SUPPLEMENT TO LECTURES ON FOREST PATHOLOGY

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During the summer of 1970 the Federal Government Forestry staffs in Winnipeg and Calgary were amalgamated and transferred to the Northern Forest Research Centre in Edmonton. The Calgary laboratory was closed and sub-offices established in Winnipeg and Prince Albert. The new headquarters under Environment Canada serves the area of Manitoba, Saskatchewan, Alberta and the Northwest Territories.

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I. INTRODUCTION

It has been demonstrated in all forested countries of the world, that much can be gained by forest administrators through an awareness on their part of the role and consequences of tree diseases in planned forestry. For example, in Alberta, the losses of wood volume in living trees because of heartrot alone has been conservatively estimated at nearly 310 million cubic feet for the five-year period of 1951-1955. Substantially increased losses due to heartrot can be expected with the increasing age of forests in this province. The dwarf mistletoe disease causes significant reductions in the growth rate of lodgepole pine in many areas. In addition, this disease kills many trees in certain areas. These are but two examples of the many diseases that affect our forests. A knowledge of how these and other diseases develop to produce their destructive effects should help in the formulation of policies and practices aimed at reducing disease losses. With this in mind, the following outline has been prepared, to serve as an introduction to certain principles involved in the investigation and solution of forest disease problems. It is directed mainly to field officers of the region, through whose actions the effectiveness of forest management practices are largely determined.

The outline has been prepared in nine main sections, to facilitate an increasing familiarity on the part of the reader with forest disease considerations: definition and importance of disease; cause of disease; development of infectious diseases; kinds of infectious diseases; important infectious diseases in Alberta; other noteworthy diseases in Alberta; pathology in practice; development of forest disease investigations in Alberta and elsewhere; and recommend procedures for detecting, collecting, and reporting tree diseases. To these has been added a glossary of terms that are useful when discussing tree diseases, and an index of diseases and pathogens that are mentioned in the outline.

II. DEFINITION AND IMPORTANCE OF DISEASE

The term disease as it applies to trees and other plants is difficult to define satisfactorily, since it covers a range of biological phenomena. A practical definition, although not universally acceptable, could be "any prolonged disturbance to the normal functioning of a plant that results in a permanent and frequently injurious abnormality". Disease therefore results in some form of permanent damage, that in turn causes some form of malfunctioning in plants.

All plant diseases are not uniformly serious. Forest tree diseases are considered to be important only when trees are either killed, or where appreciable losses of wood volume and quality are involved. Even wood volume loss is not serious in shade trees and in shelterbelts, where only mortality involving complete trees or major parts of trees is important.

The effect of some disease-causing fungi is beneficial in soil formation and maintenance. The decomposition of plant parts from pioneer vegetation on stone outcrops is an important soil forming factor. The decomposition of plant material is part of the nutrient cycle in forest stands. By this means nutrients are returned to the soil for use by other green plants. In this process many of the decay-causing fungi have an important role. Fast decomposition of slash in cut-over areas, in addition to its importance in soil enrichment, markedly decreases the fire hazard.

III. CAUSES OF DISEASE

Tree diseases only occasionally result from a single cause. Most of them are the result of a series of damaging disturbance, each having its separate cause. These are termed either CAUSAL AGENTS or DISEASE AGENTS, of which there are many examples in nature. When investigating a disease it is usually necessary, therefore, to consider more than one factor or agent.

Disease agents can be classified as being either INFECTIOUS or non-infectious, depending upon either their ability or inability to multiply and spread. Both types of agents produce SYMPTOMS, i.e., visible reactions such as foliage discolouration, thus enabling the detection of the diseases they cause. Infectious diseases sometimes produce SIGNS in addition to symptoms, i.e., visible structures of the causal agent. Signs are therefore highly diagnostic of disease, but they do not always occur and are sometimes difficult to detect.

To say that a tree is diseased implies that it is abnormal in one or more respects. This presumes a knowledge of normal healthy trees, if abnormalities are to be detected. This will allow the building of "symptom pictures" for particular diseases.

1. Non-infectious Agents and Diseases

There is a tendency in forestry to underestimate the importance of this class of disease agent when calculating forest losses. Part of the reason for this is the temporary nature of many non-infectious agents. Also, some of them serve as preconditioners to the actions of infectious agents, and their importance tends to be masked by the persistent nature of such agents. The few non-infectious agents that are persistent, and therefore cause damage in successive years, are more easily appreciated as disease agents than those whose activities are temporary.

Most non-infectious agents are part of the non-living environment of trees. To cause damage it is necessary that they represent environmental factors that are somehow unfavourable to the normal functioning of plants. It is not necessary that they kill plants, but only that they cause either some form of permanent damage or substandard rate and quality of growth. The more common and damaging non-infectious agents of tree diseases are:

cold	hail	smoke	water excess
heat	snow and ice	nutrient imbalance	wind
fire	lightning	water deficiency	animals

A. Cold

The life processes and general functioning of trees are adjusted to minimum low temperatures, below which damage occurs. Great differences in cold resistance exist in trees, not only between species but between individuals of a species. Some trees are resistant to all but the most extreme low temperatures, others are vulnerable to seemingly minor low temperatures. Cold resistance, therefore, is an important factor in determining the natural distributions of trees.

Low temperatures are damaging, depending upon the season of their occurrence, seasonal low temperatures being much less damaging than unseasonal ones. The reason for this is that plant tissues undergo changes late in the year that make them more or less resistant to low temperatures. One of these changes is the conversion of insoluble sugars to soluble ones, with the result that the freezing point of cell sap is substantially lowered. Plants are also generally dormant during winter months, and lack tender exposed tissues.

Both the rate of temperature drop and the duration of low temperatures are important. A gradual lowering of temperature is less damaging than is a sudden drop, and low temperatures of short duration are less damaging than longer ones.

The degree of cold hardiness of different species and of individual trees is important where low temperatures are concerned. The PHENOLOGY of different trees is important, i.e., their developmental sequences and rates. Trees that leaf and shoot early in the year are prone to damage from low temperatures that occur in the spring and early summer. Trees that continue their growth late in the year are prone to damage from low temperatures that occur in late summer and in the fall.

The diseases caused by low temperature are frost killing, frost cracks, and frost heaving. Frosts may be either late, seasonal, or early. Late forsts result from low temperatures that occur after plant growth has commenced in the spring. They are the most damaging, and buds, leaves shoots, branches, and the roots of trees can be killed outright. Early frosts result from low temperatures that occur before the living parts of trees become dormant for the winter. On the whole they are less damaging than are late frosts. The symptoms of frost damage are: (a) drying of buds and shoots, (b) reddening and finally browning of foliage, (c) killing of limited areas of bark and CAMBIUM, and (d) root killing.

Frost cracks are radial separations of wood, usually in stems and rarely in branches (Fig. 1). They result from sudden and great drops in temperature that can occur only in winter months. The differences in temperature between the outer and inner portions of stems initiate sudden and strong shrinkage forces. Since wood shrinks faster and to a greater degree tangentially than in other planes, the result of these shrinkage forces is a separation of the wood, usually along a line from the pith to the bark. CALLUS tissue usually forms in the bark the year following injury. Repeated rupturing and callusing causes a build-up of ridges that are called frost ribs (Fig. 2).

Frost heaving is the physical lifting of a seedling from the ground. It is caused by alternate expansion and contraction of the surface layers of soil because of freezing and thawing. Since the direction of expansion and contraction of the soil is mainly vertical, the roots of seedlings and young trees are directly involved. Shallow rooted plants are lifted free of the soil, and more deeply rooted ones have their roots broken off. Heaving is most common in heavy textured and poorly drained soils, and can be a serious problem in forest nurseries.

B. Heat

The life processes of trees are also adjusted to certain maximum temperatures, above which injuries occur directly as the result of heat. Heat is most damaging to young plants and actively growing tissues. Temperatures below 110 deg. F. seldom cause damage, but those above 120 deg. F. invariably result in some form of injury.

High temperatures are most damaging when acting together with some other variable factor of the environment, usually moisture. For example, sustained high temperatures result in excessive losses of moisture that would otherwise be available to plants. If the moisture relationships of a plant are precarious, excessive heat for even a day or two at a time can be very damaging.

Direct damage from heat depends upon the locations and conditions under which plants grow. Dark-coloured and light-textured soils are subject to large and rapid rises of temperature, more so than light-coloured and heavy-textured soils. When soils are blackened by fires, extremely high surface temperatures can occur that are lethal to young plants. Surface temperatures of up to 190 deg. F. are common in such circumstances. The exposure to the sun, and the degree of shading afforded by neighbouring plants, also affect the possibilities of heat damage.

The diseases caused by heat are SUNSCALD, BASAL STEM GIRDLE, WHITE SPOT, and ROOT NECROSIS. Sunscald is the drying and eventual killing of bark and cambium resulting from exposure of these tissues to the direct rays of the sun. Young trees, thin-barked trees, and those growing either in stand openings or at the margins of cut-over areas are the most seriously affected. Sometimes trees are damaged over their full length. A serious consequence of sunscald is the entry of fungi through killed tissues and their subsequent development in neighbouring living tissues. Sunscald can occur at any time of the year, but is most usual in the summer.

Basal stem girdle occurs in seedlings, as the result of extremely high temperatures at the soil surface. It involves an encircling LESION that is caused by direct heat injury to stem tissues. A symptom of this disease is a swelling above the point of injury. White spot is a localized killing on the stems of newly emerged seedlings, resulting from direct injury from heat. The lesion is white and watery in appearance. Affected plants topple over at the point of the lesion and eventually die. Root necrosis is the outright killing of the surface roots of seedlings, directly as the result of heat.

C. Fire

Fire is perhaps the single most destructive agent operating in forests. The potential for damage from fire is unlimited, and the total losses in a single year are usually great. Apart from the outright killing of trees by fire, other trees are sufficiently damaged to allow the entry of infectious agents and insects, which because of their ability to intensify and spread, can invade nearby undamaged timber (Fig. 3). These so-called secondary losses sometimes exceed those caused directly by fire.

D. Hail

Direct losses to forest trees from hail are only occasionally serious. Severe hail storms cause defoliation in varying degrees, wounding of the exposed sides of branches and stems, and sometimes the death of shoots and young trees (Fig. 4, 5). Usually the entrance of infectious agents through hail wounds is more serious than hail itself. In areas that have a history of repeated hail storms it is difficult to find older trees that are not seriously diseased.

E. Snow and Ice

The weight of snow and ice sometimes causes trees to break. Trees with either wide crowns or brash wood are prone to snow and ice damage. Residual trees in recently cut-over areas and trees on the margins of uncut stands are often damaged by ice and snow, mainly because such trees are usually tall and slender (Fig. 6).

F. Lightning

Considerable damage from lightning occurs in areas where lightning storms are severe and regular, since trees of all species are susceptible. Dominant trees and open-grown trees are more vulnerable to being struck by lightning than are understory trees and trees growing in closed stands. Only some forms of lightning damage are readily apparent, such as shattering and stripping of the bark. Less evident, although more common, are areas of

Plate I.

Fig. 1. Frost crack on aspen as an entrance for decay fungi.

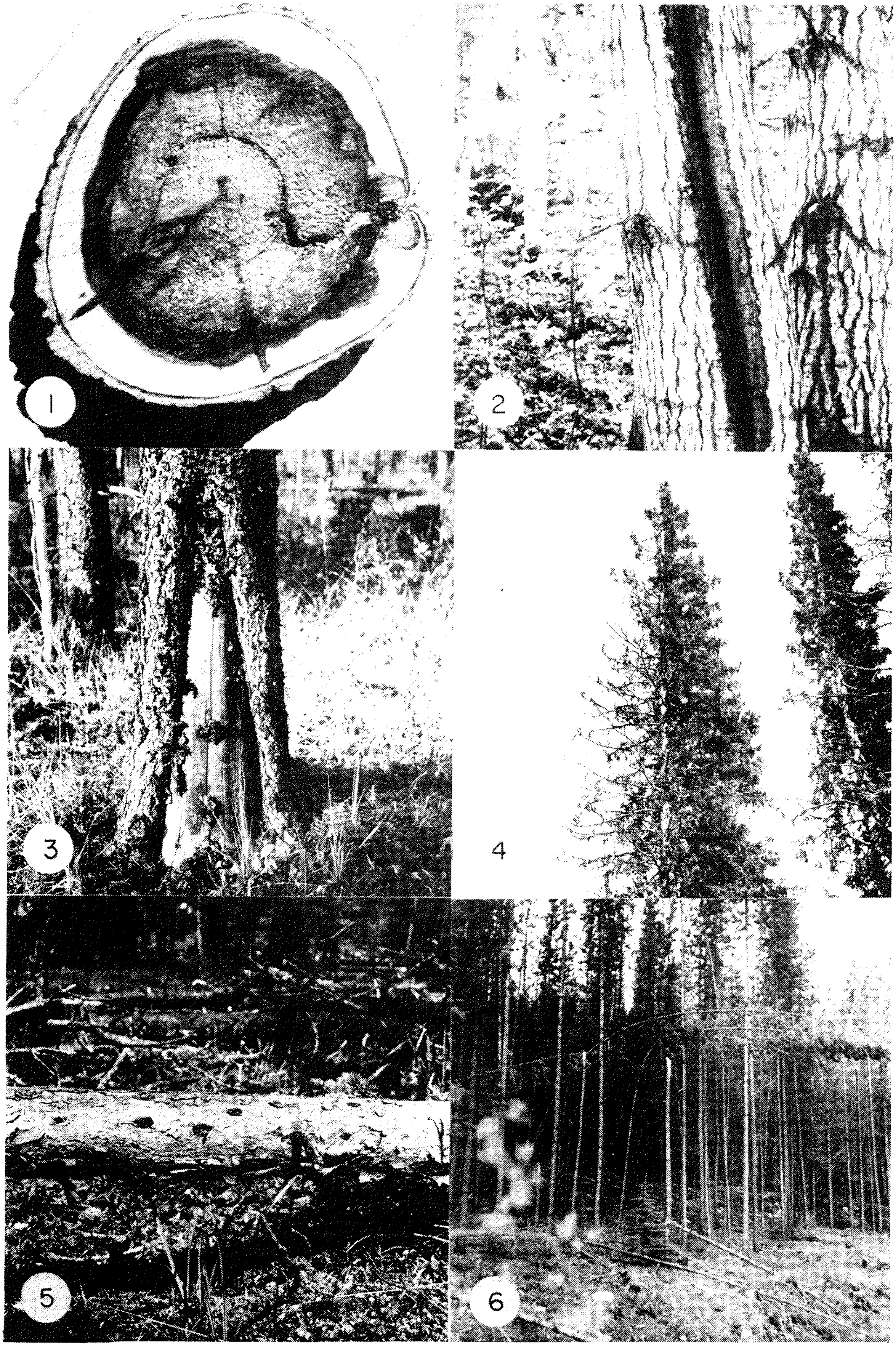
Fig. 2. Frost rib on aspen.

Fig. 3. Fire scar on lodgepole pine.

Fig. 4. Partial defoliation of spruce by hail.

Fig. 5. Healed over hail wounds on spruce.

Fig. 6. Snow damage in young lodgepole pine.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dead bark and cambium and abnormally developed wood. Defects such as these become important later, since they usually result in losses of strength and quality in the products manufactured from damaged trees.

G. Smoke

Air pollution by incombustible material can injure trees. The most damaging incombustibles are sulphur dioxide and fluorine, the sources of which are mainly smelters that treat metallic ores. Both are damaging even at low concentrations (1:500,000 of air), and since both are heavier than air the damage is often serious.

Affected foliage becomes red and finally brown. The tips and margins of coniferous foliage is affected first. In broad-leaved foliage the areas between the veins are affected first. Of the three recognizable degrees of smoke injury, i.e., (a) invisible stage, (b) chronic stage, and (c) acute stage, only the latter causes rapid discolouration, defoliation, and mortality. The chronic stage results mainly in stunting tree growth and results from persistent low concentrations of smoke.

H. Nutrient imbalance

To obtain their best growth trees require a balance of soil nutrients, among which are a number of so-called essential elements. Deficiencies or excesses of these produce a variety of ill effects that are often the forerunners of more serious diseases. Malnutrition is more common than over-nutrition, the latter usually resulting in overgrowths.

Some soils are regularly low in nutrient value, and trees growing in such soils are chronically undernourished and in a permanent state of sub-standard vigour. Other soils become impoverished through time, such as marginal agricultural soils that have reverted to forestry use. Malnutrition is most serious when it involves a lack of the nutrients required in CHLOROPHYLL production and PHOTOSYNTHESIS, mainly iron, phosphorus, magnesium, and nitrogen. Deficiencies of these elements produce the disease called CHLOROSIS, a yellowing of leaves and shoots which if allowed to persist will result in the death of foliage and entire plants. Many forest soils are naturally low in nutrients, and chronic chlorosis is common.

I. Water deficiency

Since water is necessary for plant growth, plants do not grow properly and some die when the supply is inadequate. All of the mineral nutrients for plants must pass in water solutions from the soil to the growing parts of plants. Lack of moisture in the soil prevents the necessary uptake of nutrients, and plants suffer accordingly.

The causes of water deficiency are several, the most important of which are seasonal lowering of ground water levels and seasonal variations of precipitation. Water deficiency is sometimes aggravated by an excessively dry atmosphere that increases the rate of evaporation at the soil surface and from leaf surfaces. Almost all trees suffer from a lack of moisture for at least short periods each year.

The damage caused by low moisture varies according to the length of time plants are subjected to moisture stress, with the ages of plants, and with the season of the year. The reaction from moisture stress is almost immediate, and if the stress is great and is sustained for several days, most plants are visibly affected. Young plants are more easily damaged than older ones.

The consequence of water deficiency are collectively referred to as drought, of which there are several forms, i.e., summer drought, winter drying, and RED BELT. Whatever the form, drought is a prolonged water deficiency that can occur at any season of the year. It is a chronic condition in many forested areas, and is a limiting factor to the growth and survival of trees in some sites. When drought occurs during the growing season its symptoms are: (a) wilting of foliage and branch tips, (b) yellowing and reddening of foliage, (c) early leaf drop, (d) dying back of leaders and branches.

Winter drying occurs at a time of year when water lost through the leaves cannot be replaced by water conducted from the soil, even though water is present in the soil in the frozen state. It is brought about by drying conditions in the air, which if accompanied by strong winds results in large losses of water. The symptoms of winter drying are the same as those for summer drought, except that they are delayed until spring and early summer, at which time the succession of drought symptoms is very rapid.

Red belt is believed to be an unusual form of winter drying, wherein extreme drying occurs only at well-defined altitudinal limits (Fig. 7). It is a common phenomenon in mountainous areas of Alberta, where air layering is a regular feature of local climates.

J. Water excess

Water saturation of forest soils produces a variety of ill effects depending upon: (a) tree species involved, (b) ages of trees, (c) season of the year, (d) whether the water is stagnant or flowing. In general, young trees, actively growing trees, and trees growing in stagnant water are the most seriously affected. The ill effects that can result from an excess of water in the rooting zones of trees are: (a) ASPHYXIATION, (b) changes of acid balance in the soil (c) changes of nutrient balance in the soil, (d) deposition of foreigh material on the soil surface.

K. Wind

Persistent strong winds and sudden gusts of wind can cause extensive damage to forests. The most striking form of damage from wind is blowdown, where groups of trees are either uprooted or broken off above the ground. Naturally shallow-rooted trees, and trees that root close to the soil surface because of some physical barrier to deeper rooting (high water table, HARDPAN, bedrock etc.), are vulnerable to blowdown. Areas of up to several thousands of acres can be involved in this form of damage, and where salvage prospects are limited great losses of timber are experienced.

Wind also affects trees through its drying effect, producing the so-called "wind-forms" that are found in exposed locations. Extreme drying conditions are imposed on the windward side of trees, resulting in unequal growth.

L. Animals

Animals, and man, cause a variety of damage to trees that results in large losses of wood volume and value. Through logging and other woods activities man is responsible for scarring and otherwise damaging trees (Fig. 8). The resultant trunk and root scars are focal points for DECAY to develop. Animals in the course of feeding and other activities mutilate trees to a considerable extent (Figs. 9, 10, 11, 12). Rodents such as porcupines, squirrels, and rabbits cause extensive local damage, and in addition consume large quantities of seed.

Plate II.

Fig. 7. Red belt.

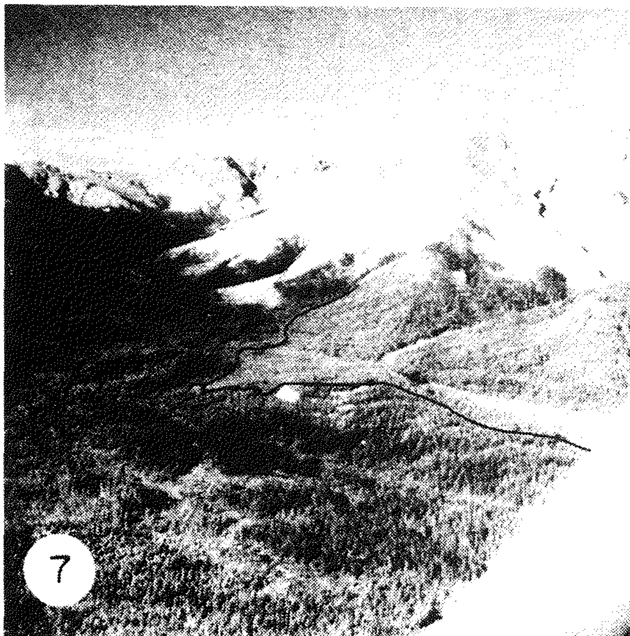
Fig. 8. Falling tree scars.

Fig. 9. Beaver damage in a young aspen stand.

Fig. 10. Bear claw marks on aspen.

Fig. 11. Sapsucker damage on lodgepole pine.

Fig. 12. Sapsucker damage on lodgepole pine.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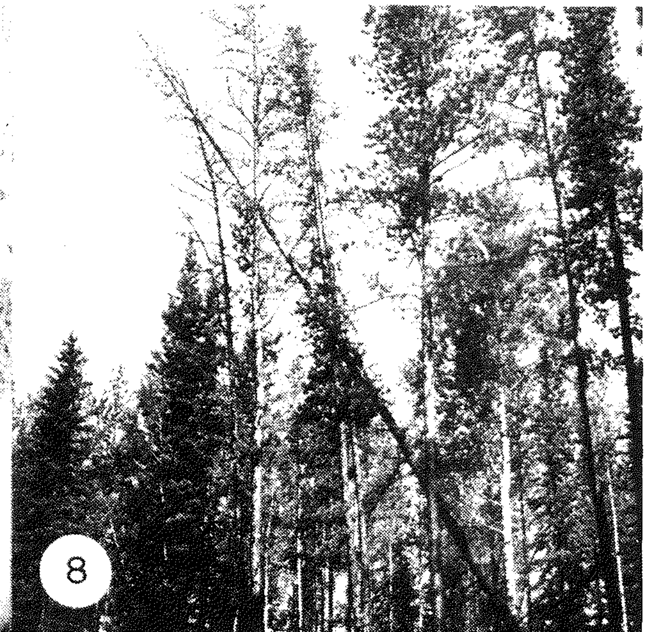
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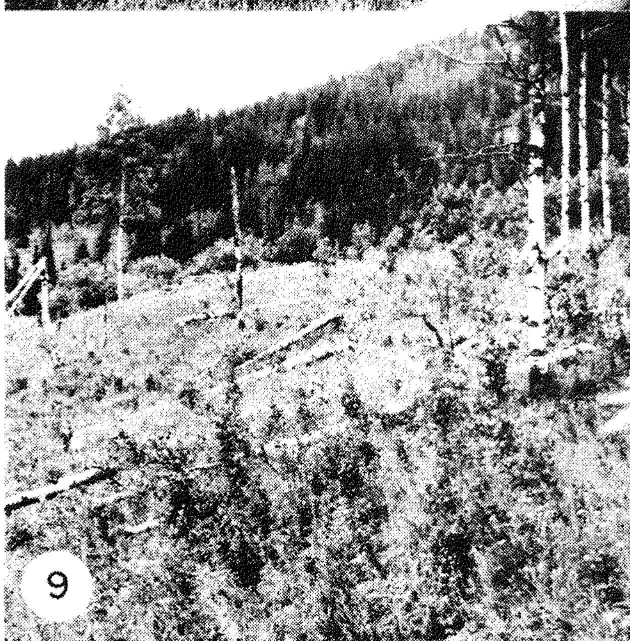
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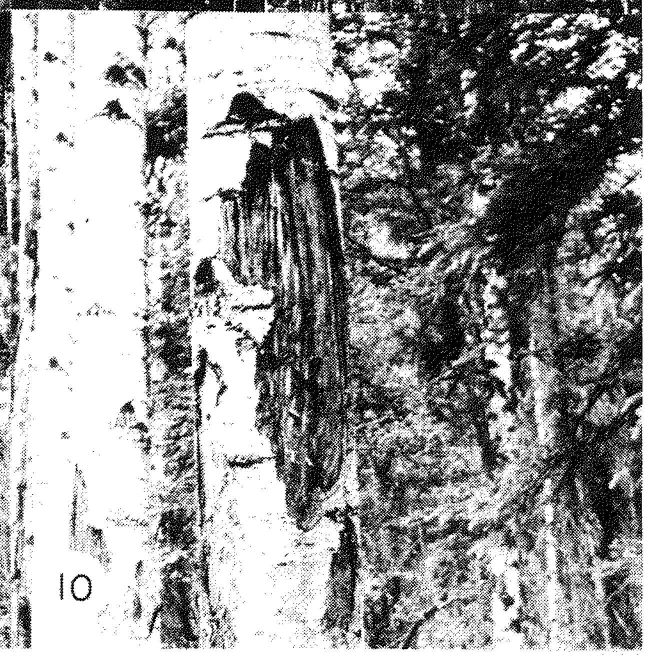
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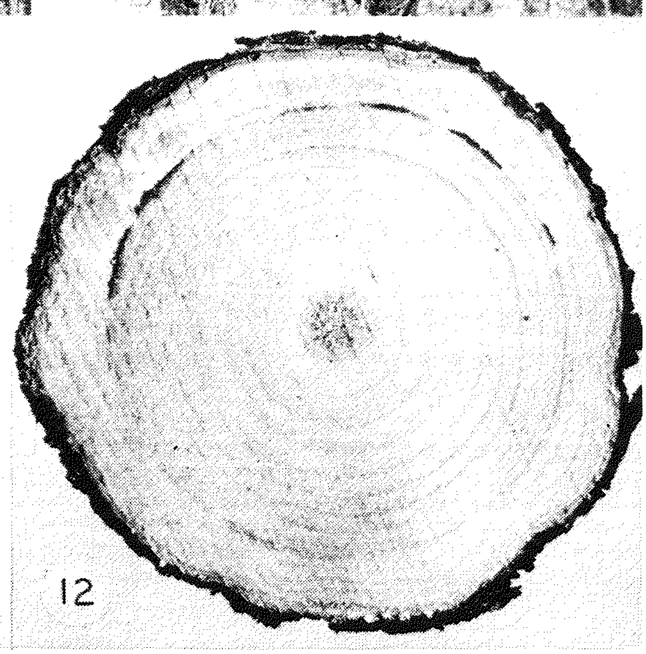
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2. Infectious Agents

Infectious diseases are contagious and each involves a causal relationship with a MICRO-ORGANISM, sometimes termed a PATHOGEN. Pathogens that colonize living plant tissues are called PARASITES, those that colonize only non-living tissues are called SAPROPHYTES.

