the increase is in part to be ascribed to that. Such an increase is extremely beneficial and economic if the stock is to be transplanted at the end of the first year, when a difference in size and sturdiness may mean the difference between success and failure, when transplanting. Jack pine cannot be raised large enough in Kansas in one year in untreated plots so that transplanting could be made at the end of the first year. If the plants are to be left in the same bed 2 years this economic effect is less magnified. But also, in the Kansas beds the seedlings in untreated plots were so small that they could not withstand winter killing and were practically all killed the first winter. The seedlings in the adjacent acid plots came thru the winter without injury.

(4) Weed Control

In some nurseries the control of weeds in the seed bed is an important problem. Without the use of disinfectants it sometimes becomes necessary to resort to hand weeding. The use of any of the 4 disinfecting solutions, however, will usually keep the weeds from the seed beds for a time after seeding, as the weeds and seeds are more susceptible to injury by the chemicals than are the tree seeds. In Nebraska the seasonal cost of keeping out the weeds

has been placed at $7.60 per 1,000 sq. ft. for untreated beds. In the year 1912 in the acid treated beds the cost was reduced $5.40 (per 1,000 sq. ft.). This saving exceeds the entire cost of the acid treatment so that any increase in density of stand or in amount of growth that was present was clear gain. In the seed beds of the Feather River Forest Experiment Station in California a light sulphuric acid treatment is in regular use simply on account of its value as a weed killer.

(5) Chemical injury to seeds

Chemical injury to the seeds and young seedlings following treatment of the seed beds with H_2SO_4, copper sulphate, mercuric chloride, formaldehyde, and lime sulphur has been many times observed. This was especially common in earlier experiments where the acid was applied after the seeds begin to germinate, and it was found that any solution strong enough to effect the activities of the damping off fungi would cause the death of some of the roots of the pine seedlings. The roots effected were always young and located in the upper 1 or 2 inches of soil, so it seems evident that the injury is caused as a result of the evaporation and consequent concentration of the solution in the upper layers of the soil before the moisture from below has had time to diffuse through the treated layers and reduce the concentration of the disinfectant.

But where the acid is applied at the time of sowing much stronger treatments can be given without injurious effects. But in order to have the solutions strong enough to control the damping off parasite it was necessary to increase the concentration to such an extent that without remedial measures injury still occurred.

Either of two procedures, however, can be used to counter this injurious effect. Since the injury is due to a concentration of the acid solution in the surface soil, then the application of water will prevent this concentration and consequently prevent chemical injury. Of course the amount of water necessary depends on the moisture content of the soil at the time of treatment and the rapidity of concentration depends also on climatic factors. However, if the soil is fairly wet when the seeds are sown, the beds may be watered daily in ordinary spring weather, every other day or even less in misty or rainy weather, and twice daily if the temperature exceeds 80° F. In clear weather the watering should approximate 0.3 inch of rainfall, while in cloudy and cool weather 0.2 inch is sufficient. This system of watering has proved practicable and has been entirely successful in preventing injury to pines from acid applied at the time of sowing.

The second preventative measure in case of acid applications, is to add lime to the soil shortly after treatment with the disinfectant. Of course theamount of lime added must not be enough to destroy the disinfectant action of the acid, and in fact, the addition of lime is not recommended for pine seed beds. For angiosperm seed beds, however, it works better, and the amount of lime added should be enough to about equalize 3/5 or more of the acid. The acid should be applied several days before seeding and

the lime raked into the surface soil just before seeding.

D. Cost of Disinfectant Treatments.

The cost of these operations is quite variable in different localities, depending on the equipment available for carrying out the operation, the scale on which the work is carried out, the extent to which weed control is a factor, the distance from shipping points supplying the materials, the fluctuating and unstable prices of chemicals at the present time, the method of treatment used, and the character of the soils to be disinfected. Figures furnished from a Nebraska nursery give the total increased cost due to the use of the acid treatment as $5.00 per 1,000 sq. ft. The average increased stand in acid treated beds is not far from 100%. This means that for every 100 seedlings produced on untreated plots 200 are produced following acid treatment. In such a case the treatment may be considered to have paid for itself twice over.

The following prices prevail for the various chemicals at the present time, and no further rise in the market is anticipated.

Sulphuric acid about 15¢ per lb., but the cost of the container and of crating small quantities as above, 50¢ additional.

Copper sulphate 8 to 10¢ per lb. in quantities of 150 lbs. or more.

Hydrochloric acid about same as sulphuric acid.

Nitric acid about twice as expensive as sulphuric acid.
Formaldehyde about 50¢ per pound.

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