The pathogen is introduced into its host in a form known as an INOCULUM. The act of introducing a pathogen is called INOCULATION. The point of entry for the pathogen is called an INFECTION COURT. The term INFECTION refers to the successful establishment of a pathogen within its HOST.

Infectious agents are grouped according to their similarities as VIRUSES, BACTERIA, FUNGI, or HIGHER PLANTS.

A. Viruses

The principal known characteristics of viruses are:

(a) they are ultramicroscopic, i.e., cannot be seen in the light microscope,

(b) they will not grow on standard artificial materials such as are used for fungi and bacteria,

(c) they will pass through bacterial filters,

(d) plant viruses have been isolated and crystalized into a form that resembles a non-living chemical, but which retains its infectivity,

(e) they can be inactivated by high temperatures.

The true nature of viruses is unknown, i.e., whether they are either living entities or purely chemical in nature. They attack micro-organisms such as bacteria and fungi as well as higher plants, although there are few known virus diseases of broad-leaved trees and none of coniferous trees.

B. Bacteria

These are minute, simple-structured plant bodies that occur either singly or in groups. Of the approximately 900 known species of bacteria, about 160 are plant pathogens. All of these are of the rod-shaped (Bacillus) type. The best known example of a bacterial tree disease in Alberta is fire blight of apple, pear, and mountain ash trees. This disease is caused by the bacterium Erwinia amylovora (Burrill) Winslow.

C. Fungi

Most known infectious diseases of trees are caused by fungi. These are plants that lack chlorophyll and hence must live either as saprophytes or parasites because they cannot use the energy of the sun to convert the raw materials of the soil and air into the complex compounds required for their growth and reproduction.

The vegetative structure of a fungus consists of few to many fine threads called HYPHAE (Fig. 13) that when grouped together form a MYCELIUM (hyphal mass). An individual thread (hypha) is a series of elongated tubular cells that are terminally connected. The individual cells are separated by cross walls called SEPTA, each septum having usually a small pore at the centre.

Occasionally hyphae are grouped to form specialized vegetative structures such as RHIZOMORPHS and SCLEROTIA. These structures are protective devices against unfavourable conditions. A rhizomorph, which is a parallel arrangement of closely packed hyphae encased in a dark-coloured rind of cells, enables a fungus to traverse areas of soil that are generally unsuited for fungus survival. A sclerotium is a rounded aggregation of hyphae, also covered by a dark rind, that enables a fungus to withstand periods of environmental stress (e.g., high or low temperature).

The material on and in which the mycelium of a fungus grows is called a SUBSTRATE. When this material is a living plant, or plant part, it is called a host; the individual hyphae, growing in a host, consume the cellular contents and ultimately destroy the host cells.

Fungi reproduce by means of SPORES, which differ from the seeds of higher plants mainly in that they do not contain an embryo plant. They are microscopic, produced in vast numbers, and vary greatly in shape. The wide variety of spore-forms is a useful basis for classifying fungi (Fig. 14).

Spores are produced either within or on special structures called SPOROPHORES (FRUIT BODIES). A type of enclosed sporophore that contains many spores is called a SPORANGIUM (Fig. 15), and another that contains a few spores (usually 8), is called an ASCUS (Fig. 16). Spores can also be borne at the tips of club-shaped structures, usually in fours, called BASIDIA (Fig. 17). At other times they are borne in indefinite numbers on specialized hyphae called CONIDIOPHORES (Fig. 18). An ascus produces ASCOSPORES, a basidium produces BASIDIOSPORES, and a conidiophore produces CONIDIA. Sporophores are sometimes grouped into structures called fruit bodies (Figs. 19-22), e.g., the cups of *Atropellis piniphila*, the conks of *Fomes igniarius*, the mushrooms of *Armillaria mellea*, and the STROMA of *Hypoxylon pruinatum*. On the basis of the manner in which spores are produced fungi can be classified as follows:

Phycomycetes - spores born in sporangia
Ascomycetes - spores born in asci
Basidiomycetes - spores born on basidia
Deuteromycetes -
(or Fungi Imperfecti) spores born on conidiophores.

Fungi reproduce typically both SEXUALLY and ASEXUALLY. A simplified and conventionalized life cycle is given in Fig. 23. This is a very general plan and there is an almost infinite number of variations and changes, deletions and additions, that can be made to such a plan to make it true for any given fungus.

D. Higher plants

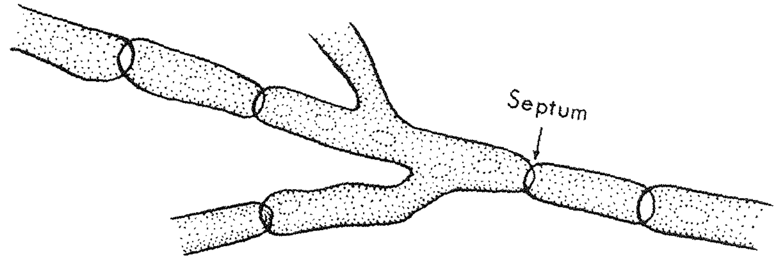
Although the number of kinds of parasitic higher plants is few, some of them are very important in forest pathology. One of the more serious forest diseases in the Alberta region is caused by dwarf mistletoe. This is a true seed plant and has a certain amount of chlorophyll, and as a result is not totally dependent on the host for food. It does take enough from the host, however, to cause growth reduction and eventual death of part or all of the tree.

Plate III

Fig. 13. Fungus hypha with septa

Fig. 14. Various types of spores

Fig. 15. Sporangium and spores



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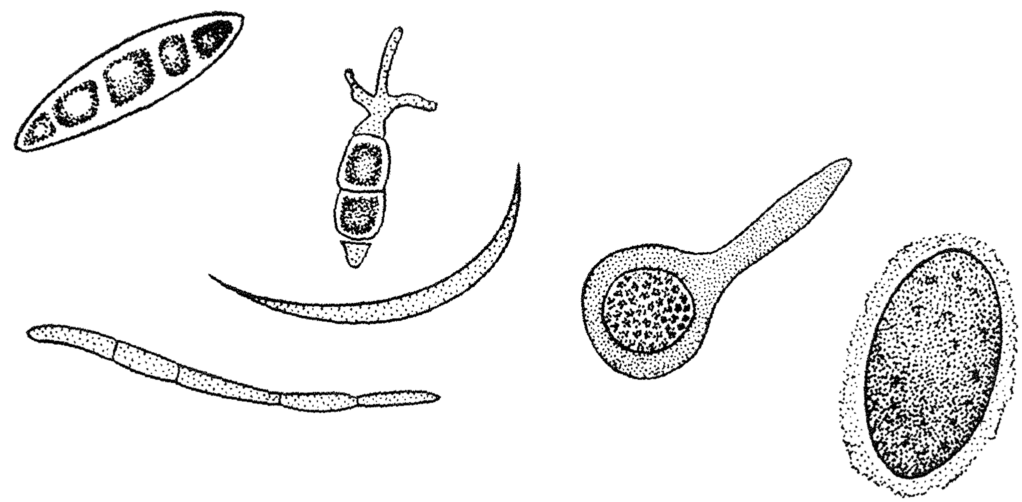

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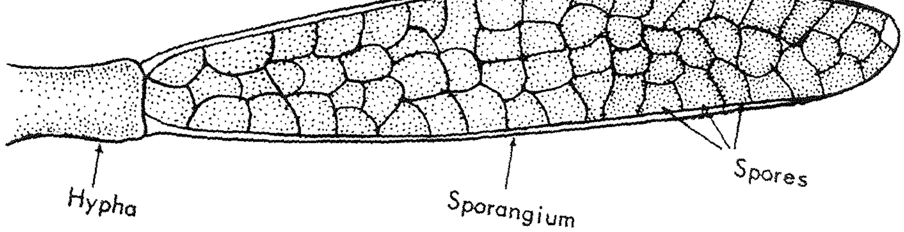

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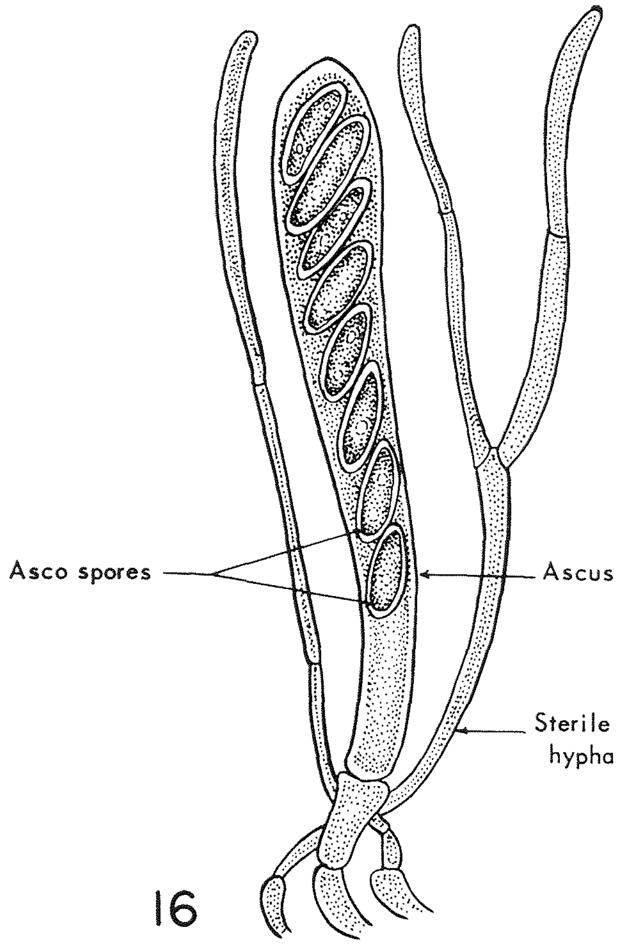
Plate IV

Fig. 16. Ascus with ascospores.

Fig. 17. Basidium with basidiospores.

Fig. 18. Various types of conidiophores with conidia.


Asco spores
Ascus
Sterile
hypha

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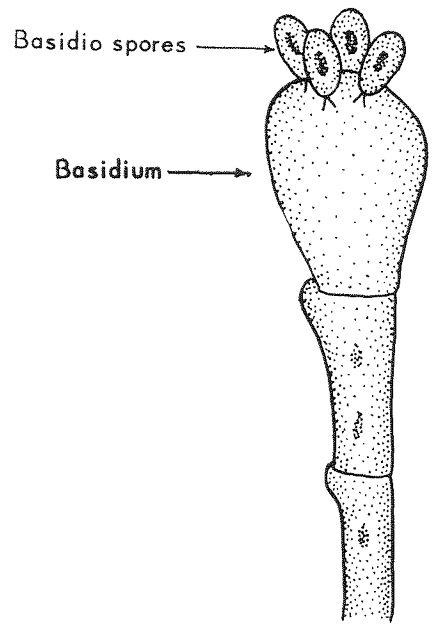
Basidio spores
Basidium

17

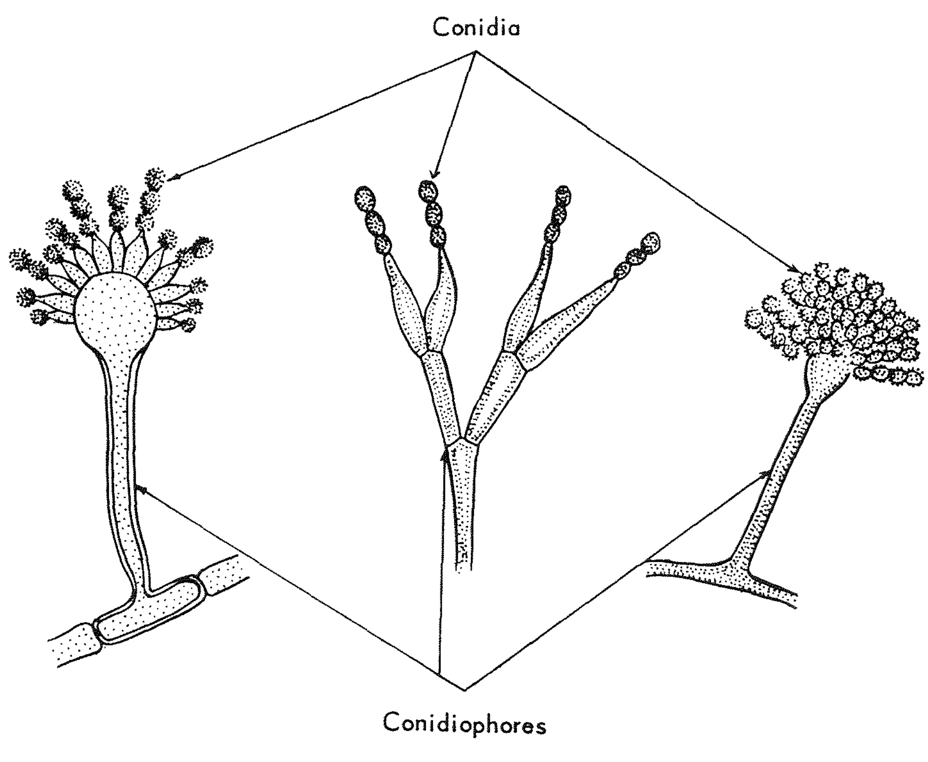
Conidia
Conidiophores

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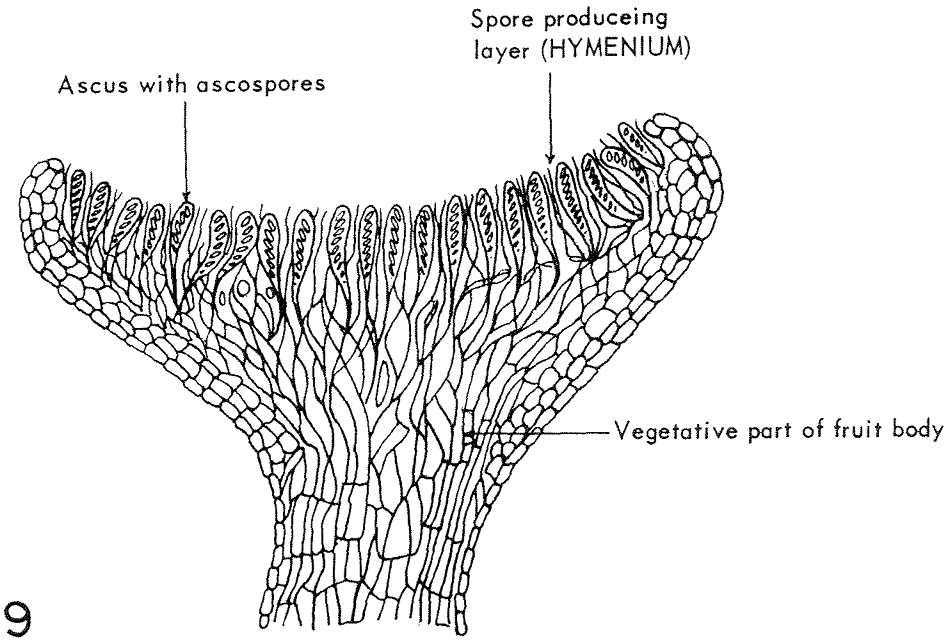
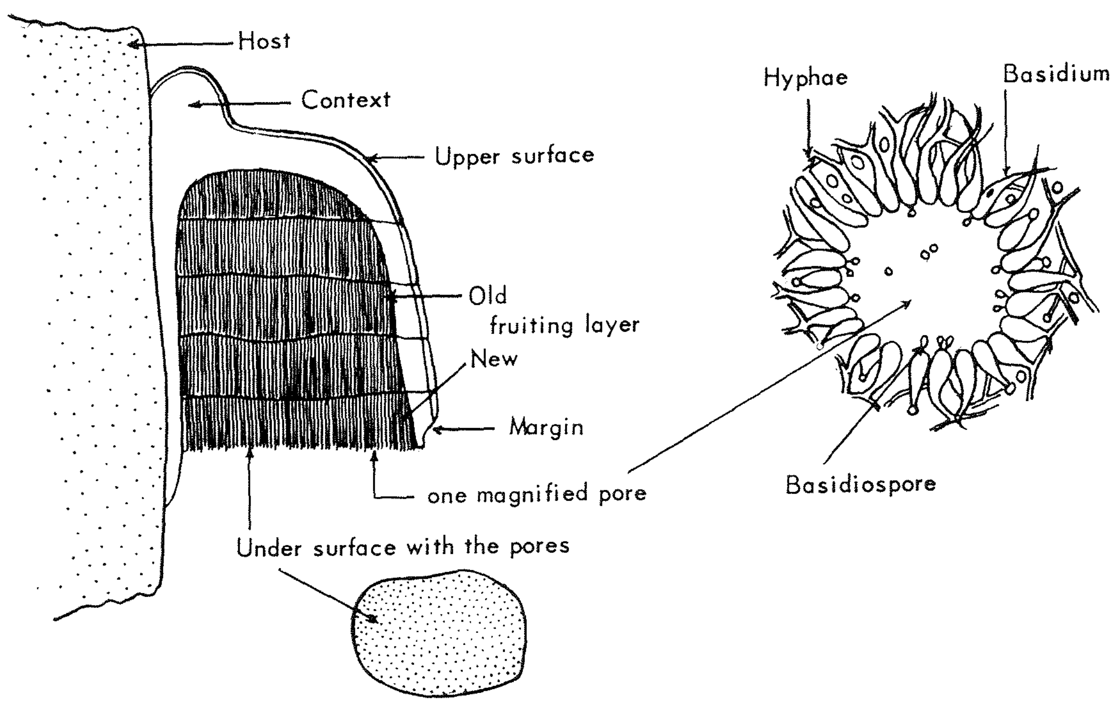
Plate V

Fig. 19. Cup-shaped fruit body (APOTHECIUM) with asci and ascospores.

Fig. 20. Conk-type fruit body with an enlarged pore to show basidia and basidiospores.


Spore produceing layer (HYMENIUM)
Ascus with ascospores
Vegetative part of fruit body

19

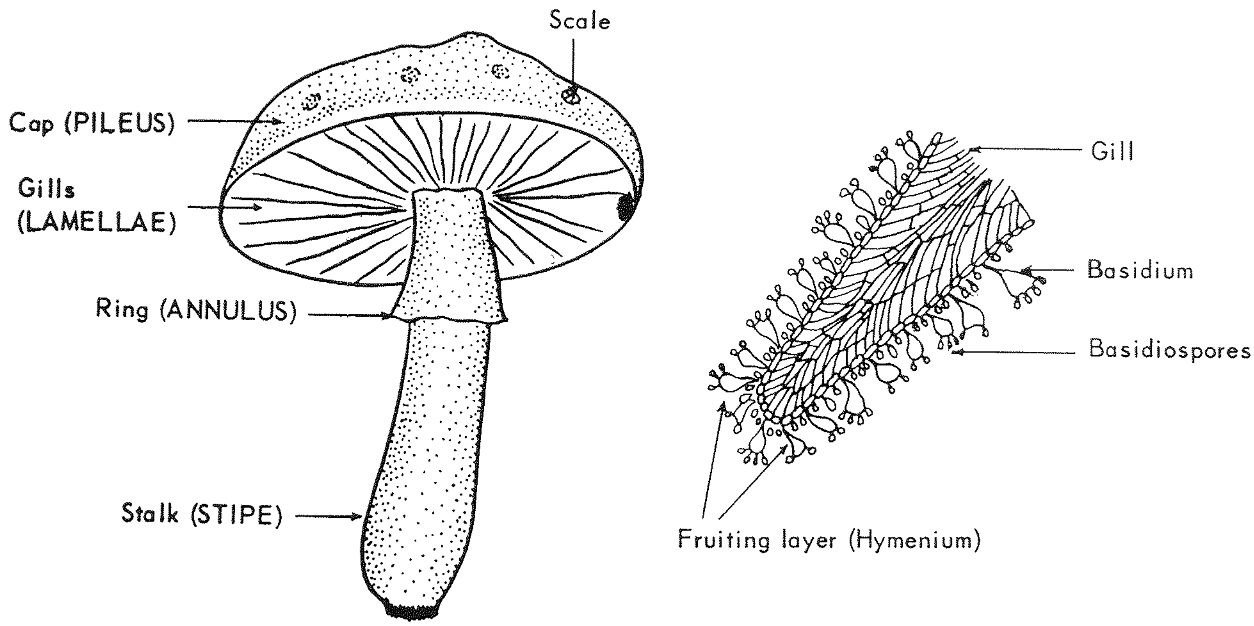

Host
Context
Upper surface
Old fruiting layer
New
Margin
one magnified pore
Under surface with the pores
Hyphae
Basidium
Basidiospore

20

Plate VI

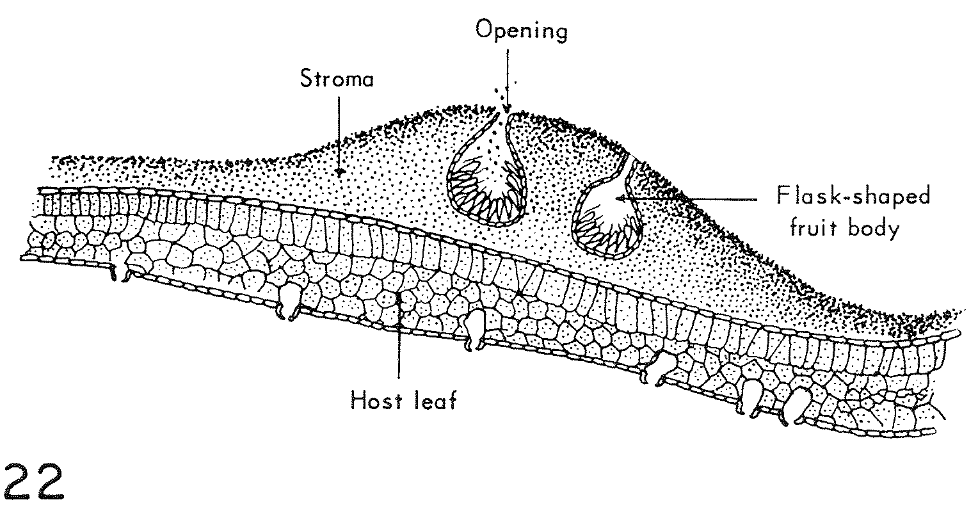
Fig. 21. Mushroom-type fruit body with an enlarged gill to show basidia and basidiospores.

Fig. 22. Flask shaped fruit bodies (PERITHECIUM) in a stroma with asci and ascospores.



Scale
Cap (PILEUS)
Gills
(LAMELLAE)
Ring (ANNULUS)
Stalk (STIPE)
Gill
Basidium
Basidiospores
Fruiting layer (Hymenium)

21

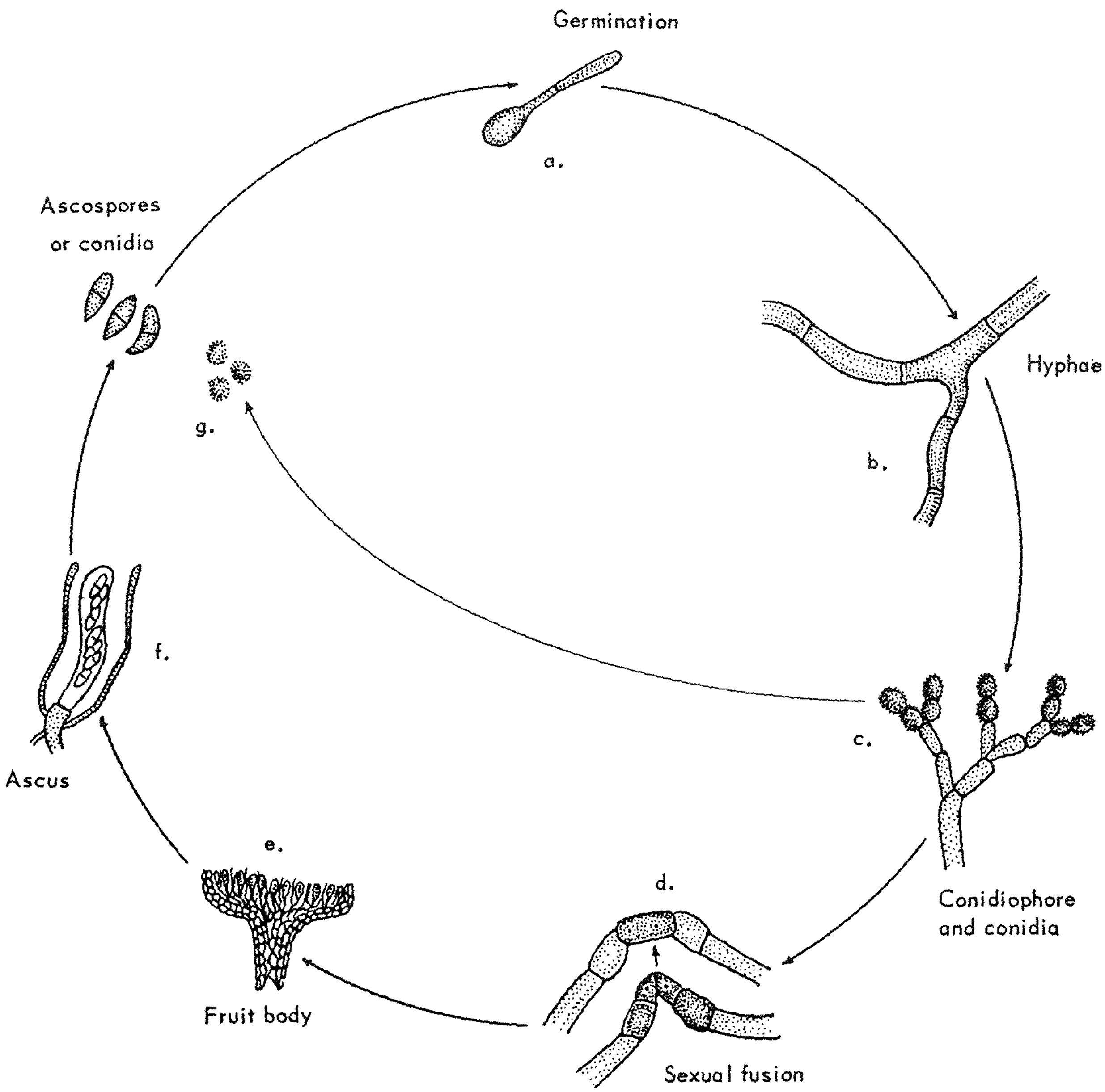


Opening
Stroma
Flask-shaped
fruit body
Host leaf

22

Plate VII

Fig. 23. Simplified life cycle of an Ascomycete.


Germination
a.
Ascospores
or conidia
g.
Hyphae
b.
f.
c.
Ascus
e.
d.
Conidiophore
and conidia
Fruit body
Sexual fusion

23

IV. DEVELOPMENT OF INFECTIOUS DISEASES

Infectious diseases are incited by organisms called pathogens, usually micro-organisms. The act of living together of a pathogen and its host is called PARASITISM, which is a one-sided relationship that is never beneficial to the host and is sometimes harmful. There are various degrees of parasitism as follows:

1. OBLIGATE PARASITISM - the pathogen obtains all of its food from and completes its life cycle on living material.

2. FACULTATIVE SAPROPHYTISM - the pathogen normally exists on living material but can exist temporarily on dead material.

3. FACULTATIVE PARASITISM - the pathogen normally exists on dead material but can exist temporarily on living material.

4. OBLIGATE SAPROPHYTISM - the pathogen can exist only on dead material.

There are many examples of two organisms living together without any harmful effects to either. Sometimes the relationship is mutually beneficial and referred to as SYMBIOSIS, each participant being known as a SYMBIONT. Lichens are composite plants that embody a fungus and an ALGA, wherein the alga manufactures carbohydrates for itself and for the fungus by photosynthesis. The fungus supplies mineral and organic nutrients from the substrate (bark, wood, duff) that are essential to its own development and that of the alga.

Although the development of a disease is a continuous process, various developmental stages can normally be recognized.

1. Inoculation

While not truly a developmental stage inoculation is a necessary prelude to disease development. It is the physical act of transporting a pathogen to a suitable substrate in a form capable of causing disease.

2. Penetration

This is the initial invasion of the substrate by the pathogen. It can follow one of several courses, but invariably involves first an actual penetration of plant cells.

3. Infection

This is the successful establishment of the pathogen on or within its substrate. Infection is not always a result of penetration, since some pathogens do not always proceed beyond the penetration stage. The interval between infection and the appearance of symptoms in called the INCUBATION PERIOD. Some tree diseases have an incubation period of many years duration, e.g., heart rots.

Hosts vary in their reaction to invasion by a pathogen. A host that supports a pathogen readily is termed SUSCEPTIBLE. One that suppresses the development of the same pathogen is said to be RESISTANT. Complete resistance, i.e., where disease never results is termed IMMUNITY.

Some time following infection, symptoms, i.e., host reactions, may develop. While symptoms can change as the disease progresses the symptom pattern tends to be constant for each disease, and sometimes for each host. The symptom pattern therefore is the chief diagnostic feature of a disease. Symptoms are usually classified as follows:

(a) NECROTIC SYMPTOMS - are those produced by the death of host tissue, e.g., rot, canker etc.

(b) ATROPHIC SYMPTOMS - are those resulting from the under development of affected tissues, e.g., dwarf needles.

(c) HYPERTROPHIC SYMPTOMS - are those resulting from excessive development of host tissues, e.g., witches' brooms, swellings.

4. Reproduction and spread

Reproduction is usually necessary for the spread of a disease.

It may take place either inside or on the surface of a host. Some pathogens overwinter in the form of structures specialized for the purpose and others in the mycelial stage (e.g., Sclerotium). Whatever the resting form may be, it becomes the source of PRIMARY INOCULUM for the next season. In fungi the primary inoculum is usually spores. These infect susceptible hosts and during the season another crop of spores may arise from the diseased host. This additional crop of spores is termed SECONDARY INOCULUM. With many diseases long distance spread of the associated pathogens is accomplished by primary inoculum, and intensification of the disease locally is accomplished by secondary inoculum.

V. KINDS OF INFECTIOUS DISEASES

Diseases may be classified in several ways; according to the symptoms they produce (SPOTS, WILTS, BLIGHTS, DECAYS, CANKERS, etc.); according to the kind of agent involved (non-infectious, infectious, parasitic, saprophytic, etc.); according to the part of the host plant affected (foliage, bark, wood, root, stem). The classification of certain diseases by the latter method is difficult because the penetration occurs in one part of the host and the development in another, e.g., white pine blister rust. In spite of these difficulties this method is probably the most meaningful way to classify infectious tree diseases.

1. Diseases Affecting Foliage.

In assessing the harmful effects of foliage diseases, it is necessary to recall that the leaf is the main organ for the manufacture of plant food. Serious interruption of this plant function is certain to result from diseases that affect foliage directly, provided much of the total complement of foliage is involved.

The manufacturing process for plant food is called photosynthesis, a process involving the combination of hydrogen (delivered to the leaves as a component of water by the roots and stems) with carbon dioxide (absorbed from the atmosphere). The energy needed for this reaction is the radiant energy of the sun. The product of photosynthesis is sugar, which is transportable to the growing points in plants. The key structure in the photosynthetic reaction is the CHLOROPLAST, which is in part a specialized aggregation of green colouring matter called chlorophyll. The radiant energy that enables the photosynthetic process to occur is absorbed from sunlight by the chlorophyll. Hence, any plant disease that either reduces the amount of chlorophyll in leaves or destroys leaves completely, will slow or stop the photosynthetic process. This will result in subnormal supplies of the plant sugar needed for plant growth.

Pathogens enter leaves either through natural openings (STOMATA), wounds of various kinds (insect punctures, etc.), or directly through the leaf surface. Direct penetration is either wholly or mainly by mechanical means through growth of the pathogen. Following penetration the pathogen spreads through and among the host cells. Most leaf pathogens produce spores after a short period of vegetative development.

A. Leaf and needle rusts

Rust diseases are caused by fungi that are obligate parasites. This highly specialized group of fungi is differentiated by the characteristic spores they produce. As many as five kinds of spores are produced by some rust fungi. When all of the spore forms that characterize a species of rust are produced on one host plant the fungus is said to be short cycled. If two species of host plants are involved the fungus is said to be long cycled. The developmental stages of rust fungi that have the full complement of spore forms are:

Stage			Fruit body	Spore form
PYCNIAL	=	0	PYCNIUM	PYCNIOSPORE
AECIAL	=	I	AECIUM	AECIOSPORE
UREDIAL	=	II	UREDIUM	UREDOSPORE
TELIAL	=	III	TELIUM	TELIOSPORE
BASIDIAL	=	IV	PROMYCELIUM	BASIDIOSPORE

Long-cycle tree rusts usually have their pycnial and aecial stages on coniferous hosts and their remaining stages on broad-leaved hosts. Most foliage rusts are long-cycle rusts. Pycnia appear in the spring and early summer as light- to dark-coloured spots. Pycniospores are exuded in a sweet liquid from the pycnia (Fig. 24). The fusion of uni-nucleate pycniospores results in the formation of bi-nucleate hyphae, which is the beginning of the aecial stage.

Aecia are formed usually one year later in the sites of former pycnia. They are either white to yellow or orange blisters that contain masses of aeciospores. The spores are air-borne to infect (usually) a different host (Fig. 25).

Uredia develop as reddish-orange pustules on the secondary host. They produce one to several crops of uredospores that serve to intensify the rust infection locally (Fig. 26).

Telia develop in late summer in former uredial locations as columnar masses of teliospores (Fig. 27). The teliospores either germinate in the same year or overwinter as such and germinate the following spring. The germinated teliospore produces a promycelium, which in turn bears four uni-nucleate basidiospores (Fig. 28). These spores are air-borne to infect the foliage of the primary host.

The life cycle of most needle rusts is one year from aecial stage to aecial stage. They are most important on young trees in the seedling and sapling stages. The effect is to kill individual needles. In severe cases all the needles of a growing season may be involved, but since rusts vary in intensity from year to year trees are seldom completely defoliated and killed. The usual effect is a reduction in the growth of heavily infected trees.

B. Needle casts

Needle cast diseases are caused by several different but closely related fungi, all of which are ascomycetes. They are easily recognized by the presence of dark (usually black) fruit bodies. The most conspicuous symptom of needle casts is a red-brown discolouration of the affected foliage. This may be differentiated from the rather similar symptoms of non-infectious diseases, such as drought, since in needle casts only parts of needles may be affected and healthy needles are often intermingled with diseased ones. A further symptom is the premature casting of needles.

Plate VIII

Fig. 24. Pycnia and pycnial exudate on the leaf of Saskatoon.

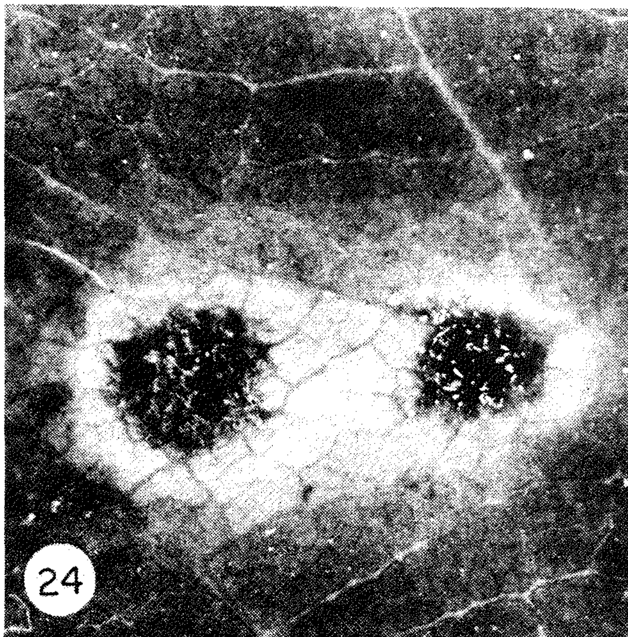
Fig. 25. Aecia on the bark of lodgepole pine.

Fig. 26. Uredia on the sepals of a winter green flower.

Fig. 27. Telia on a juniper branch.

Fig. 28. Drawing of a telial column with germinated teliospores, producing promycelium and basidiospores. (Reproduced from Journ. Agr. 15, No. 12).

Fig. 29. Tar spot on willow leaf.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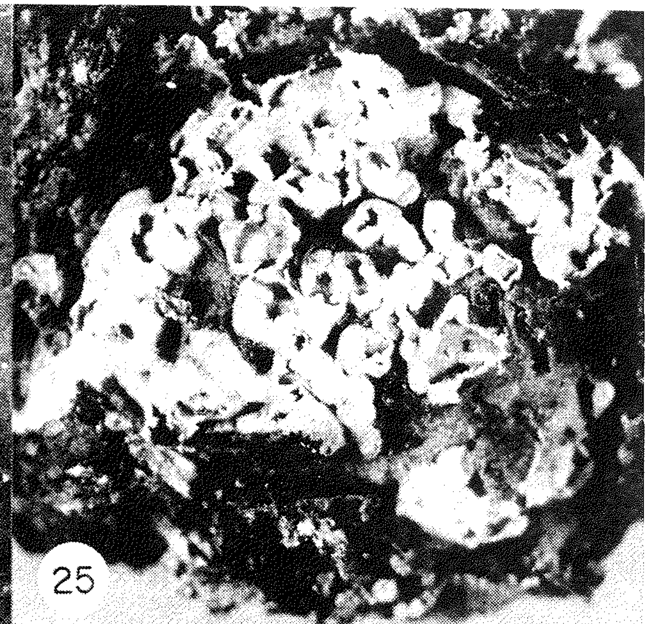
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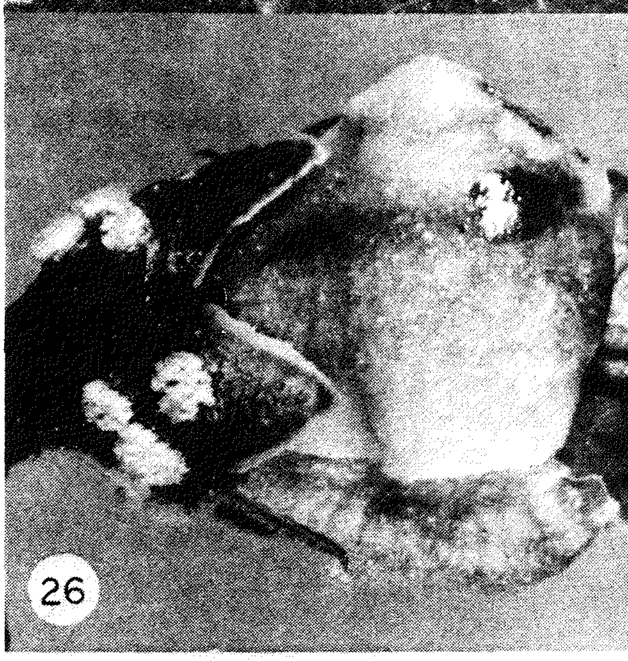
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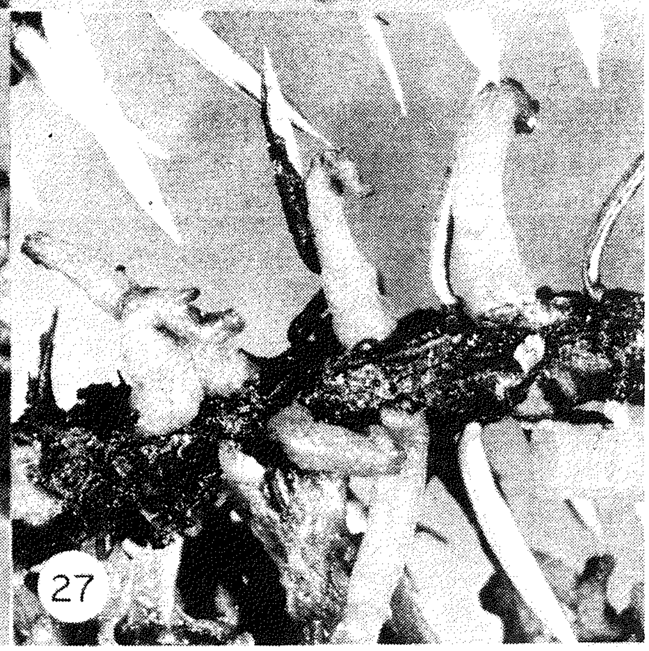
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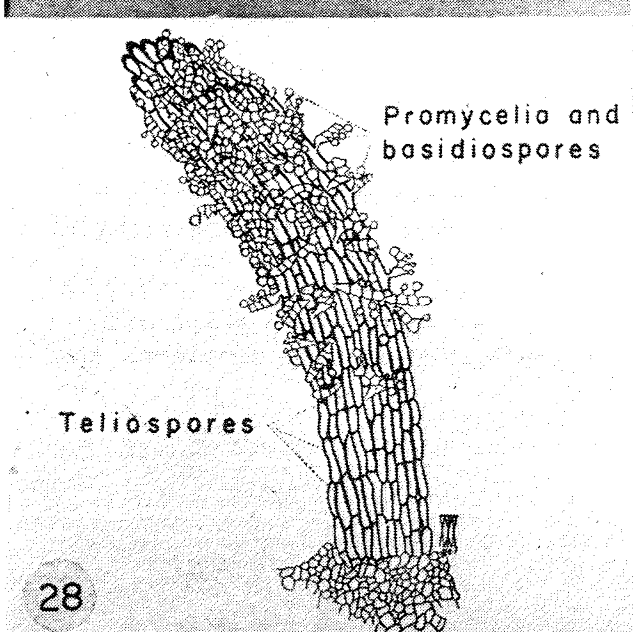
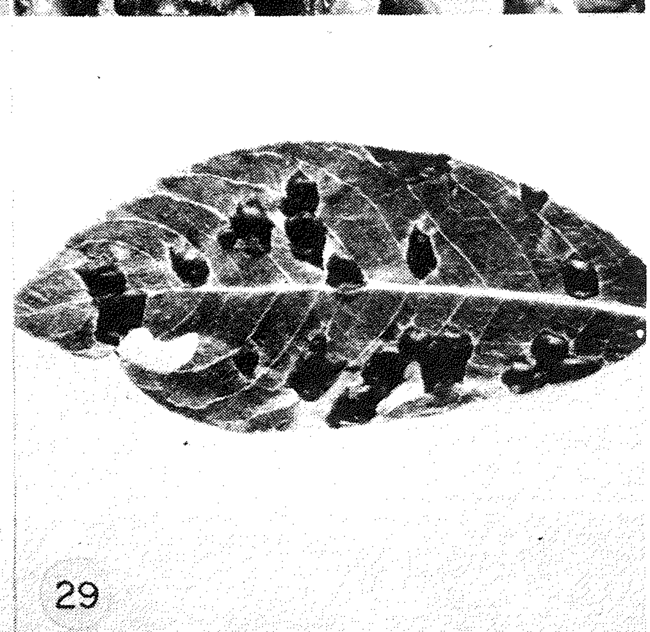

Promycelia and
basidiospores
Teliospores
28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The fruit bodies are embedded in the host tissue. At maturity and in wet weather they break open to expose a layer of asci, which in turn liberate wind-borne ascospores.

The pathological effects of needle casts vary with the pathogens involved, from very minor to very damaging. This type of disease is important mainly when young needles and young trees are affected, although defoliation is seldom severe enough to kill trees beyond the seedling stage.

C. Leaf spots

This class of disease is caused by a great number of different ascomycetes and deuteromycetes. It is characterized by sharply delineated necrotic areas on otherwise healthy foliage. The necrotic areas are either brown or black in colour, and vary greatly as to size. Sometimes the affected portions of leaves fall away to produce a "shot-hole" appearance. Large, conspicuous black leaf spots are called TAR SPOTS and INK SPOTS (Fig. 29). They are seldom important, unless the damage is repeated for several successive years.

2. Diseases Affecting Fruit.

Any of the diseases destroying the fruit of a tree will decrease the seed crop and reduce regeneration. The spruce cone rust disease is the only known economically important disease of forest tree fruits in Alberta. The aecia are produced on the cone scale. The whole cone is affected by the rust and all the seeds are destroyed.

3. Diseases Affecting Bark.

Fundamental to an understanding of bark diseases is a knowledge of bark structure and function. Bark is a vague term, but is here regarded as all tissues external to the wood; it therefore includes the cambium. Each tree species has a characteristic type of bark, some smooth, and some scaly, etc. The bark characteristics also change as the tree grows older. The bark near the top of a tree is much thinner, and usually smoother, less fissured than bark near the base of a tree.

Bark consists of three main tissues (Fig. 30), the precise structure of which varies from species to species. Considerable differences exist between coniferous and hardwood tree species in this regard, but all species possess a cambium, PHLOEM and PERIDERM.

The cambium is a thin unbroken cylinder of tissue surrounding the wood. It is composed largely of long, thin-walled cells which actively divide as the tree grows. The cambium is thus responsible for laying down new tissues and increasing the girth of the stem throughout the life of the tree.

The phloem is a complex tissue present in the form of a cylinder lying outside the cambium. Its main function is to transport food materials from the leaves to other parts of the plant. The phloem of many species is believed to function for one year only, partly as a result of compression caused by the formation of new tissues by the cambium. Damage to the phloem will interrupt the transportation of food, and if the damage girdles the stem then the tissues below the girdle are eventually starved and die.

A second cambial layer called the PHELLOGEN lies outside the phloem, and through cell division gives rise to corky tissue which is usually referred to as outer bark.

The bark varies considerably in different tree species, but is always composed of dead, closely packed cells that are impregnated with a substance called SUBERIN which gives waterproofing qualities to the bark.

Superficial damage to the outer bark usually results in the development of a further layer which takes over the function of the phellogen and continues bark formation. Damage extending to the cambium results in the formation of a tissue called callus. The callus tissue slowly grows over the exposed area, the period elapsing being dependent on the extent of the damage. Callus tissue may eventually form a phellogen within itself and restore the outer bark over the exposed tissue. In many coniferous species resin ducts are present within the wood and bark and release resin over exposed tissues. This also has a protective function.

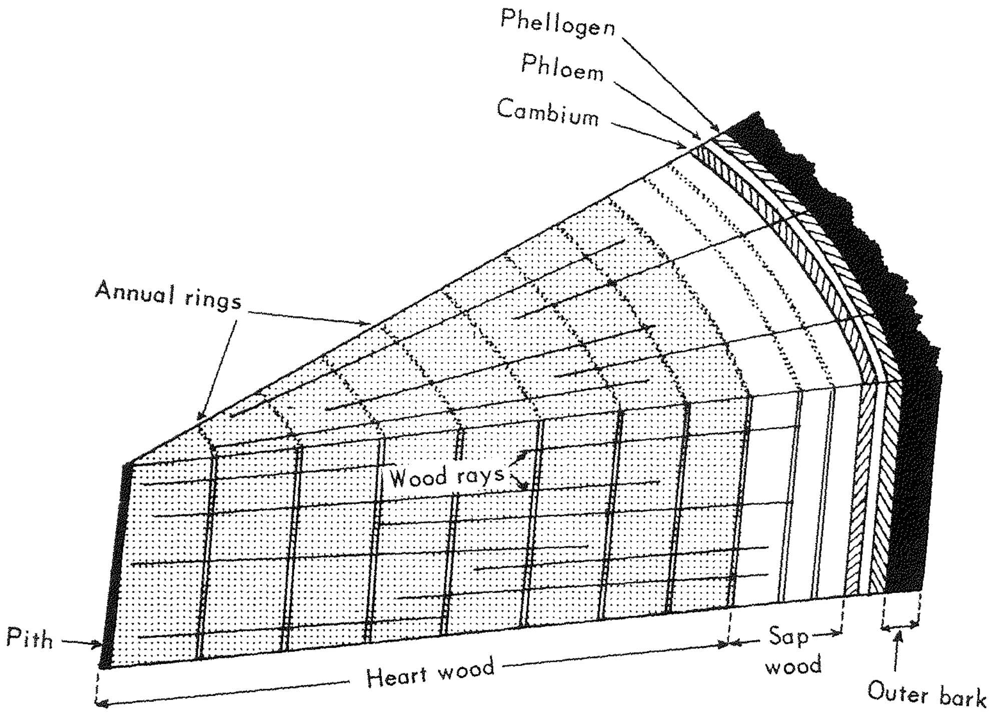
Distributed over the surface of the bark are LENTICELS, which aid gaseous exchange between the living bark and the atmosphere. They are slit-like and are composed of loosely arranged cells with large air spaces between them.

The bark provides an effective barrier against the entry of most micro-organisms. However, damage to the bark may permit micro-organisms to enter before the host defence reaction can repair the damage. Other points of entry are lenticels, dead branches, and needle scars.

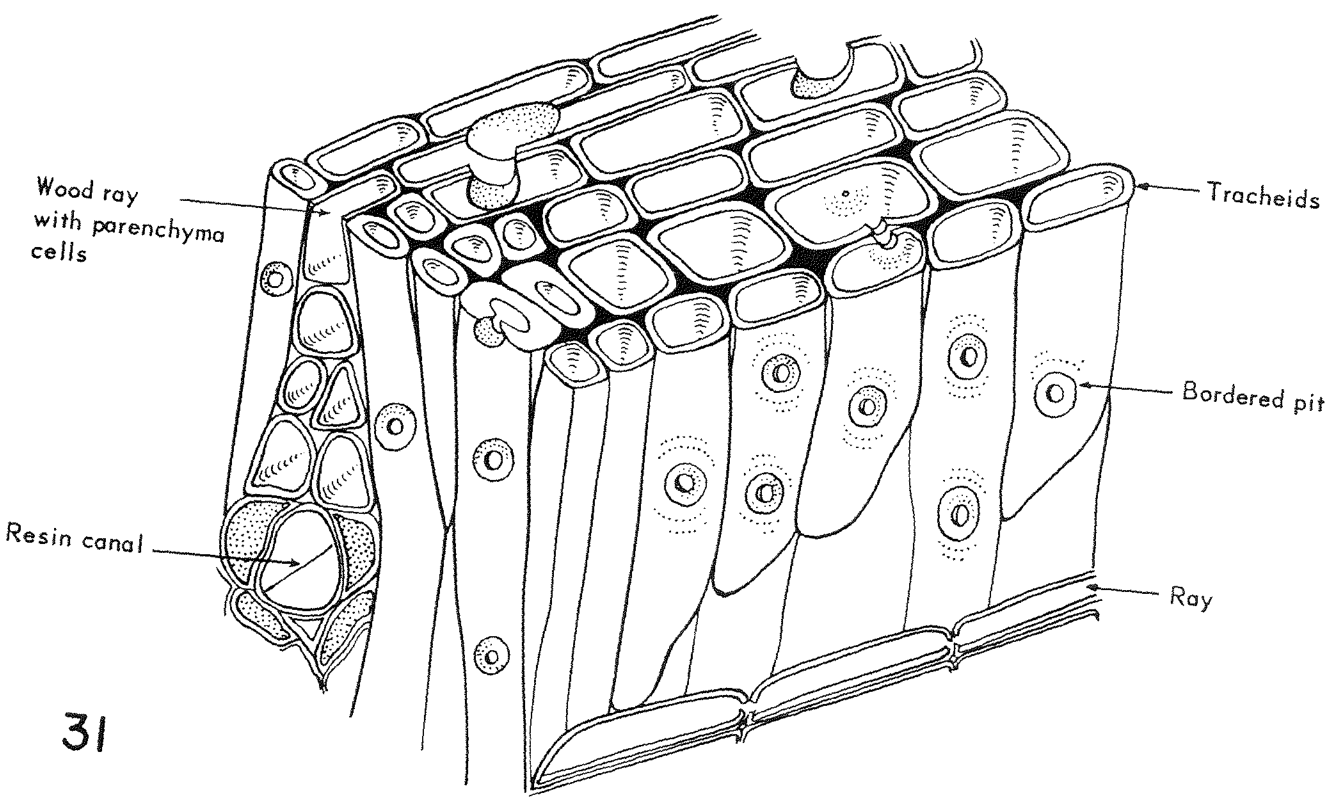
Plate IX

Fig. 30. Section of tree stem showing wood and bark tissues.

Fig. 31. Structure of wood.


Phellogen
Phloem
Cambium
Annual rings
Wood rays
Pith
Heart wood
Sap wood
Outer bark

30


Wood ray with parenchyma cells
Tracheids
Bordered pit
Resin canal
Ray

31

A. Canker diseases

Canker is a term which covers damage and diseases causing death of a localized region of the bark. Cankers either slow down or stop the normal functioning of the bark tissues affected. In large trees the damage is often localized and has little effect on tree growth, but seedlings are often killed. Cankers may also be important in permitting entry of stem decaying organisms.

Cankers are either annual or perennial. In the former the injury occurs for one season only, the injured tissues then being sloughed off or overgrown by callus. Perennial cankers continue from year to year. Cambial activity usually continues on the side of the stem unaffected by the canker organism. Continued growth of the host for many years may result in a mis-shapen stem, bulging on the side opposite to the canker and flattened or ridged on the affected side.

4. Diseases Affecting Wood.

A knowledge of wood structure and functioning is essential to an understanding of diseases affecting this kind of plant tissue. The woody tissues of plants are collectively called XYLEM, which is formed on the inward side of the cambial layer (Fig. 30-31).

New xylem cells are alike at first, but differentiate later as to their form and function. TRACHEIDS in coniferous wood and TRACHAE in the wood of broadleaved trees are chiefly water conducting cells and have large tubelike cavities. WOOD FIBERS are greatly elongated cells with small cavities, thick, hardened walls and function in support. Xylem PARENCHYMA is tissue composed of living cells that function in food storage.

Only the last few years' growth of xylem functions in conduction and food storage, and is collectively called SAPWOOD. The cell walls of the older wood, which is called HEARTWOOD, sometimes becomes stained with oils, resins, and pigments, and the cavities clogged with gummy deposits. Heartwood therefore does not function a great deal in conduction but mainly in support. WOOD RAYS are a prominent feature of the xylem. They are thin ribbons of tissue extending radially from the center toward the periphery of the stem. They consist mainly of living parenchyma cells and function in the storage and radial transportation of food material.

One of the most conspicuous features of wood is the concentric layering of annual rings, each representing a year's addition to the xylem.

5. Diseases Affecting More Than One Kind of Tissue

Some of the infectious disease organisms use certain tissues of the host for part of their development. They then may grow through these tissues towards entirely different parts of the host, where they give rise to the characteristic disease. Development at the point of infection is only a transitional stage with these pathogens. The characteristic symptoms of the disease often occur in tissues remote from the point of infection. Examples of this are parasites that are capable of attacking tender organs, e.g., unfolding buds, young leaves, twigs, and floral parts, and subsequently invade other parts of the plant. Flowers of apple and pear trees are the commonest infection points for fire blight. Infection spreads from the blighted bloom to the fruit and then to the living tissue of the twigs.

Further examples are witches' brooms caused by rust fungi which are initiated through the infection of new shoots. The mycelium over-winters in the infected branch, and dwarf shoots are produced the following spring forming the broom. Pycnia and aecia develop on the needles of these dwarf shoots, causing defoliation of the broom. Dwarf mistletoes develop their "root" system in the bark, sometimes growing into the MERISTEMATIC tissue of the buds.

VI. IMPORTANT INFECTIOUS DISEASES OF THE PRAIRIE REGION

1. Diseases Affecting Foliage

A. Name: Pine needle cast

Organism: This disease is caused by any one of several closely related fungi, as follows:

Hypodermella concolor (Dearn.) Darker
H. montivaga (Petr.) Dearn.
H. montana Darker
Elytroderma deformans Darker

These can be separated with the following key:

a(1) - Needles showing prominent brown or black ridges or oval pustules.

b(1) - Needles showing black oval pustules, these located on straw-coloured segments of the needle which are separated from the green portion by a dark orange-brown band.

Hypodermella montana (Fig. 32)

b(2) - Needles not as above.

c(1) - Needles bearing elongated, dark ridges with prominent, lighter coloured slit running the length of the ridge.

Hypodermella montivaga (Fig. 33)

c(2) - Needles showing black oval to irregularly shaped pustules. No prominent slit.

Elytroderma deformans (Fig. 34)

a(2) - Needles showing light straw to red-brown discolouration, no convex pustules or ridges.

d(1) - Discoloured part of needle hollow.

Needle Miner (an insect) Fig. 35)

d(2) - Discoloured part of needle not hollow.

e(1) - Discoloured part of needle straw-coloured, showing small, round to broadly oval depressions similar in colour to the remainder of the discoloured portion.

Hypodermella concolour (Fig. 36)

e(2) - Discoloured part of needle showing no such depressions. Colour tends to reddish-brown rather than straw colour.

Climatic Damage or Other

Hosts: All of these fungi attack the foliage of lodgepole pine (*Pinus contorta* var. *latifolia*). *Elytroderma deformans* also attacks the foliage of jack pine (*Pinus banksiana* Lamb.).

Plate X

Fig. 32. *Hypodermella montana*. Black fruit bodies on straw-coloured needle segment which is bordered by a dark orange-brown band.

Fig. 33. *Hypodermella montivaga*. Fruit bodies with central light-coloured slits.

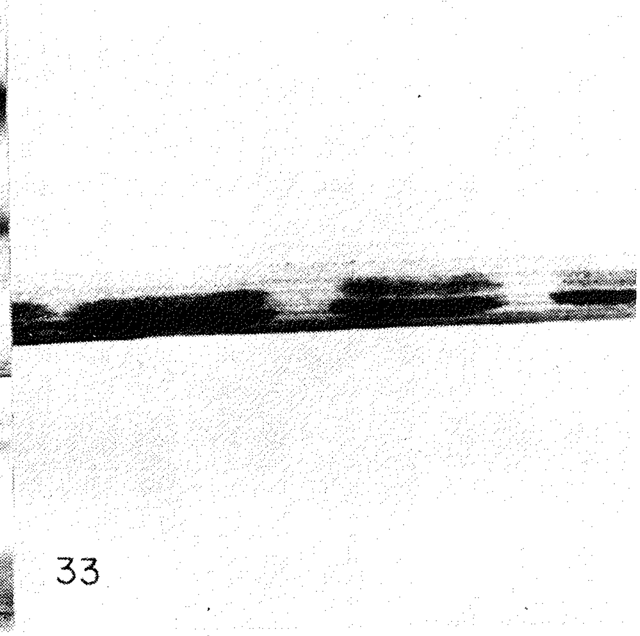
Fig. 34. *Elytroderma deformans*. Fruit bodies showing the lack of prominent light-coloured central slits.

Fig. 35. Needle miner damage. Discoloured part of needle is hollow.

Fig. 36. *Hypodermella concolor*. Fruit bodies and shallow depressions that are concolourous with the infected parts of needles.

Fig. 37. *Rhabdocline pseudotsugae*. Affected needles are mottled in appearance.

32



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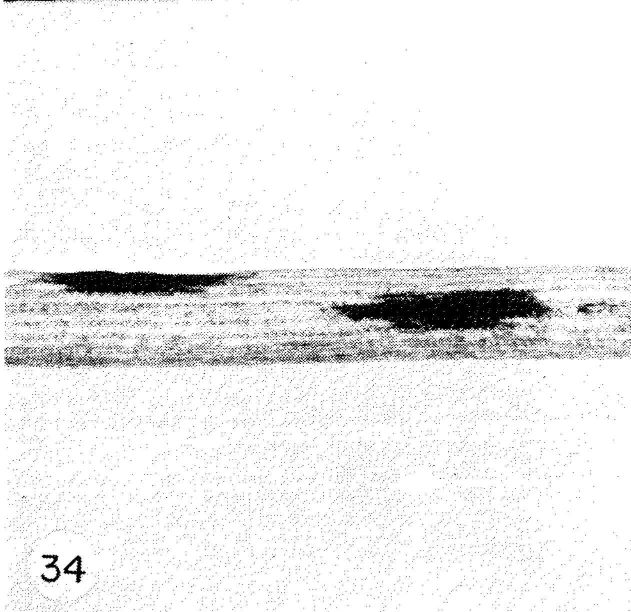

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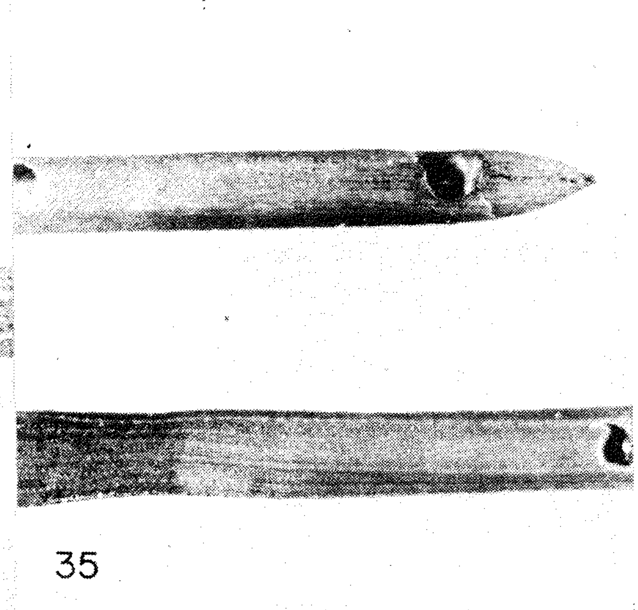

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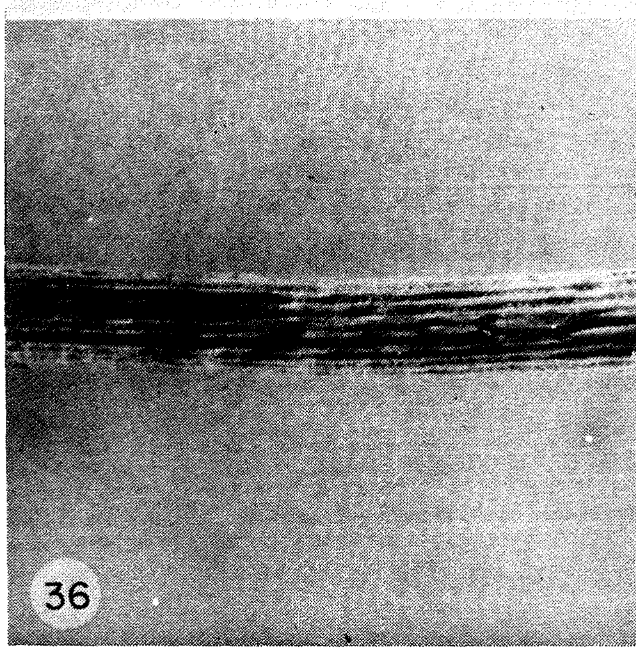

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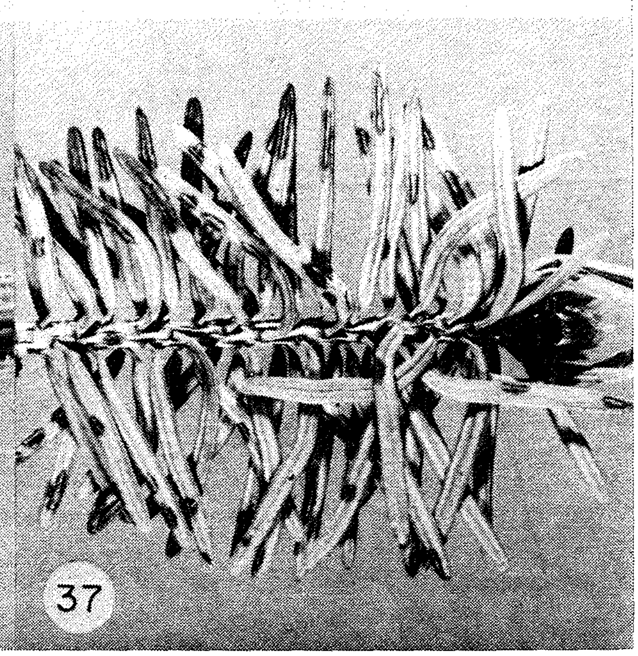

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Disease: *H. concolor* - infected needles are yellowish to red-brown, with small oval depressions. Symptoms appear in the spring of the year following infection. The mature fruit bodies appear as depressions on the leaf surface and are the same colour as the remainder of the affected needle. Spores are released to infect needles of the current season in July and August. This disease is sometimes confused with winter injury.

H. montivaga - affected needles turn brown. Fruit bodies appear in July as elongated dark ridges, with a median longitudinal slit lighter in colour.

H. montana - affected needles have straw coloured segments, which are separated from the green healthy portion by a dark orange-brown band. Fruiting bodies appear on the straw-coloured segments in July as shiny, black, oval pustules.

E. deformans - affected needles are brown in colour and have oval to irregularly shaped black pustules. The pustules do not have a median slit as in *H. montivaga*.

Distribution: *H. concolor* - from Waterton Lakes National Park to Coalspur.

H. montivaga - from the International Boundary, north to the vicinity of Grande Prairie on lodgepole pine.

H. montana - sporadic from the Cypress Hills, Waterton Lakes National Park, north to Grande Prairie.

E. deformans - sporadic on lodgepole pine from the Cypress Hills to Grande Prairie. Reported once on jack pine near Grande Prairie.

Importance: *H. concolor* - continuous attacks reduce the complement of foliage to that of the current year only. Tree mortality is unknown.

H. montivaga - defoliation is often severe enough to cause losses in height and diameter growth. Young trees may be killed.

H. montana - as for *H. concolor*.

E. deformans - premature needle cast, usually of little consequence.

B. Name: Douglas fir needle cast.

Organism: Rhabdocline pseudotsugae Syd.

Hosts: Douglas fir (Pseudotsuga menziesii).

Disease: First symptoms occur in the fall or winter, as yellowish spots on the distal portion of the needles (Fig. 37). By spring the spots are reddish-brown, giving affected needles a mottled appearance. The fruit bodies are brownish apothecia that mature in about late June. Affected needles drop off in July. Seasons of high humidity and rainfall favour the disease.

Distribution: This disease is sporadic throughout the host's range. It reached epidemic levels near Banff in 1959.

Importance: Can be serious in seedlings and trees to about 30 years of age. Repeated attacks cause complete defoliation and tree death. Even moderate attacks are harmful to trees of Christmas tree size and shape.

Control: In nurseries spraying with Bordeaux mixture, or lime-sulphur at the time of spore discharge is effective. Possible control through the use of antibiotics is under investigation.

C. Name: Spruce needle rust.

Organism: Chrysomyxa ledicola (Peck) Lagerh.

Hosts: Coniferous hosts are white, black and Engelmann spruces, (Picea glauca, P. mariana, P. engelmanii) and the broad-leaved host is labrador tea (Ledum groenlandicum).

Disease: Pycnia and orange-yellow aecia on the current year's needles (Fig. 38). Needles can be discoloured so badly that trees appear yellowish in colour and may be visible from a distance such as in aerial survey. Uredia are scattered on the upper side of the leaves of the alternate host (Fig. 39). Closely resembles the other needle rusts Chrysomyxa ledi and Chrysomyxa empetri and is distinguishable from these on spruce only by microscopic examination of the spores. The life cycle of this rust can be completed in one year. In the spring, basidiospores produced on Labrador tea infect the needles of spruce. Pycnia and aecia are formed, the aeciospores usually being shed in late summer. These infect Labrador tea plants and the rust overwinters as binucleate mycelium in the current season's leaves. In the spring uredia and telia are produced almost simultaneously.

Basidiospores are produced from the telia and they are carried by the wind to infect spruce needles.

Distribution: Widespread over the range of spruces. It is perhaps the dominant rust of the Canadian BOREAL FOREST and has been found without difficulty in almost every area where Labrador tea is plentiful. Severe outbreaks were reported in the Lac La Biche - Philomena and Smith areas in 1954-56. The southern part of Kootenay National Park had a severe outbreak in 1954 as well. Epidemic conditions were reported from 5 areas, around Whitecourt, Lesser Slave Lake, Grande Prairie, Edson, and Rocky Mountain House in 1960.

Importance: Infected needles are generally shed late in their first season but defoliation is not usually serious enough to kill the trees.

Organism: *Chrysomyxa ledi* (Alb. & Schw.) de Bary.

Hosts: As with *C. ledicola*.

Disease: As with *C. ledicola*. This rust resembles *C. ledicola* except for spore details and the locations of uredia and telia. Superficially they are difficult to separate.

Organism: *Chrysomyxa empetri* (Pers.) Schroet.

Hosts: White, black, and Engelmann spruces, and crowberry (*Empetrum nigrum*).

Disease: Symptoms are similar to those of *C. ledicola*. Pycnia and aecia are formed on spruce needles, aecia often on all four faces. The uredia are scattered on the upper surface of crowberry leaves. Telia are also produced on the upper surface of these leaves but on the recurved leaf margins; they are yellow and cushion-shaped. The teliospores germinate at maturity in early summer, promycelium is produced with subsequent release of basidiospores. These are windborne to infect spruce needles.

Distribution: Occurs on spruce generally wherever crowberry is present. Close to the tree line across the continent it is probably of equal importance to C. *ledicola*. This rust is common In 1953 it reached epidemic proportions at Calling Lake, Cold Lake, and in Kootenay National Park.

Importance: Infection of current year's needles is causing them to be shed. Repeated infection over a number of years could cause considerable defoliation. Moderate infection probably causes some reduction in growth increment.

D. Name: Pine needle rust.

Organism: *Coleosporium solidaginis* Thuem.

Hosts: Coniferous host is lodgepole pine and broadleaved hosts are aster (*Aster* spp.) and golden-rod (*Solidago* spp.).

Disease: Pycnia and aecia are formed on pine needles in the spring or summer (Figs. 40 and 41). The aeciospores infect the secondary hosts and uredia soon form on the leaves. The uredospores spread infection on the same host, but later in the season the reddish-brown telia appear. When the teliospores germinate, the basidiospores reinfect the pine needles, and the life cycle is complete. The rust may overwinter in the uredial stage, thus maintaining itself indefinitely without the pine host.

Distribution: Scattered in the southern and central part of Alberta.

Importance: Premature defoliation. Considered to be of little importance.

E. Name: Poplar ink spot.

Organism: *Ciborinia whetzelii* (Seaver) Seaver (=*Sclerotium* sp.)

Hosts: Aspen (*Populus tremuloides*).

Disease: The sclerotia or ink spots are black and approximately circular and vary from 2 - 8 mm. in diameter. Many of the black spots drop from the leaves during the summer leaving so-called shot-holes. Severely infected leaves are killed by midsummer but persist on the tree until fall (Fig. 42).

Distribution: Common in its host range. High incidence of the disease was observed in the Lac La Biche area in 1959 - 1960.

Importance: Premature defoliation. Not considered to be important except in shelterbelts and shade trees.

F. Name: Poplar leaf spot.

Organism: *Marssonina tremuloidis* (Ell. & Ev.) Kleb.

Hosts: Aspen

Disease: This fungus attacks both leaves and shoots. Crowns of diseased trees show a light tan discolouration. Affected leaves have irregularly shaped spots of varying sizes that are tan or brown at first, later becoming black. Bordering these spots the leaf tissues are yellowish (Fig. 43). Epidemic development of the disease follows spring and summer seasons characterized by abundant rain fall.

Distribution: Widespread in its host range.

Importance: Not considered to be important, except in shelterbelts and shade trees.

2. Diseases Affecting Fruit.

A. Name: Spruce cone rust.

Organism: *Chrysomyxa pirolata* Wint.

Hosts: On the cones of white, black, and Engelmann spruce. The broadleaved host is wintergreen (*Pyrola* spp., and *Moneses* sp.).

Disease: Infected cones turn yellow and produce no seed (Fig. 44). Generally all the cone scales are affected. Aecia are produced chiefly on the outer sides of the scales (Fig. 45). Uredia and telia are produced on the lower surface of leaves and sepals of wintergreen (Fig. 46).

Distribution: Spruce cone rust is coincident with the natural distribution of its coniferous hosts. Widespread infection of white and Engelmann spruces was observed in 1954, particularly on the east slopes of the Rockies in southern Alberta. It was abundant on white spruce in the Hinton-Whitecourt-Grande Prairie area in 1959 and occurred more sporadically on the same host south to Kananaskis. The rust was common in eight localities in 1960, the highest incidence being near Rocky Mountain House.

Control: Maintenance of high vigor in the host by cultural methods is important. Removal and disposal of infected material will reduce the danger of infection to neighbouring trees.

B. Name: Hypoxylon canker

Organism: *Hypoxylon pruinatum* (Klotzch) Cke. This pathogen spreads by air-borne ascospores and conidia which are released during the growing season. Ascospore release is initiated by rain. The spores, after germination, penetrate through wounds, particularly insect injuries, in the bark. Stem infections are frequently centered at branch nodes. As trees grow older, new infections are found higher and higher up the trunk.

The fungus is perennial within the host, and produces conidia approximately one year after infection. The fungus produces a grayish layer of conidia within the bark. These are exposed by the rupture of the surface layers. A further one or two years elapse before the appearance of the first grayish to black perithecia from which the ascospores are released.

Hosts: Occurs mainly on aspen; less commonly on other species of poplar.

Disease: The first symptom is a small yellow to reddish-brown slightly sunken area which appears two to eight weeks following infection (Figs. 48, 49). As cankers enlarge, the infected bark becomes mottled gray and black. Callus is often produced at the edges of cankers. Canker enlargement continues from year to year and may reach 3 or more feet in length before the tree is girdled. A brownish sap flow may occur at the canker margin. The advancing margin is irregular, and yellowish to reddish-brown in colour. Abnormally small, slightly yellowish leaves are produced on stems and branches seriously affected by the canker. Girdled trees may break off at the canker level. The fungus penetrates to the wood.

Distribution: The disease is widely distributed in North America. It is found over most of Alberta except for the high foot-hills and mountains. The incidence appears to be high in mixed wood and parkland regions.

Importance: Hypoxylon canker can cause serious damage to poplar stands since it may girdle and kill a pole sized tree in three to four years. It is an important pathogen in parts of the province in which the host is used for shelterbelts.

Control: Infected trees should be removed and destroyed. Selection of trees for thinning should be done during the dormant season since leaves may hide cankers from view.

C. Name: Atropellis canker

Organism: *Atropellis piniphila* (Weir) Lohman & Cash. The organism spreads by means of ascospores which are produced during the growing season in apothecia at the center of old cankers. In the dried state, the apothecia are small black and shrunken bodies which swell up rapidly after moistening, and release their spores. The ascospores are spread by wind.

Hosts: Occurs on lodgepole pine and lodgepole-jack pine hybrids.

Disease: Cankers occur on branches and stems. Direct infection of the stem occurs mainly at branch nodes, and invasion can proceed through undamaged bark.

The first symptom is slight resin flow over the infection which consists of a more or less circular black spot. Following this the bark ruptures and resin flow is profuse (Fig. 50). The cambium is killed in the infected areas, and the cankers enlarge from year to year, mainly logitudinally. The mycelium is largely intracellular and imparts a blue-black discolouration to the infected tissues (Fig. 51). In vigorous trees continued diameter growth in the surrounding host tissues may produce a sunken cankered zone. Circumference growth of the pathogen is very slow but may eventually girdle suppressed trees. Larger trees can be girdled by the coincidence of several cankers at the same level.

Distribution: Within Alberta the disease is widespread, most pure pine stands having a few cankers. However, the incidence is highly variable; several locations occur in which incidence rates of virtually 100 per cent are combined with multiple stem infections.

Importance: This is a serious disease. The heavy resin flow results in a debarking problem which can increase costs and degrade pulp. The wood discolouration degrades lumber and can add to bleaching costs in pulp preparation. The effect on tree growth is not yet fully known but mortality is common because of girdling action of cankers.

Control: Control is automatic in clearcutting operations. The removal of older infected trees left by a haphazard burn is advisable, to protect the surrounding regeneration.

D. Name: White pine blister rust.

Organism: *Cronartium ribicola* J. C. Fischer. This fungus requires two different host plants to complete its life cycle. It has five spore stages, pycniospores (O) and aeciospores (I) are produced on pine bark, uredospores (II), teliospores (III) and basidiospores (IV) are produced on currant and gooseberry (*Ribes*) foliage. Only aeciospores and uredospores are known to infect currant, and only basidiospores to infect pine.

Hosts: The coniferous hosts are the 5-needled pines. In Alberta these are: white bark pine (*Pinus albicaulis*), and limber pine (*Pinus flexilis*). The broadleaved hosts are wild and domestic currant and gooseberry bushes (*Ribes* spp.).

Disease: Symptoms: The first indication of the disease is a small yellow to brown spot on the pine needle at the point of infection. This spot appears a few months after penetration. One to three years later infected bark of the twig which supported the needle becomes yellowish-orange in colour. This colouration is usually accompanied by swelling. The following spring shallow blisters appear on this area of the bark. These are the pycnia which rupture and exude honey-coloured droplets. Normally the droplets are washed away by rain, dry up, or are eaten by insects leaving pycnial lesions which persist through the season and become dark brown. Frequently rodents are attracted to the pycnia and they gnaw the bark in this area causing a conspicuous wound. The aecia appear in the spring or early summer on the same area of the canker one year after the pycnia (Fig. 53). Following rupture of the aecia and the release of aeciospores the host bark dries out and cracks, and the cambium of the underlying wood is killed. A well developed canker has four distinct zones, a necrotic area in the center surrounded by a band bearing aecia which is bordered by a zone bearing pycnia, beyond which is a zone of orange discoloured bark marking the furthest advance of the fungus. The necrotic zone continues to enlarge each year until the stem is girdled. Small twigs may be girdled and killed with no further advance of the fungus, but if the mycelium reaches larger branches and eventually the main stem before complete girdling occurs, the trunk of the tree will be girdled resulting in death of the crown (flagging) above the canker. If the canker develops low on the trunk the tree will be killed. Partially girdled stems, particularly the smaller ones, are often enlarged above the canker. This is due to the fact that the fungus thrives in the phloem tissue and interferes with the downward conduction of food.

On Ribes the rust produces symptoms ranging from light to severe, depending on the susceptibility of the host species, the time and conditions of infection, and the amount of inoculum available. The uredia appear as slightly raised yellow spots, chiefly on the lower side of the leaves (Fig. 54). The uredia and telia vary in size and arrangement with the species of Ribes; in some the infection spots are small and in others they are large and closely crowded. The telia which follow the uredia are slightly darker in colour (Fig. 55). Some Ribes varieties defoliate prematurely following infection.

Distribution: Since the introduction of this rust into Vancouver in 1910, it has spread until it now covers almost the complete range of white pine species in northwestern United States and British Columbia. In Alberta it is common in Waterton Lakes National Park, and the Crowsnest Forest Reserve. A collection has been made in Yoho Park and there is reason to believe that the range extends considerably further north.

Importance: This disease threatens to destroy both species of white pine in Alberta. Since these species have little commerical use, the economic loss attributed to the disease in this region is slight. However no estimation of the aesthetic value of these species, particularly in the National Parks, can be given. These species occupy sites at high elevations that are not well suited to other native trees.

Control: Ribes eradication within approximately 1,000 feet of pine stands has been the principal control technique in areas where it could be justified economically. Although still in the experimental stage control with antibiotics has shown much promise.

E. Name: Comandra blister rust.

Organism: Cronartium comandrae Peck. This is a long-cycle rust with a life cycle very similar to that of Cronartium ribicola. The fungus grows perennially on living pine bark and annually on toad flax leaves and stems. Aecia appear on the infected bark in early summer one year after the pycnia (Fig. 56). The bright orange aeciospores infect toad flax, and after about 10 days uredia appear on both surfaces of the leaves and stems. The uredospores can infect other toad flax but not pine. Telia develop about 15 days after the uredia on the toad flax (Fig. 57). The teliospores germinate and produce basidiospores which are capable of infecting pine. Pycnia appear two or three years after pine infection occurs. This rust can be

Plate XIII

Fig. 50. *Atropellis piniphila* showing the profuse resin flow, and sunken cankered zone.

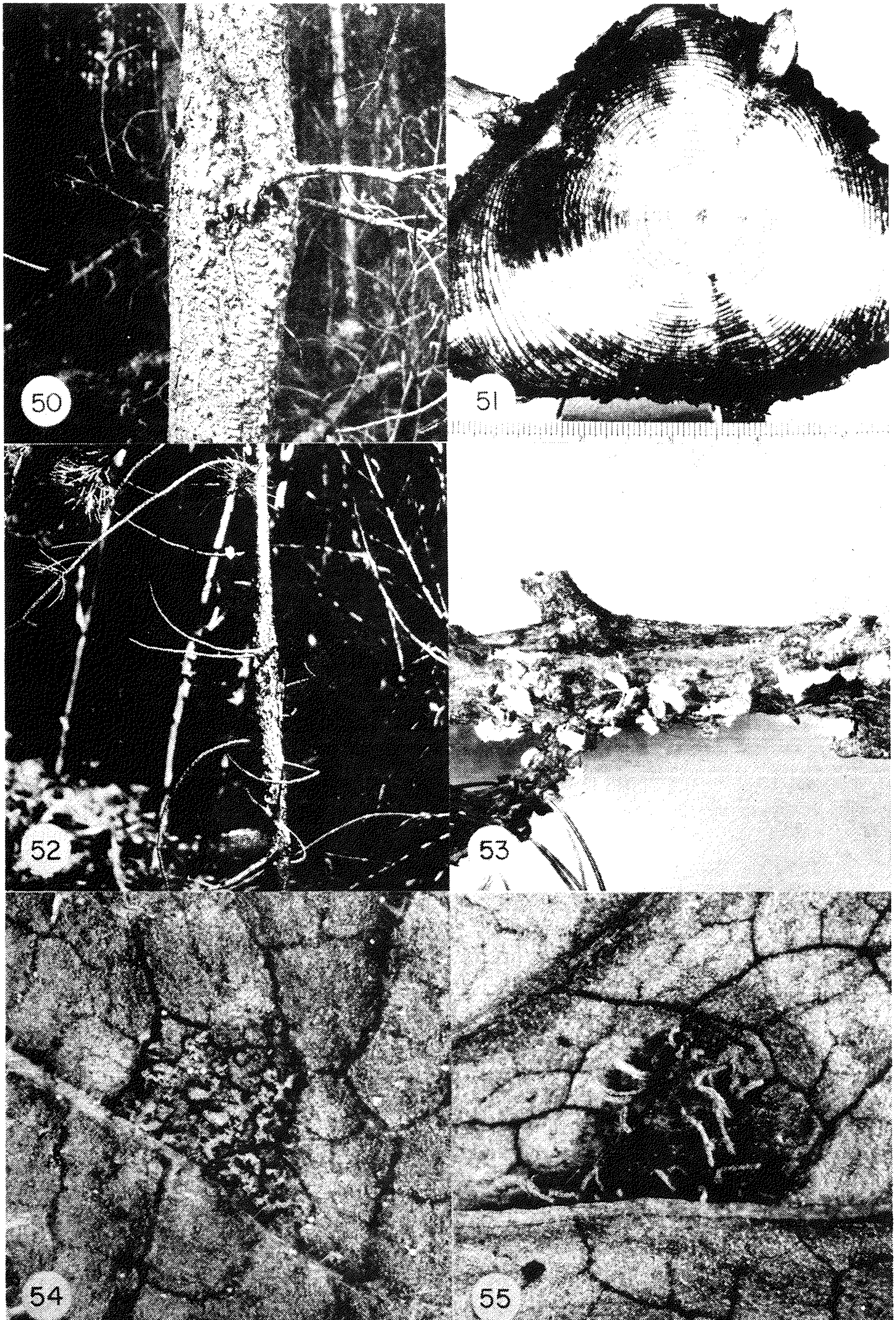
Fig. 51. Cross section through *Atropellis* cankers showing blue-black discolouration and distorted tree growth.

Fig. 52. Dead suppressed lodgepole pine girdled by *Atropellis*.

Fig. 53. Aecia of *Cronartium ribicola* at the margin of a branch canker on limber pine.

Fig. 54. Uredia of *C. ribicola* on a Ribes leaf.

Fig. 55. The columnar telia of *C. ribicola* on a Ribes leaf.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differentiated from all other Cronartium rusts by the pear-shaped pycniospores and aeciospores.

Hosts: The coniferous hosts are hard pines. These are; lodgepole, jack, and Scots pines (Pinus sylvestris). The broadleaved hosts are bastard toad flax (Comandra pallida), and Geocaulon lividum.

Disease: Although it is not certain whether infection takes place through the needles or the bark of young stems, cankers only originate on needle-bearing stems and branches. Swelling accompanies the infection on young stems and a characteristic spindle-shaped canker appears very similar to white pine blister rust cankers. In Alberta cankers usually occur on young trees, and seldom higher than three feet above the ground. The canker usually girdles the branch or stem and either flagging or mortality results. On Comandra very small yellow spots (uredia) appear on both surfaces of leaves during the summer. These are followed by brownish hair-like telia.

Distribution: Widely distributed from Quebec to British Columbia and N.W.T. In a given area the rust is often limited by the distribution of the alternate host. Comandra pallida is a plant of prairie grassland and gravelly slopes and is not common in dense pine stands. Therefore the disease is usually found in its highest incidence in stands bordering open areas.

Importance: This is mainly a disease affecting regeneration and young stands. Where stands are too dense it may have the beneficial effect of thinning. Where the incidence is very high, serious damage can result. It could be a threat to nursery culture and in the reforesting of unproductive grazing land.

F. Name: Stalactiforme rust

Organism: Peridermium stalactiforme Arth. & Kern. (Cronartium coleosporioides (D. & H.) Arth. on secondary host). Although the life cycle of this rust has not been worked out in detail, it is believed to be long-cycled. Aeciospores have been proven experimentally to infect Indian paintbrush, but there is no evidence that they are capable of infecting pine (Figs. 58-60).

Hosts: The coniferous host in Alberta is lodgepole pine. The broadleaved host is Indian paintbrush (Castilleja spp.).

Disease: An elongate diamond-shaped stem canker is characteristic of the disease on lodgepole pine. Infection usually enters the stem through small twigs and advances faster longitudinally than laterally. Girdling is a relatively uncommon. Cankers over 30 years old and up to 25 feet long have been observed. Rodents frequently remove the bark from the infected area resulting in a conspicuous elongate scar. Pycnia and aecia appear in the summer on the newly infected bark bordering the scar.

Distribution: The range is not well defined. It is believed to be largely confined to the Pacific Coast and Rocky Mountain regions, but it has been reported as far east as Saskatchewan and Minnesota. Localized pockets of high incidence of the disease are scattered along the eastern slopes in Alberta, usually in young pine stands.

Importance: The disease is not of great economic importance in this region at the present time. It could possibly be a serious pest in nurseries and plantations of the future.

G. Name: Western gall rust

Organism: Peridermium harknessii J. P. Moore (Cronartium coleosporioides (D. & H.) Arth. on secondary host). Pycnia are rare in this rust. Aecia are produced each year in early summer on the surfaces of spherical galls. Aeciospores can infect pines, giving rise to new galls. In some areas this appears to be the only way that infection occurs. Therefore, this rust appears to be short cycled. There are reports that aeciospores also infect Scrophulariaceae, producing uredia, telia, and basidiospores. The latter are believed to infect pine. The aecial stages of P. harknessii and P. stalactiforme are distinctive, but their telial stages on Scrophylariaceae have never been distinguished. The stages of both rusts that occur on Scrophulariaceae are called C. coleosporioides.

Hosts: The coniferous hosts are western hard pines. The broadleaved hosts may be Indian paintbrush (Castilleja spp.), owl clover (Orthocarpus sp.), cow wheat (Melampyrum sp.), and certain other Scrophulariaceae.

Disease: The rust mycelium stimulates the stem cambium to divide rapidly, thus producing pronounced swellings (Fig. 61). Infections tend to remain localized and do not advance from branches into the main stem. Galls may persist for many years without killing the branch, but growth reduction of the host is often pronounced.

Distribution: This rust is common throughout western North America. It usually occurs in pockets of high incidence.

Importance: Serious only in local areas.

Plate XIV

Fig. 56. Aecia of *Cronartium comandrae* on lodgepole pine with spores (inset).

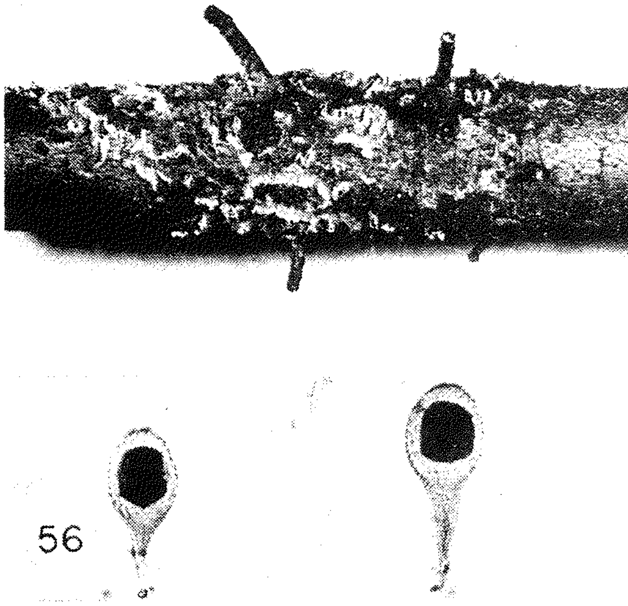
Fig. 57. Uredia and telia of *C. comandrae* on leaf of bastard toad flax.

Fig. 58. Typical diamond-shaped canker of *Peridermium stalactiforme* with aecia and aeciospores (inset).

Fig. 59. Indian paintbrush, the alternate host of *P. stalactiforme*, showing infected leaves.

Fig. 60. The telia of *P. stalactiforme* on the leaf of Indian paintbrush.

Fig. 61. The gall caused by *Peridermium harknessii*.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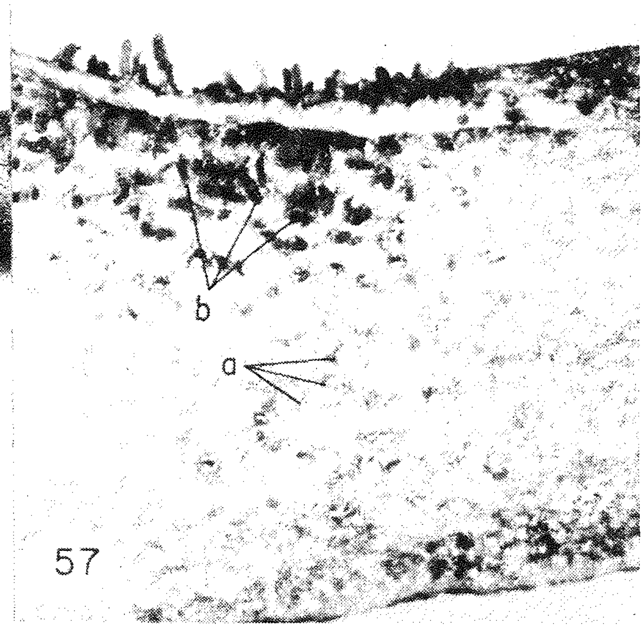

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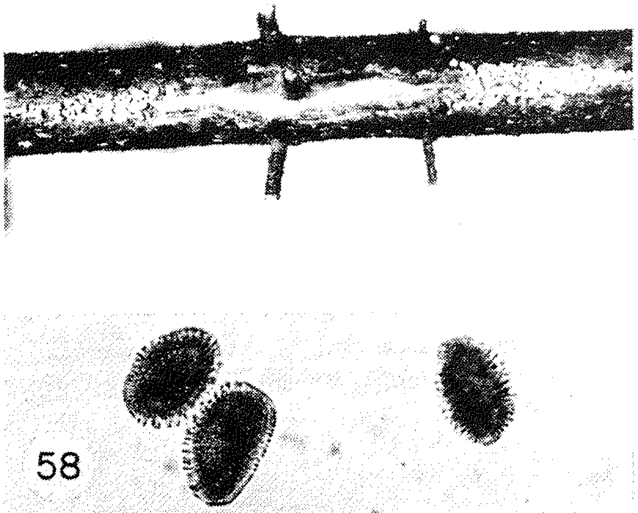
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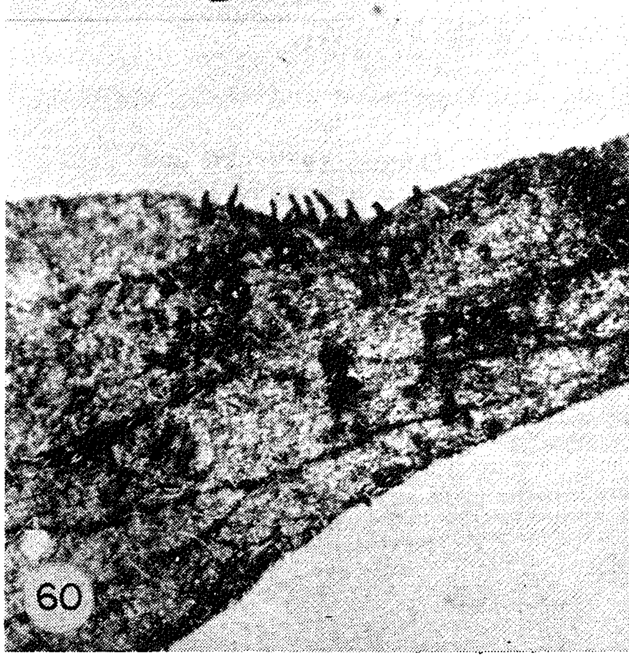
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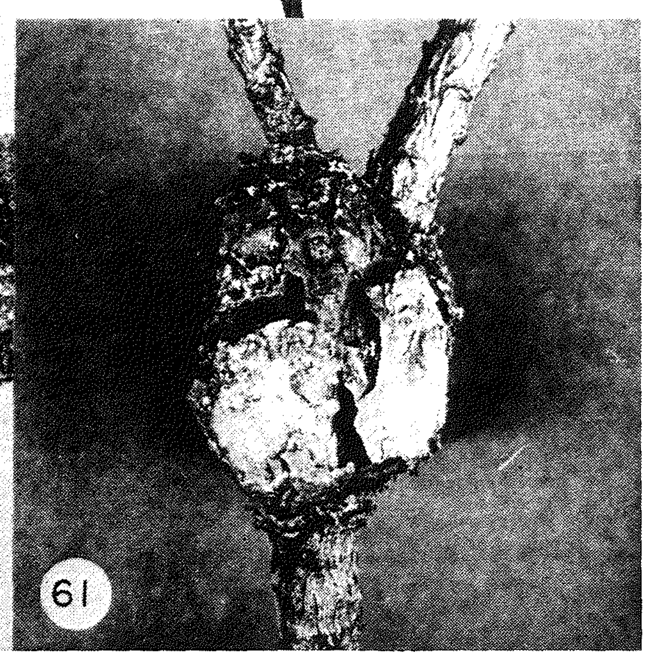
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4. Diseases Affecting Wood.

A. Root and butt decays

Certain fungi are characteristically more active in the root and butt zones of trees than in the stems and tops. The volume loss resulting from root and butt rots is not as great as that resulting from stem rots. Butt rots are important mainly because of their location in the commercially valuable basal part of the tree. In addition, root rots regularly predispose otherwise healthy trees to windthrow and other forms of premature death. Some of the more common root and butt decays in Alberta are:

(a) Name: Shoestring root rot.

Organism: *Armillaria mellea* (Vahl ex Fr.) Quel. (Fig. 62-63).

Hosts: All commercially important trees of the region.

Disease: The symptoms and signs of the disease are: yellowing of foliage, basal resin flow, white mycelial fans under bark, rhizomorphs under bark of stem and roots.

Distribution: Is widespread.

Importance: Sometimes causes extensive mortality in reproduction, otherwise moderate losses through decay.

(b) Name: Brown cubical butt rot.

Organism: *Coniophora puteana* (Schum. ex Fr.) Karst.

Hosts: Occurs on lodgepole pine, and Engelmann and white spruces.

Disease: The advanced rot caused by this fungus is brown and cubical in nature. The fruit bodies are RESUPINATE (flat, lying on substrate), olive brown to dark brown, and occur on slash (Figs. 64 and 65).

Distribution: Occurs widely in north temperate zone.

Importance: Causes significant loss in wood volume through decay in mature and over-mature spruce stands.

(c) Name: Red root and butt rot of conifers.

Organism: *Polyporus tomentosus* Fr.

Hosts: Occurs on lodgepole pine and Engelmann and white spruces. In the early stages of decay the wood is firm and red in colour. In the advanced stages it is characterized by small elliptical white pockets. The fruit bodies may occur at the bases of trees and may be SESSILE or STIPITATE (Figs. 66, 67). These are the only external indications of the decay in lodgepole pine. Circular stand openings in spruce, plus the presence of stipitate fruit bodies near standing trees, usually indicates extensive *Polyporus tomentosus* activity.

Distribution: Occurs widely in North America.

Importance: Losses are highly variable between stands.

(d) Name: Yellow stringy butt rot of conifers.

Organism: *Flammula alnicola* (Fr.) Kummer

Hosts: Occurs on lodgepole pine, Engelmann spruce, white spruce, and alpine fir (*Abies lasiocarpa*).

Disease: In the advanced stage the wood is yellow and stringy, with laminate and radiate patterns in cross-section. Mushrooms usually develop on dead trees and stumps, but rarely on living trees. They occur most commonly on wood that has become exposed. Occasionally they are found in the duff with their bases appressed to the bark of stumps. Fruit bodies develop in August and September (Fig. 68).

Distribution: Occurs sporadically usually in mature and over-mature stands

Importance: Causes occasional high losses.

(e) Name: Brown mottled root rot.

Organism: *Pholiota adiposa* Fr. and *Pholiota spectabilis* (Fr.) Quel.

Hosts: Occurs on trembling aspen and balsam poplar.

Plate XV

Fig. 62. White mycelial fans of Armillaria mellea under the bark of an infected tree.

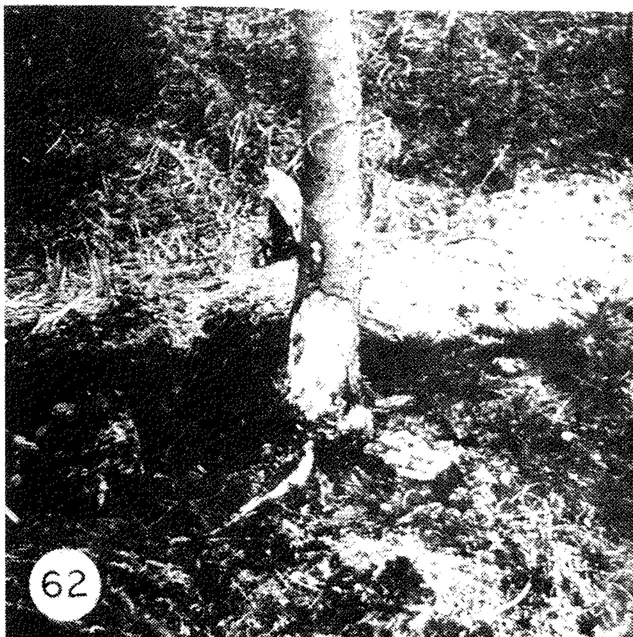
Fig. 63. The honey-brown mushrooms of A. mellea covered with blackish-brown scales, showing the membranaceous ring (ANNULUS) and gills.

Fig. 64. Resupinate, olive-brown to dark brown fruit bodies of Coniophora puteana on slash.

Fig. 65. Brown cubical decay caused by C. puteana entering through fire scar.

Fig. 66. Yellowish-brown, velvety upper surface of Polyporus tomentosus.

Fig. 67. Pale orange margin and cinnamon coloured lower surface of P. tomentosus.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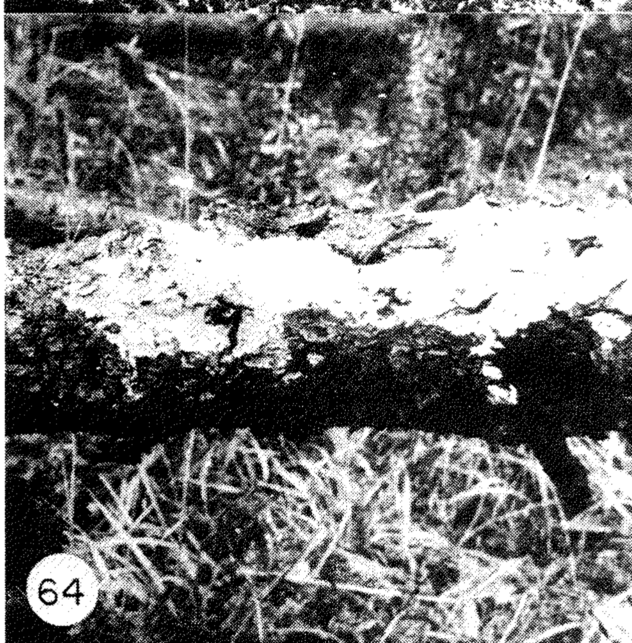
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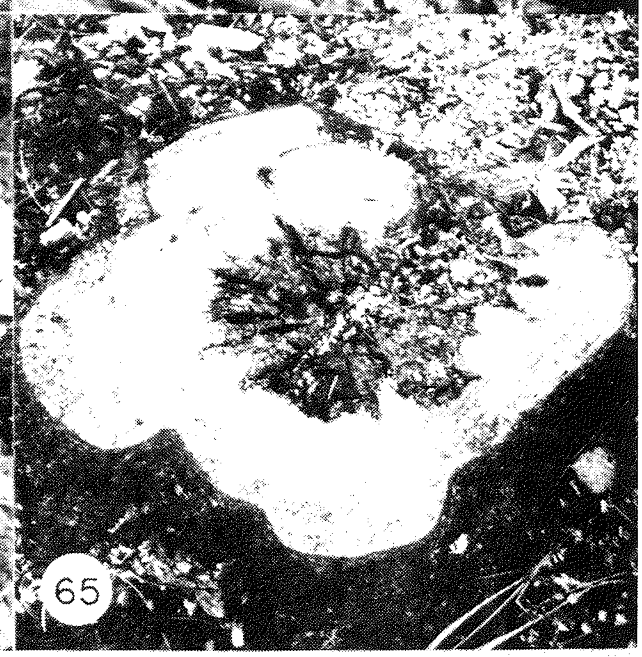
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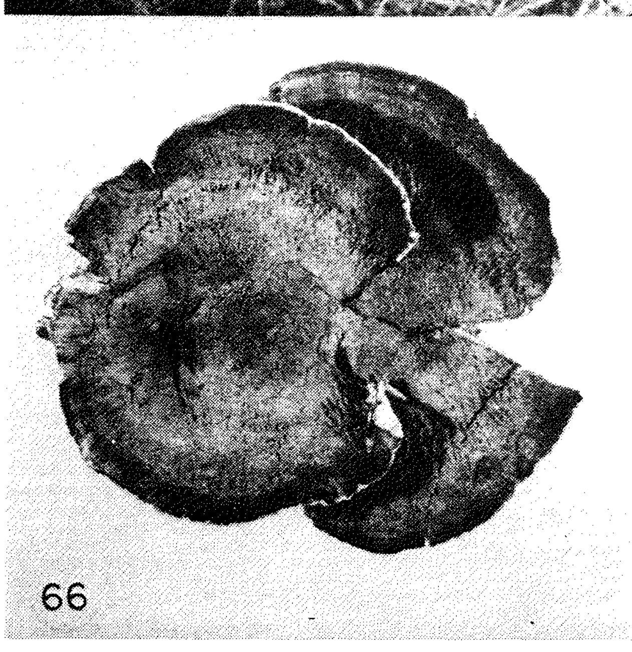
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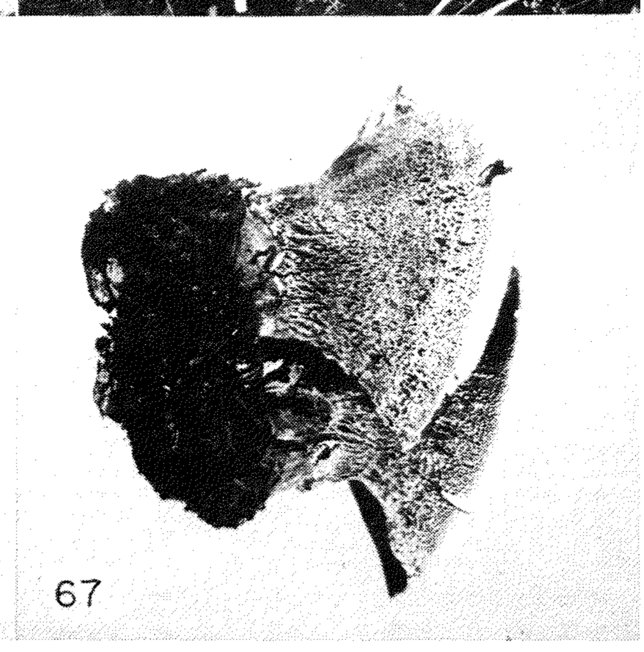
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Disease: Both fungi have been found associated with a stringy butt rot in aspen and balsam poplar. The mushroom-like fruit bodies often develop in clusters on dead stumps or at the bases of infected trees, mainly in August and September.

Distribution: Occurs generally throughout the range of aspen and balsam poplar.

Importance: Occasional high losses, mainly in older trees.

B. Stem decays

Heartrot accounts for most of the commercial cull in living trees. It depreciates both the volume and value of otherwise sound wood. The spread of heartrot from tree to tree is almost always by spores. The usual infection courts for stem rot fungi are dead and broken tops, dead and broken branches, and scars of various kinds. Heartrot is best controlled by close observance of the pathological rotation ages for the different tree species and sites. Where partial cutting methods are used care should be taken to prevent undue damage to the residual stand. Other precautionary measures are the exclusion of fire and the prevention of overgrazing. Some of the more common stem decays in Alberta are:

(a) Name: Red ring rot

Organism: Fomes pini (Thore ex Pers.) Lloyd.

Hosts: Lodgepole pine, Engelmann spruce, jack pine, alpine fir, balsam fir (Abies balsamea), white spruce.

Disease: The early stage of decay is a solid core of firm reddish-brown stain in the heartwood, advanced decay is a white pitted rot. The perennial fruit body varies in shape, from thin and shelf-like to bracket-like or hoof-shaped. The upper surface is rough, either dull grayish or brownish-black with approximately concentric furrows parallel to the margin. The context is cinnamon brown, the lower surface is light brown and has round to irregularly-shaped pores. The fruit bodies occur on living trees and on slash. PUNK KNOTS and RESINOSIS are external indications of decay (Figs. 69-72).

Distribution: This fungus occurs everywhere in the north temperate zone.

Importance: Loss in wood volume through decay.

(b) Name: Red heartrot.

Organism: *Stereum sanguinolentum* Alb. and Schw.

Hosts: Lodgepole pine, Engelmann spruce, white spruce, black spruce, alpine fir, Douglas fir.

Disease: The early stage of decay is a reddish-brown stain which in cross section may form either a solid, irregularly-shaped core or may radiate from the centre. Advanced decay is brown and stringy. In longitudinal section white to buff mycelial sheets, are evident in rotted wood. The fungus rarely produces the advanced stages of decay except in alpine fir and balsam fir. The thin, annual, leathery fruit bodies of the fungus occur abundantly on slash, and occasionally on scars and on the underside of dead branches on living trees (Fig. 73).

Distribution: Widespread in North America and Europe.

Importance: Degrade and volume loss.

(c) Name: Brown stringy rot.

Organism: *Echinodontium tinctorium* E. and E.

Hosts: Alpine fir, Engelmann spruce.

Disease: The early stage of decay appears as light brown areas in the heartwood, but is generally difficult to detect. Advanced rot is brown and stringy with red streaks throughout. The fruit bodies are hoof-shaped; the upper surface is rough, black, and cracked; the interior and the under surface is an aggregation of hard spines. Fruit bodies are common at branch bases (Fig. 74).

Distribution: In the prairie region the distribution seems limited to the high foothills

Importance: Volume loss through decay.

(d) Name: White trunk rot.

Organism: Fomes igniarius (L. ex Fr.) Kickx

Hosts: Aspen, poplar, white birch (Betula papyrifera).

Disease: The early stage of decay appears as either yellowish-white spots, streaks, or larger areas in the heartwood that are usually surrounded by a yellowish-green to brownish-black zone. Advanced rot is light in weight, soft, whitish, and rather uniform in texture, with fine black lines running throughout. The fungus continues its development in dead trees. The hard, woody, thick, perennial fruit bodies are usually hoof-shaped, but sometimes shelf like. The upper surface is grayish-black to black, dull, smooth at first but becoming rough and cracked with age. The under surface is brown with the mouths of the tubes very small and circular, giving it a velvety appearance. The context is rusty-brown, showing many layers of tubes, those in the older layers being conspicuously stuffed with white mycelium. The upper surface of Fomes pini, Echinodontium tinctorium and Fomes igniarius are very similar, but they may be identified with confidence on the basis on the characteristics of their under surfaces (Figs. 76 and 77).

Distribution: Widespread in the north temperate zone, particularly on poplars and birch.

Importance: Volume loss through decay.

(e) Name: Brown mottled stem rot.

Organism: Pholiota destruens (Brond.) Quel.

Hosts: Aspen and poplars.

Disease: Early stages of decay are difficult to detect in dark-coloured heartwood, but are more obvious in light-coloured heartwood where it appears as buff to dark brown streaks. Advanced rot is either white-mottled or yellowish to tan. Rotted wood is often readily separable along the annual rings. The mushroom fruit bodies grow from midsummer to late autumn, either at the surfaces of scars or at broken points on living trees and log ends. The cap (PILEUS) is up to 7 ins. broad, fleshy when fresh and drying to tough and leathery. It is tan to brown and usually has white patches on the upper surface. The gills are white when fresh, becoming brown later (Figs. 78 and 79).

Plate XVII

Fig. 74. Fruit body of Echinodontium tinctorium and the advanced stringy heartrot.

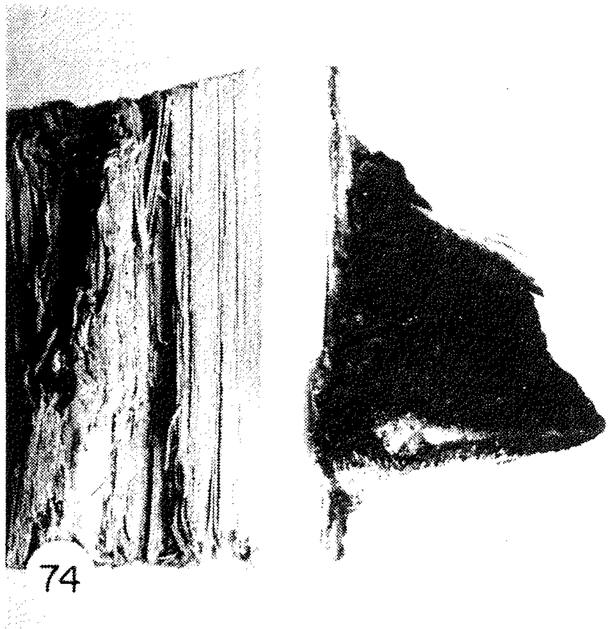
Fig. 75. Resupinate fruit body of Radulum casearium on the underside of aspen slash.

Fig. 76. Black cracked upper surface of Fomes igniarius and the smooth, brown under surface.

Fig. 77. Decay caused by F. igniarius.

Fig. 78. Upper surface of Pholiota destruens.

Fig. 79. Under surface of P. destruens.



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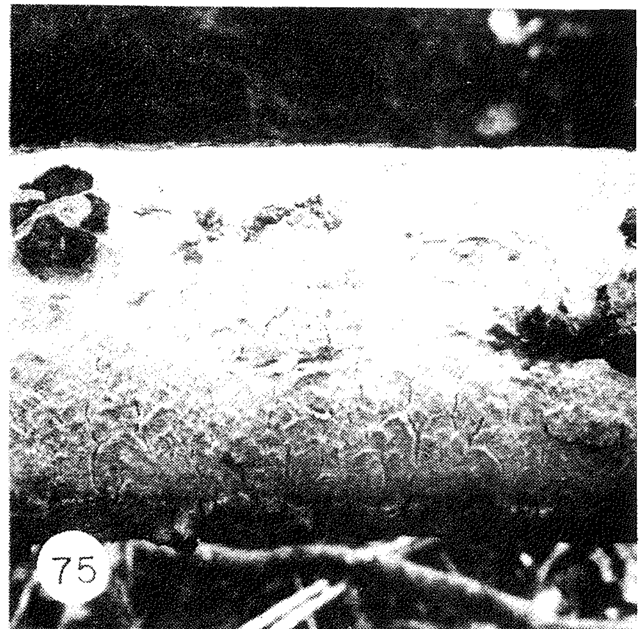

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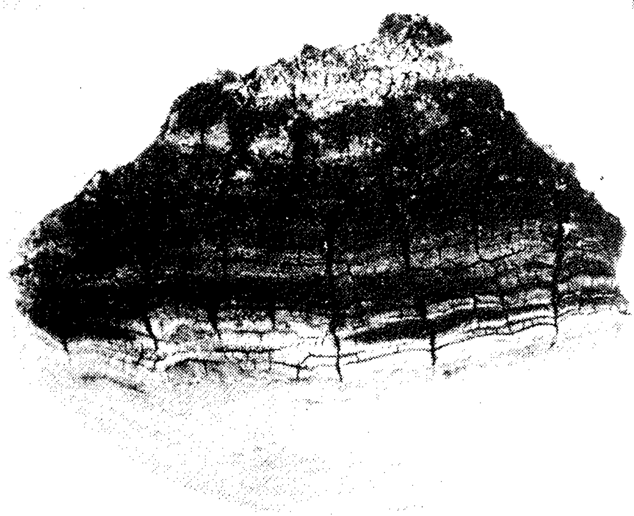

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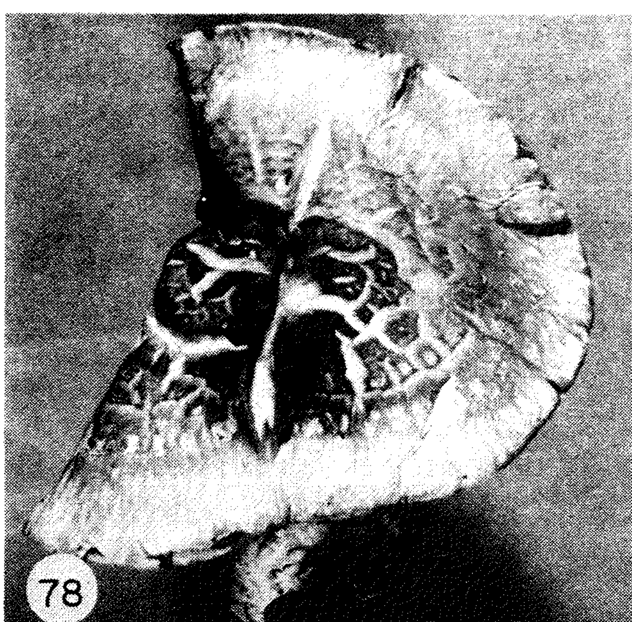

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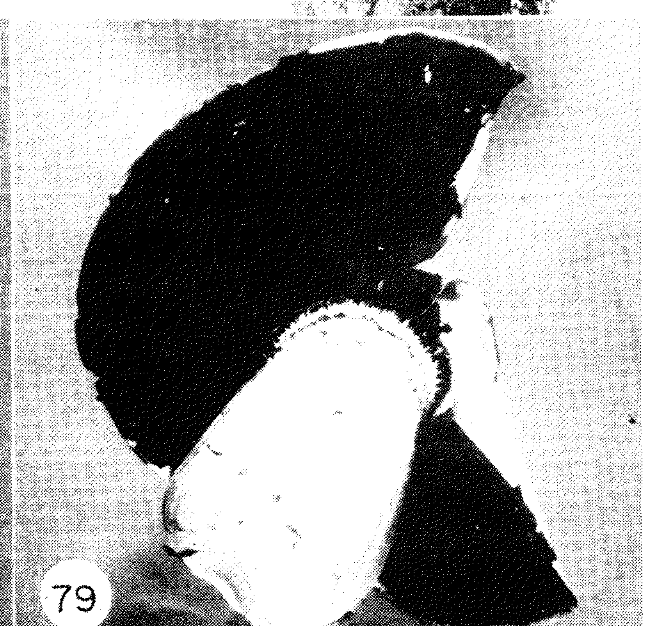

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Distribution: Widespread in north temperate zone.

Importance: Loss in wood volume through decay.

(f) Name: Yellow stringy rot.

Organism: *Radulum casearium* (Morgan) Lloyd.

Hosts: Aspen

Disease: The early stage of decay caused by this fungus is sometimes confused with a corresponding stage of decay caused by *Peniophora polygonia* (Pers. ex Fr.) Bourd. & Galz., particularly in young trees (40-80 years). The early stage of decay is a light reddish-brown stain. In older trees (80+ years) *Radulum casearium* and *Peniophora polygonia* are thought to be responsible for about 30% of the total decay volume of aspen. Advanced decay is yellow and stringy. Sporophores are formed only on slash, as extensive crusts of yellowish-brown spines. The older crusts crack into numerous sections on drying (Fig. 75).

Distribution: Widespread in North America.

Importance: Loss in wood volume through decay.

(g) Name: Yellow stringy rot.

Organism: *Peniophora polygonia* (Pers. ex Fr.) Bourd. & Galz.

Hosts: Aspen.

Disease: *Peniophora polygonia* and *Radulum casearium* produce identical incipient and advanced decays in trembling aspen. The incipient stage of decay is a light reddish-brown stain (Fig. 80). The advanced stage is yellow and stringy. *Peniophora polygonia* becomes established earlier in aspen than *Radulum casearium*, but its rate of decay is slower. The fruit bodies are relatively common on branch stubs of living trees, but they are difficult to detect because of their resupinate form and small size. They are thin and crust like, brownish-pink with narrow light margins (Fig. 81).

Distribution: Widespread in North America.

Importance: Loss in wood volume through decay.

C. Stains

(a) Name: Red stain of lodgepole pine

Organism: *Peniophora pseudo-pini* Weres. & Gibson.

Hosts: Lodgepole pine, jack pine.

Disease: The stain is pink to red in colour (Fig. 82). It frequently develops along the wood-rays, but also in irregularly shaped patches in the heartwood. It is most common in trees less than 120 years. The fruit bodies are small, rosy-brown to brownish-purple, velvety crusts that occur on either the bark of dead branches on living trees, or on the bark of trunks of standing dead trees (Fig. 83).

Distribution: Widespread in Alberta

Importance: Causes degrade.

(b) Name: Blue stain (Fig. 84).

Organism: *Leptographium* sp.
Ceratocystis montia Rumb.
Ceratocystis minuta (Siem.) Hunt
Ceratocystis minor (Hedgc.) Hunt
Ceratocystis sp.

Hosts: Conifers

Disease: Blue stain is associated with a complex of fungi, and usually develops in the sapwood following attacks by bark beetles. *Ceratocystis* and *Leptographium* spp. seem to be equally responsible for blue stain volumes in newly attacked lodgepole pine, while *Leptographium* sp. is primarily associated with blue stain volumes in trees killed following beetle attacks. The fruit bodies are small and difficult to see with the naked eye.

Distribution: Widespread in North America.

Importance: Causes degrade, and may be a factor in the death of trees.

D. Decays of Dead Timber and Slash

The deterioration of dead standing timber and slash is a complex process, involving the combined actions of wood boring insects, fungi, and bacteria. The end result is raw humus, but the rate at which this is attained depends upon many factors. The more important of these are, (a) the natural durability of the species of wood involved, (b) the relative proportions of sapwood and heartwood present, (c) the amount of moisture present in the substrate, and (d) the temperature of the substrate.

Different species of trees have different durabilities, i.e., resistance to deterioration (lodgepole and jack pine are more durable than alpine and balsam firs and aspen). Sapwood is more easily decayed than heartwood, and because of this young trees and the tops of trees usually decay quickly. Moisture is a critical factor in the decay process, and if wood dries to less than about 15 per cent moisture content it will not decay. The optimum moisture content for many fungi is about 30 per cent, and when wood becomes saturated the growth of most fungi stops. Temperature is also important, but wood-decaying fungi differ widely in their temperature requirements. Best growth usually occurs between 20 deg. C. and 36 deg. C. The maximum temperatures at which fungi will grow also vary widely. The more important fungi that occur in dead trees and slash in Alberta are:

(a) Name: Brown cubical rot.

Organism: Fomes pinicola (Swartz ex Fr.) Cke. This fungus also causes heartrot in living trees but is primarily a destroyer of dead coniferous timber, and to a lesser extent of dead hardwoods. Fruit bodies are common on dead wood, and sometimes occur on dead portions of living trees.

Hosts: All commerical forest trees in the Prairie region.

Disease: The early stage of decay is a faint yellowish to brownish discolouration. Advanced rot is a yellowish-brown to light reddish-brown crumbly mass that tends to form into cubes. Prominent mycelial felts develop in the shrinkage cracks. The hard, woody, perennial, shelf- to hoof-shaped fruit bodies may attain a width of 2 feet, but on average they vary from 2 to 10 inches. The upper surface is smooth, zoned, gray to black in colour, and commonly has a wide red margin. When fresh the undersurface is white to yellowish, but on drying becomes cream to brownish (Fig. 85).

Distribution: Widespread,

Importance: Little damage by volume loss in living trees. An important decayer of dead timber.

(b) Name: Brown cubical pocket rot.

Organism: *Lenzites saepiaria* (Wulf. ex Fr.) Fr. This fungus is one of the most common destroyers of coniferous slash, but it also causes extensive damage by decaying timber in service, particularly poles, posts and ties. It is sometimes found on dead hardwoods. It rarely occurs on living trees.

Hosts: All conifers in Alberta and occasionally on aspen and balsam poplar.

Disease: The early stage of decay appears as elongated yellowish to yellowish-brown patches. Advanced decay is characterised by elongated pockets that are filled with brown, friable wood that breaks up into small cubical pieces. Mycelial felts in varying shades of yellow and brown are common in these pockets. The annual fruit bodies are usually long, narrow, shelf-like formations issuing through cracks in the bark or through shrinkage cracks on exposed wood. The velvety upper surface varies from yellowish-red to dark reddish-brown, but on weathering becomes grayish-black. The undersurface has light to dark brown rather thick gills with occasional cross connections (Fig. 86b).

Distribution: World wide.

Importance: Little damage by volume loss in living trees. An important decayer of dead coniferous timber.

(c) Name: Brown cubical pocket rot.

Organism: *Trametes odorata* (Wulf. ex Fr.) Fr.

Hosts: Lodgepole pine, jack pine, white spruce.

Disease: The decay and fruit bodies are similar to those of *Lenzites saepiaria*, except that the lower surface of

Plate XVIII

Fig. 80. Early stage of Peniophora polygonia with light reddish-brown stain.

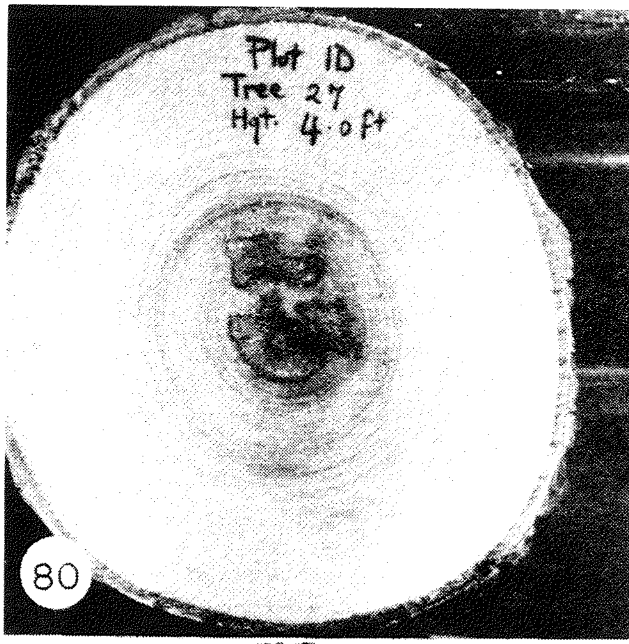
Fig. 81. Brownish-pink fruit bodies of P. polygonia with light margin.

Fig. 82. Red stain of lodgepole pine caused by Peniophora pseudo-pini.

Fig. 83. Fruit body of P. pseudo-pini on dead branch of lodgepole pine.

Fig. 84. Blue-stain.

Fig. 85. Fomes pinicola. The smooth, zoned upper surface has a wide red margin. The undersurface is white to yellowish.



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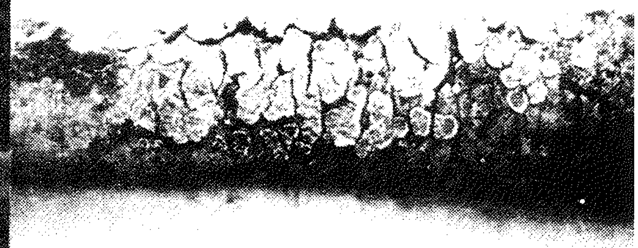
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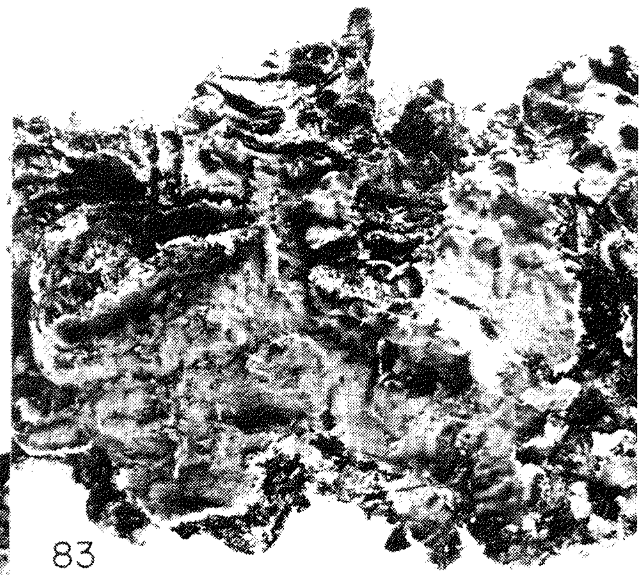
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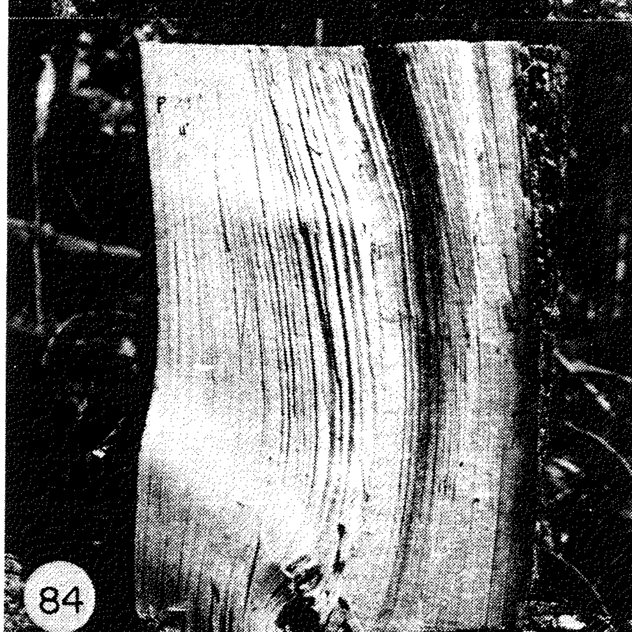
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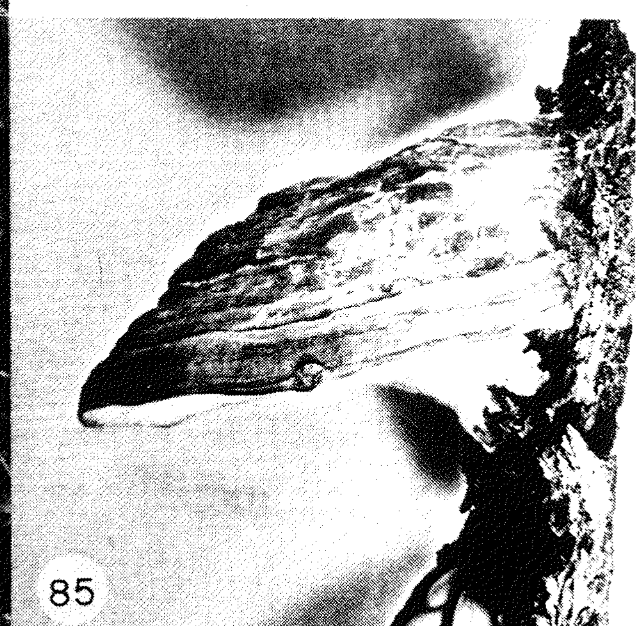
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the fruit body is comprised of tubes and not thick gills (Fig. 86a).

Distribution: Widespread.

Importance: Little damage by volume loss in living trees. An important decayer of dead timber.

(d) Name: Brown cubical pocket rot.

Organism: Fomes subroseus (Weir) Overh.

Hosts: Conifers

Disease: The early stage of decay is difficult or impossible to distinguish. Advanced decay appears as elongated pockets, filled with brown cubical pieces of charcoal-like decayed wood. The annual fruit bodies sometimes appear on dead branches and on dead tops of living trees, but mainly on slash. They are up to 3 inches wide and irregular in shape. Both the upper and lower surfaces are pinkish to rose-coloured (Fig. 90).

Distribution: Widespread

Importance: Little damage by volume loss in living trees. An important decayer of dead coniferous timber.

(e) Name: Yellow spongy rot.

Organism: Peniophora phlebioides Jacks. and Dearden

Hosts: Lodgepole pine

Disease: The decay has not been fully described, but the advanced stage appears as a yellowish to yellow-brown spongy rot. The fruit bodies are crust-like, cream to buff coloured, developing underneath the bark on the sheltered undersurfaces of slash.

Distribution: Widespread in Alberta.

Importance: No known occurrence on living trees, but is important as a lodgepole pine slash decayer.

(f) Name: Pitted saprot.

Organism: *Polyporus abietinus* Dicks. ex Fr.

Hosts: Conifers

Disease: The early stages of decay are yellow to tan with the wood slightly softened. Advanced decay is a honeycomb of small pockets that at first may be filled with whitish fibers, but are later empty. Dead sapwood is primarily affected. The annual fruit bodies are small, thin, and either shelf-like or crust-like, with a hairy, zoned, grayish uppersurface and a lavender to purplish undersurface that turns light brown with age. Fruit bodies develop abundantly along bark crevices or on exposed wood (Figs. 88 and 89).

Distribution: Widespread

Importance: Loss of sapwood volume near wounds on living trees, but mainly an important slash decayer.

(g) Name: White spongy rot.

Organism: *Ganoderma applanatum* (Pers. ex Wallr.) Pat.

Hosts: Mainly hardwoods, but occasionally on conifers.

Disease: In the early stage of decay wood is bleached, with the bleached area encircled by a dark-brown band. In the advanced stage of decay wood is whitish to cream in colour, soft, and spongy, with fine, black zone lines through it.

The hard, woody, shelf-like, perennial fruit bodies may attain a width of 2 or more feet. The upper surface is smooth, zoned, and grayish or grayish-brown. The undersurface is white when fresh, becoming yellow-brown with age. If the fresh undersurface is bruised it immediately turns brown. Fruit bodies are produced abundantly on dead timber and less frequently on living trees (Fig. 87).

Distribution: Widespread

Importance: Little damage by volume loss in living trees. Mainly a decayer of dead trees.

(h) Name: White mottled rot.

Organism: *Fomes fomentarius* (L. ex Fr.) Kickx

Hosts: Mainly on dead birches in Alberta.

Disease: In the early stage of decay wood is brown to tan. In the advanced stage wood is yellowish-white, soft and spongy, with narrow dark brown to black zone lines. Decay usually begins in the upper part of the bole, and progresses downward.

The hard, perennial, hoof-shaped fruit bodies are up to 8 inches wide and develop in great abundance on dead trees. (Fig. 91). They have a smooth, dark gray, or gray-black, concentrically zoned uppersurface. The undersurface is gray to gray-brown.

Distribution: Widespread.

Importance: A most important decayer of dead trees.

5. Diseases Affecting More Than One Tissue.

A. Name: Dwarf mistletoe.

Organism: *Arceuthobium americanum* Nutt. ex Engelm. This is a parasitic plant that depends upon its host for water, shelter, support, and most of its mineral and organic nutrients. Its dependency upon the host plant is reflected in its form, which features a well developed "root" system, a branching aerial stem, reduced "leaves" and a highly developed fruit.

Hosts: This organism affects lodgepole and jack pine, and occasionally white spruce.

Disease: The most conspicuous symptom of dwarf mistletoe infection is a WITCH'S BROOM (Fig. 92). The sizes and shapes of brooms vary depending upon the tree species, those of jack pine being the largest, those on white spruce being quite small but very dense, and those on lodgepole pine being somewhat intermediate. Less obvious symptoms are spindle-shaped swellings of branches and stems (Fig. 93).

Plate XIX

Fig. 86. a. Upper and under surface of _Trametes odorata_.

b. Upper and under surface of _Lenzites saepiaria_.

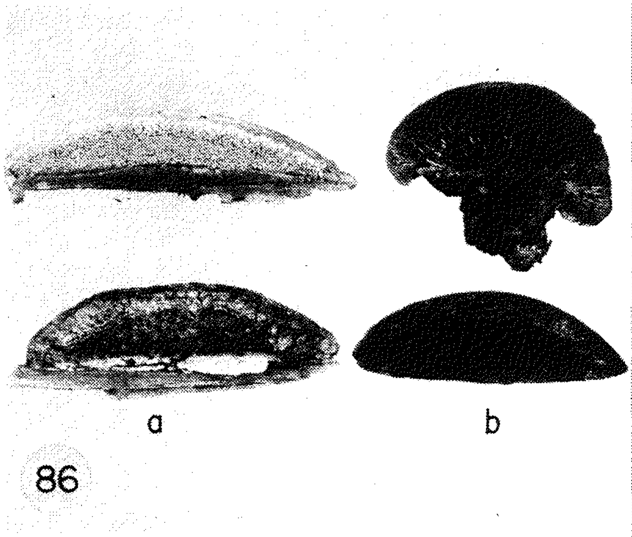
Fig. 87. Upper and lower surface of _Ganoderma applanatum_.

Fig. 88. Shelf-like fruit bodies of _Polyporus abietinus_.

Fig. 89. Crust-like fruit bodies of _P. abietinus_.

Fig. 90. Both surfaces of _Fomes subroseus_ are pinkish to rose-coloured.

Fig. 91. Hoof-shaped fruit bodies of _Fomes fomentarius_.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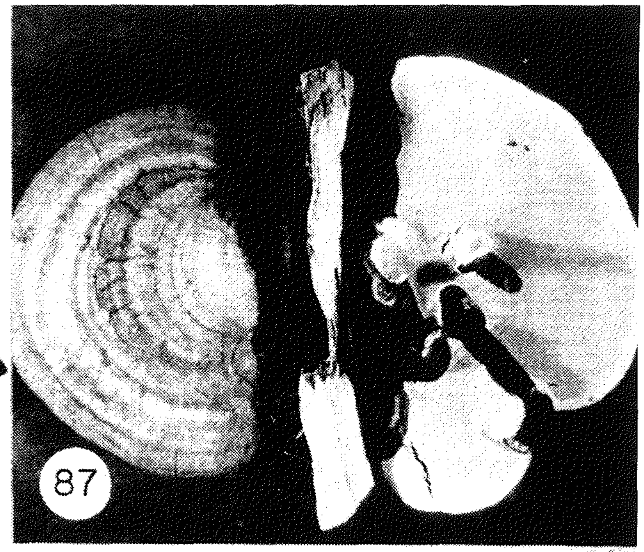
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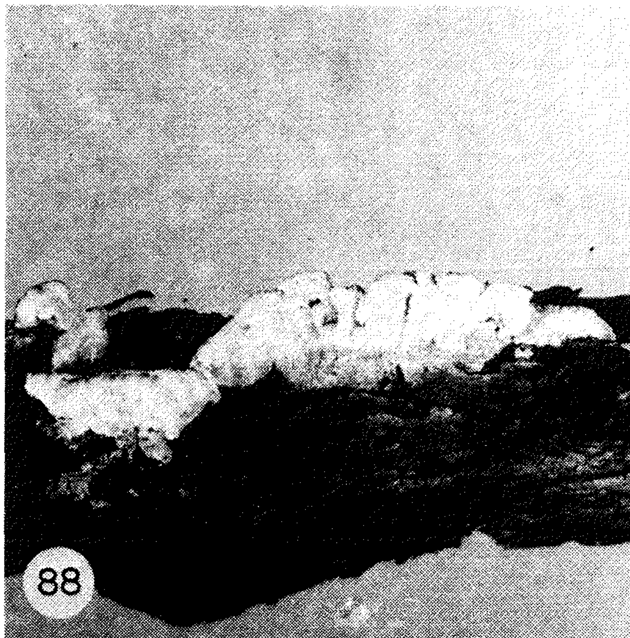
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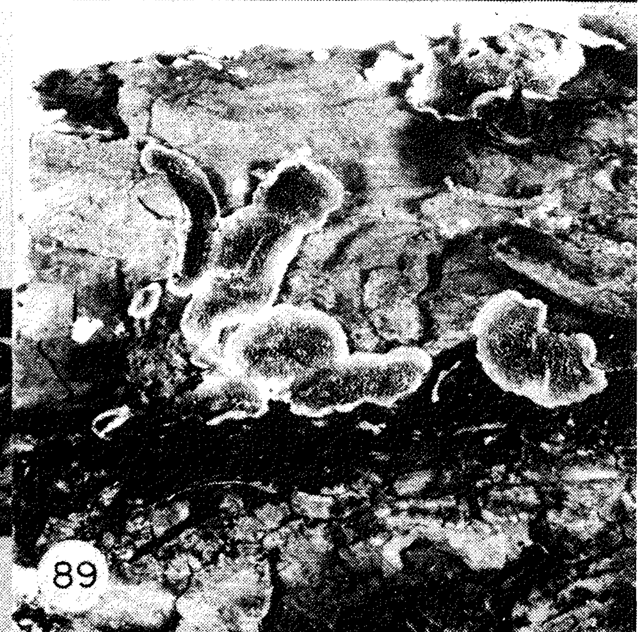
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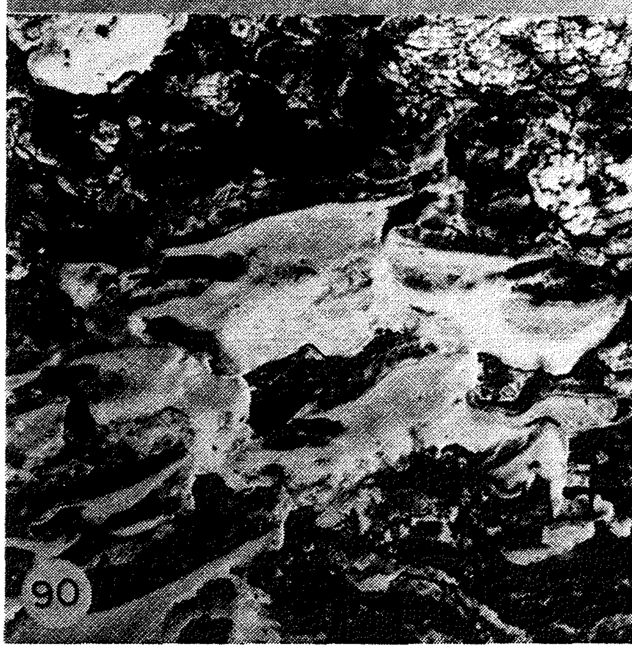
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Aerial shoots of dwarf mistletoe arise at the edges of these swellings, and provide the most diagnostic sign of the disease. The shoot varies from purplish-brown to green, and at maturity it may be about 5 inches long. Male and female plants usually develop on the same tree, but from separate infections.

Life cycle: The plants are perennial, and flower for several years in succession. The fruit is produced singly at the tip of a short stalk, which is in turn attached to the shoot. Many fruits (berries) are produced on a single plant. The oval, green, fleshy berry contains a single large seed. By the time the fruit has ripened the stalk has become elongated and recurved (Fig. 94). As the result of moisture uptake an internal pressure develops within the fruit sufficient to expel the seed and to project it for distances up to 20 feet (Fig. 95). The expelled seed is coated with VISCIN, which enables it to adhere to any surface. Most of the seeds land on the needles of the same or adjacent trees (Fig. 96). On wetting, the viscin becomes gelatinous and allows the seed to slide along the needle to its base where germination occurs (Fig. 97). The germ tube elongates until its growing tip is obstructed, usually at the junction of the leaf and twig. At this point a wedge-shaped pad develops, and penetration of the host bark occurs. A "root system" develops in the cambial region of the host. As the tree grows, parts of this root system become embedded in the wood as sinkers. The root system remains perennial within the host, and after about 4 years it produces aerial shoots.

Distribution: Dwarf mistletoe on lodgepole and jack pines is known in Alberta from the Cypress Hills to Wood Buffalo Park. Many heavily affected stands occur in this region. Its occurrence on spruce has been reported from four localities, Snaring River (J.N.P.), Johnston Canyon (B.N.P.), Kananaskis Forest Experiment Station, and Cypress Hills.

Importance: Old witches' brooms sometimes weigh several hundred pounds and are easily broken off. Dry brooms at the base of infected trees increase the fire hazard. In addition the resulting wounds are excellent openings for fungus attack.

Branch swellings and stem infections have a marked effect on the properties of the wood, causing abnormal grain, resin impregnation, and spongy texture. Larger than usual knots develop because of the witches' brooms.

The parasite tends to reduce the life functions of the host. If death does not result from this cause alone, the way is opened for various secondary agents which do not attack vigorously growing trees.

Plate XX

Fig. 92. Witch's broom caused by *Arceuthobium americanum* on lodgepole pine.

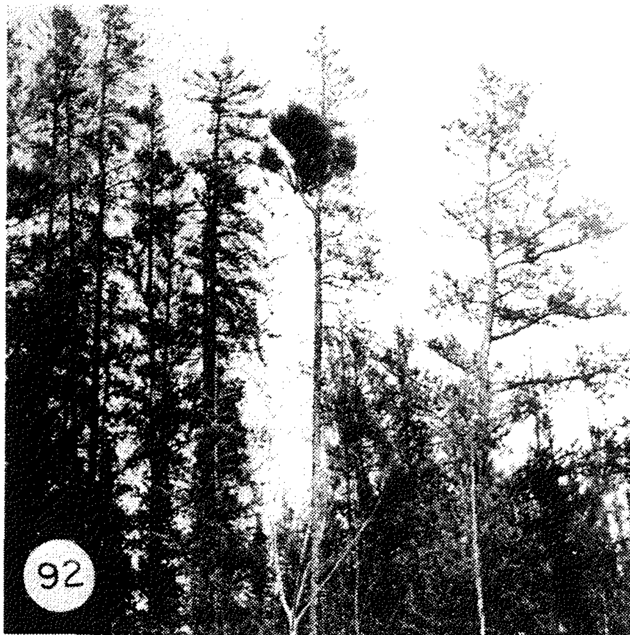
Fig. 93. Fusiform branch swelling with dwarf mistletoe plants.

Fig. 94. Oval green fleshy berries of dwarf mistletoe.

Fig. 95. Dwarf mistletoe seed at the moment of ejection.

Fig. 96. Dwarf mistletoe seeds adhering to lodgepole pine needles.

Fig. 97. Germinating dwarf mistletoe seed.



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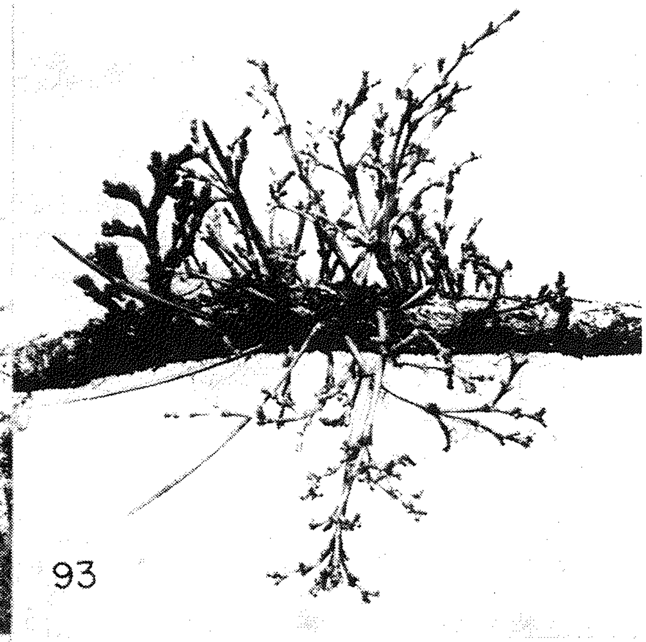

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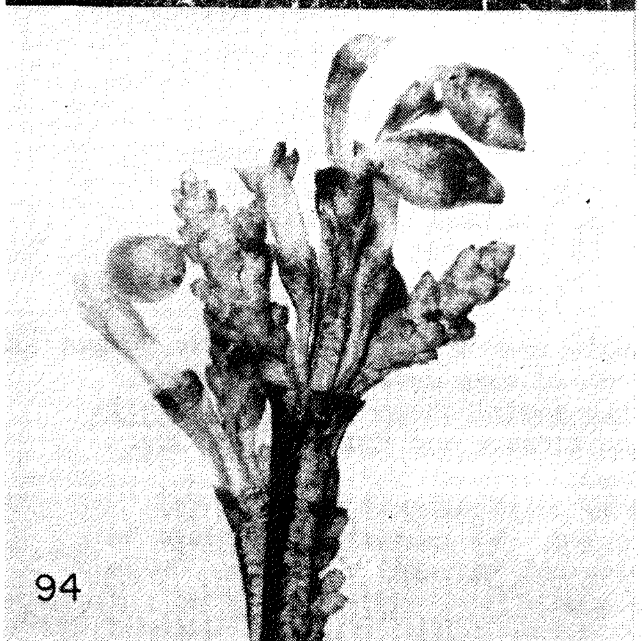

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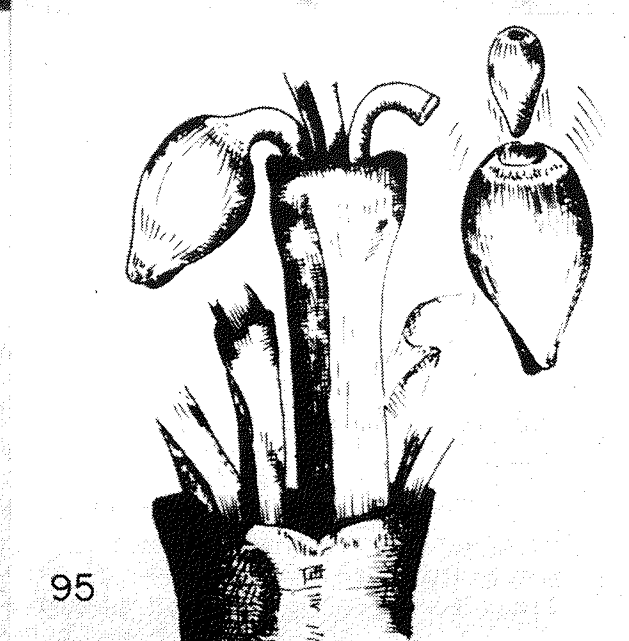

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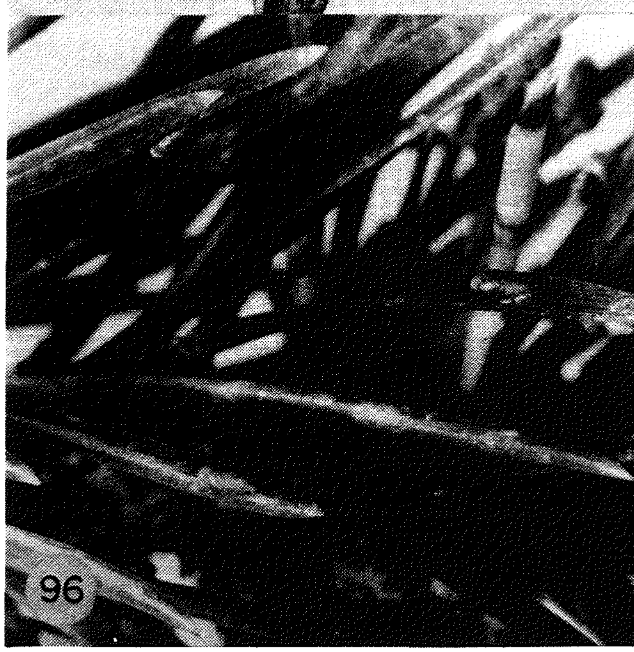

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Dwarf mistletoe reduces not only the quality of the wood but also the quantity. The following data were taken from an 84 year old stand, and show the severe growth reduction that can occur as a result of mistletoe attack.

Dominants & Codominants	Heavy infection	Not infected
Avg. height	14 ft.	36 ft.
Avg. d.b.h.	2.1 in.	5.2 in.
Merch. volume/acre	0.0 cu.ft.	1,850 cu.ft.
Basal area/acre (living)	58.4 sq.ft.	192.9 sq.ft.
Percentage of trees dead	18.0	3.0

Control: Dwarf mistletoe is subject to control by direct means for the following reasons since (a) it is confined to the above ground parts of its host, (b) its seed has limited dispersal, (c) it requires a living host, and (d) it occurs in infection centres that are surrounded by disease-free trees.

There are no known chemicals that are effective. Two fungus HYPERPARASITES provide limited control in some areas in some years, *Septogloeum gillii* Ellis acting on the aerial stems and *Wallrothiella arceuthobii* (Pk.) Sacc. acting on the flowers and fruits (Fig. 98).

Control is best obtained by silvicultural means by (a) eliminating overhead sources of inoculum, (b) sanitation cuttings in young infected stands, and (c) pruning out infected branches. Guide lines for pruning infected branches are:

Diam. of Infected Branch (ins.)	Prune if distance between infection and main stem is greater than:
0 - 1.0	6.0
1.1 - 2.0	8.0
2.1 - 3.0	10.0
3.1 - 4.0	12.0

Once a stand has been sanitized by either eliminating overhead inoculum sources, cleaning, or pruning, it should be further protected by a clear-cut zone 50 feet or more wide. Periodic treatment of the standard protective zone is necessary.

B. Name: Yellow witch's broom.

Organism: Melampsorella caryophyllacearum Schroet.

This is a long-cycled rust. The fungus grows perennially in living branches and annually on chickweed. In the spring or early summer orange coloured pycnia appear on both surfaces of fir needles. By midsummer aecia develop on the under surface of the needles as two rows of orange-yellow blisters (Fig. 99). The aeciospores are windborne and infect the leaves of chickweed. Uredia and telia are produced on this host. Teliospores germinate and infect fir in the following spring.

Hosts: The coniferous hosts in this region are alpine and balsam firs The broad-leaved hosts are chickweed (Stellaria spp. and Cerastium spp.).

Disease: Infected branches develop numerous upright shoots from one point resulting in a compact witch's broom (Fig. 100). The infected twigs and foliage are dwarfed. The leaves are yellowish and drop by the following spring, leaving the brooms bare until the new shoots develop. In addition to witches' brooms, pronounced swellings of the trunk or branches can occur.

Distribution: The fungus is fairly common through most of the range of the hosts.

Importance: Considered economically unimportant in Alberta.

C. Name: Yellow witch's broom.

Organism: Chrysomyxa arctostaphyli Diet. (Synonym: Peridermium coloradense (Diet.) Arth. & Kern).

Hosts: Coniferous hosts are white, black, and Engelmann spruces. Broad-leaved host is bearberry (Kinikinik, Arctostaphylos uva-ursi).

Disease: The life cycle and symptoms of this disease are the same as for *Melampsorella caryophyllacearum* on fir, except that swellings on the trunk and branches are unknown (Fig. 101).

Distribution: Common everywhere in spruce stands of the region.

Importance: Considered economically unimportant.

D. Name: Fire blight.

Organism: *Erwinia amylovora* (Burrill) Winslow. This bacterium infects blossoms of many species of the Rosaceae. Infection spreads from the blighted bloom to the young fruit and down to the living tissues of branches where cankers are formed. The bacteria overwinter in this tissue at the edge of cankers. In moist spring weather bacteria appear on the surfaces of cankers as shiny drops which are spread by rain or insects to new blossoms.

Hosts: Mountain ash, (*Sorbus* spp.), apple, and pear trees and *Cotoneaster* spp.

Disease: Blossoms and leaves of infected twigs wilt, turn dark brown to black, shrivel and die, but remain attached to twigs. The bark is shrunken, dark brown to purplish. Brown or black blighted branches with dead persistent leaves look as if scorched by fire.

Distribution: Settled areas of the region.

Importance: Important in shade and ornamental trees.

E. Name: Aspen shoot blight.

Organism: *Venturia tremulae* Aderh. (*Pollaccia radiosa* (Lib.) Bals. & Cif.)

Hosts: Aspen.

Disease: The tip of infected leaves are curled, black, brittle, and shrivelled. Young shoots are black, blighted, and bent back in the form of "shepherds' crooks" (Fig. 102). Blighted tissues may be coated with a green, velvety layer of conidiophores.

Distribution: Scattered throughout the range of aspen.

Importance: Not important in forest stands, may be of concern in shelterbelts.

F. Name: Poplar shoot blight.

Organism: *Venturia populina* (Vuill.) Fabric. (*Pollaccia elegans* Serv.).

Hosts: Balsam poplar.

Disease: As for *V. tremulae*.

Distribution: As for *V. tremulae*.

Importance: As for *V. tremulae*.

G. Name: Brown felt blight.

Organism: This disease is caused by two fungi: *Herpotrichia nigra* Hart., *Neopeckia coulteri* (Pk.) Sacc.

Hosts: *H. nigra* occurs on conifers other than pines.
N. coulteri is confined to pines.

Disease: These fungi develop on foliage under snow at high elevations. Lower branches which become exposed when the snow melts are covered with a dense, brown to almost black mycelial felt (Fig. 103). The foliage is killed by the dense mycelium excluding light and air. The hyphae also penetrate leaf tissues.

Distribution: These fungi are confined to mountainous regions.

Importance: Considered to be economically unimportant.

Plate XXI

Fig. 98. Black fruit bodies of Wallrothiella arceuthobii on the fruits of dwarf mistletoe.

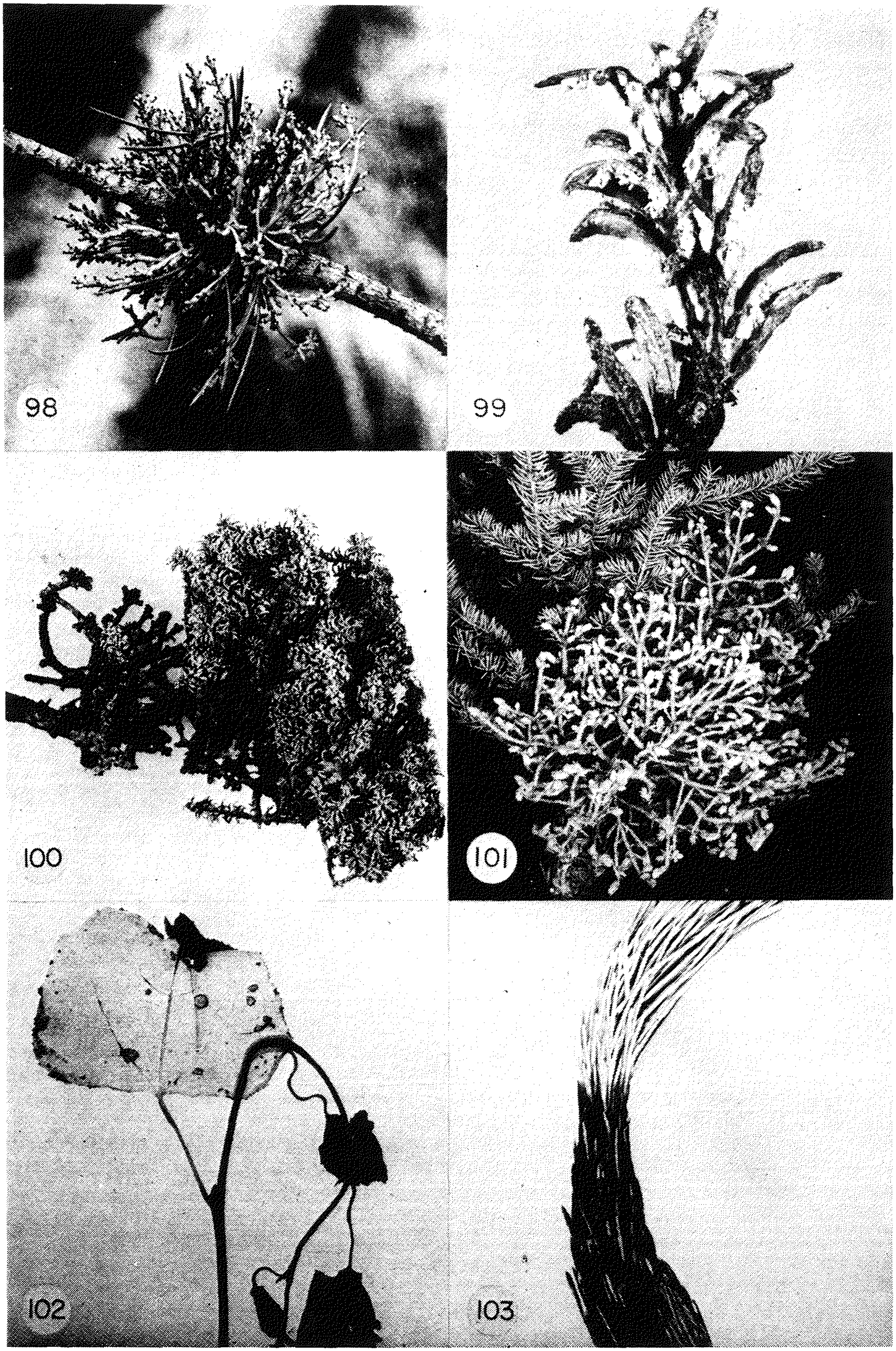
Fig. 99. The orange-yellow aecia of Melampsorella caryophyllacearum develop of the under surface of needles.

Fig. 100. Compact witch's broom of M. caryophyllacearum.

Fig. 101. Witch's broom caused by Chrysomyxa arctostaphyli which is looser than that of M. caryophyllacearum.

Fig. 102. Shoot blight caused by Venturia tremulae.

Fig. 103. Dark mycelial felt of Neopeckia coulteri on lodgepole pine foliage.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VII. OTHER NOTEWORTHY INFECTIOUS DISEASES OF THE REGION

Disease & Causal Agent	Host in Alberta	Tissues Affected	Remarks
1. Cankers:			
A. Black canker of Aspen, caused possibly by bacteria.	Aspen	Stem	Large black flaring cankers on small pockets of trees. Not serious unless widespread.
B. Black canker of spruce, caused possibly by *Retinocyclus abietis* (Crouan) Groves & Wells	White and Engelmann spruce	Stem	Dark resinous cankers appear to be initiated by mechanical damage and then kept open by the fungus. Not serious from forestry standpoint.
2. Needle Casts:			
A. Larch needle cast, caused by *Hypodermella laricis* Von Tub.	Western larch	Needles	Affected needles remain on trees for years. Not considered dangerous.
B. Pine needle cast caused by *Lophodermium pinastri* (Schrad. ex Fr.) Chev.	Lodgepole and Jack pine	Needles	May be confused with other more serious needle cast diseases.
C. Spruce needle cast caused by *Bifusella crepidiformis* Darker	White spruce	Needles	Needles do not fall but remain attached longer than normal.

2. Needle Casts cont'd.

D. Fir needle cast caused by *Hypodermella abietis-concoloris* (Mayr.) Dearn. and *H. mirabilis* Darker	Alpine and Balsam fir	Needles	Not considered serious.

3. Needle and Leaf Rusts:

A. Douglas fir needle rust caused by *Melampsora albertensis* Arth.	Douglas fir	Needles	Alt. hosts are species of *Populus*. Not considered serious on either host.
B. Spruce needle rust caused by *Chrysomyxa weirii* Jacks.	White and Engelmann spruce	Needles	Alt. hosts are species of *Moneses* and *Pyrola*. Not serious but occurs mixed with other rusts.
C. Fir needle rust caused by *Pucciniastrum goeppertianum* (Kuehn) Kleb.	Alpine and Balsam fir	Needles	Alt. hosts are species of *Vaccinium*. Not considered serious.
D. Willow leaf rust caused by *Melampsora epitea* Thuem.	Willows	Leaves	Alt. hosts are firs, larches, currants and gooseberries. Probably more than one variety of rust involved, not considered serious.

VIII. FOREST PATHOLOGY IN PRACTICE

Effective control of tree diseases is based on knowing what causes them and how they develop. In addition, it is necessary to find out the kinds of trees that can be affected if the spread of a disease is to be checked. When infectious agents are involved, it is also necessary to learn their life cycles and biological requirements. Information of this kind can only be obtained as the result of carefully planned surveys and research that may take up to several years to complete.

Learning the identity of a pathogen is sometimes a difficult task. Apart from this, some of the complications of investigating the life cycles and biologies of forest pathogens are: certain pathogens need up to several years to complete their life cycles; more than one host may be needed to complete a life cycle; some pathogens grow on only living plant tissues, others on only dead tissues, and others grow on both living and dead tissues but at different rates; pathogens vary in their ability to attack trees and tissues of different kinds and ages; weather, climate, soil and other non-living components of the environment can influence the development of not only pathogens but also their hosts. Reliable information on points such as these is needed if the ways of controlling tree diseases are to be found. Control measures that are based on an inadequate accumulation of biological facts are quite likely to either fail or be only partly effective.

Once the information is on hand to show that control is possible, certain decisions have to be made on how to carry it out in a practical and economical way. In general, the kind and amount of control carried out will depend upon the value of the forest to be protected, e.g., only forests having high values will justify extensive and costly control measures. Complete control is usually possible and desirable where it involves shade and ornamental trees, shelterbelts, parklands, and sometimes in forest nurseries. The possibilities for complete control in the forest are limited and are seldom attempted because of large areas, inaccessibility, varying topography and environments, long rotations, and the relatively low value of individual trees in the forest. Control under these circumstances is designed to either reduce losses to an acceptable level, or to prevent large losses in the future.

There are four general ways to control forest diseases. They may be either prevented from entering an area (i.e., excluded), totally removed from an area (i.e., eradicated), prevented from attacking trees by applications of protective chemicals to potentially susceptible trees, or prevented from attacking trees successfully (i.e., immunization) by eliminating susceptible hosts. Each of these methods can be effective, depending upon the kind of disease to be controlled and the amount of funds that are available for control work.

Exclusion. Diseases can be excluded from an area either by intercepting diseased material in shipments of planting stock and forest products, or by prohibiting the importation of living plant material that is known to be susceptible to specific diseases. These approaches to control have been only partly effective because of: (1) limited inspection and plant quarantine services; (2) incomplete knowledge of the diseases of foreign plants; (3) the lack of natural barriers to airborne pathogens. Because of these limitations it is unlikely that a particular disease can be permanently excluded from an area. This method of control is useful, however, since it can provide time to devise alternative and more permanent means for control.

Eradication. This form of control usually involves finding and destroying all of the diseased material. This can be done either by destroying complete trees, by pruning out and destroying the diseased portions of trees, or by disinfecting diseased material by chemical means. Sometimes a disease can be controlled by eliminating one or other of its alternate hosts.

Control by eradication requires an efficient detection service and the continuous supply of funds to complete the eradication program. This form of control is best applied when infection centres are small and widely separated. It is also useful in parklands, shelterbelts, and to preserve shade and ornamental trees. It is a very costly method under any other circumstances.

Protection. Artificial barriers can be placed between infectious agents and their potential hosts. This is usually done with chemicals, that can be applied either in the form of sprays or dusts. This form of control is effective, provided that the proper chemical is used and is applied before the pathogen has reached its host in sufficient volume to cause much damage. However, the use of chemicals is a temporary measure that often has to be repeated several times, either in the same year or in successive years. For this reason control by chemical means is best employed to protect individual trees, shelterbelts, and nursery stock. Occasionally chemicals are used over wide areas, but usually only to gain the necessary time to find more effective and lasting ways to control diseases.

Trees can be protected from disease by indirect means, either by changing the environment in which they are growing, or by placing them in environments that are unfavourable to disease development. By regulating the density of stands through thinnings and planting patterns the opportunities for diseases to develop can be decreased. Chemical fertilizers can be used to promote tree vigour, which in turn can diminish the opportunities for diseases to develop. Fall planting of seedlings sometimes avoids diseases that are active mainly early in the year.

Immunization. The purpose of this form of control is to either find or create disease resistant trees that can be used as sources of seed for the establishment of plantations. This can be done either by selecting and protecting naturally resistant trees, or by breeding. Tree selection is based on the knowledge that, over long periods, most species of plants become resistant to specific diseases. Tree breeding is done mainly when there is little or no evidence of resistance in natural stands. The tree selection method is preferable, since prospective seed trees can be selected not only on the basis of their resistance to disease but also because of superior growth and form. A major difficulty in tree breeding is to produce trees that are not only disease resistant, but which also have good form and growth. Extensive periods of testing for disease resistance are needed in both methods, but despite these limitations tree selection and breeding theoretically give the final solution to disease problems.

Taking into account the number of opportunities that exist for controlling tree diseases, only a very limited start has been made in this aspect of forest protection. Part of the reason for limited effort towards disease control has been the lack of research and surveys, until recent years, to provide the information on which to base control action. Another contributing factor to the lack of control work has been the generally slow trend towards intensive forest management. Until forest values increase and become stabilized at a high level, mainly because of local and national demands for wood products, the incentive and justification to spend large sums of money on disease control will remain questionable.

Thus far, disease control in Alberta has been limited to considerations of heartwood decay and stains. Research and surveys in this direction have made it possible to set up cutting practices for trees of different species and ages. Within a very few years it is quite likely that the growing concern over the quantity and quality of young forests in the Province will reach a point where disease control will be justified on a fairly broad scale. Until then the practising forester can help to control forest diseases by:

1. recommending the cutting of diseased and poor quality trees where possible,

2. recommending the cutting of old stands in preference to young stands,

3. preventing where possible mechanical damage to residual trees in cut-over areas,

4. protecting superior growing sites from fire,

5. favouring the best species of trees in particular sites,

6. detecting and reporting new or unusually damaging diseases to research and survey agencies.

IX. DEVELOPMENT OF FOREST DISEASE INVESTIGATIONS

Robert Hartig, a German forester who lived between 1839 and 1901, was the father of forest pathology. It was he who in 1874 properly diagnosed, for the first time, the relation between fungus hyphae in decayed wood and the fruit bodies on the tree. Since Hartig's time, forest pathological research has increased greatly in Europe where, up until recently, the possibilities of disease control through stand manipulation have been much greater than in North America.

In the United States, forest disease research was begun in 1899 with the creation of a Federal Government Laboratory at St. Louis under the direction of the U.S. Department of Agriculture. In that country there has been a slow but steady growth until at the present, there are many regional research centres operated by the U. S. Forest Service. A building program to provide needed increases in space and facilities is currently under way. The universities in the United States support forest disease research by the appointment of staff members to teach and conduct research in this field.

Forest disease research in Canada has been carried out largely by the Federal Government. The first properly qualified forest pathologist was appointed in 1920. This number had grown to 4 by 1941. After the Second World War, research efforts in forest pathology were greatly expanded and today there are 51 research scientists and approximately 100 field and laboratory technicians employed by the Federal Government in this field. In addition, 71 forest insect and disease rangers collect and assess both disease and insects within the framework of a continuing forest insect and disease survey.

Commencing in 1947, the Alberta region was served by forest pathologists based at a Federal Laboratory in Saskatoon. In 1951 a forest pathology unit was added to the Forest Entomology Laboratory of the Canada Department of Agriculture at Calgary. The area served by this laboratory comprised the Province of Alberta, the Rocky Mountain National Parks, and the Northwest Territories.

In 1971 the staff from Calgary and Winnipeg were combined in a new Environment Canada headquarters called the Northern Forest Research Centre in Edmonton serving the prairie region, the North West Territories and the Yukon.

At the present time, forest disease work involves not only research on specific disease problems, but also a continuing survey of forest disease conditions in the region. The aim of this survey is to detect, identify, record, and interpret the significance of tree diseases. The earliest surveys emphasized general collecting to build up an herbarium and to point up the most important problems of the region. The more recent survey work has emphasized damage appraisals to an increasing degree.

This brief sketch emphasizes that forest pathology has been a subject of study and research in Canada for a relatively short period. While much useful information has been gained during this time, there is still a great deal of work needed to bring about effective control of tree diseases in this country.

X. RECOMMENDED PROCEDURES FOR DETECTING, COLLECTING, AND REPORTING TREE DISEASES

Because of staff limitations, assistance in the detection and reporting of diseases is required. The cooperation provided by the Alberta Department of Lands and Forests, the National Parks Service, and industrial concerns has been and continues to be important. Contacts can be made directly with either laboratory field staff or headquarters at 5320 - 122nd Street in Edmonton.

Disease detection is basically the recognition of unnatural forest conditions, and requires continuing careful observations whenever travelling in forested areas. An important follow-up for detecting diseases is the collecting of suitable material to show the signs and symptoms of diseases. When such material is sent to the Laboratory for identification, it should be accompanied by an "ENCLOSURE SLIP" (Fig. 104). These forms are to provide the information that is necessary to make a proper evaluation of the disease. The original copy of this form should accompany the specimen; the carbon copy can be retained by the sender. Instructions for completing the enclosure slip are printed on the first page of each booklet of forms. These are obtainable on request.

Material being sent to the laboratory for identification should be representative of the disease conditions as observed in the field. If possible it should be surface dry before shipping. Leafy material should be pressed if possible, and shipped in this condition. Paper bags and cardboard boxes are the most suitable shipping containers. Plastic and cellophane containers are not suitable for this purpose because they promote molding of the contents. The name and address of the sender is needed so that replies can be made.

XI. GLOSSARY

Adventitious shoots: those shoots which develop in either an irregular or unusual position.

Aecial stage: the second spore stage in the life cycle of rust fungi producing aeciospores (Figs. 25, 38, 40, 41, 45, 53, 56 and 58).

Aeciospore: Bi-nucleate rust spore formed in an aecium (Figs. 56 and 58).

Aecium, pl. Aecia: A cup-like structure, which produces chains of aeciospores (Fig. 25).

Alga, pl. Algae: A simple green plant lacking stems and leaves.

Alternate host: One or other of the two hosts necessary for the completion of the life cycle of certain rust fungi.

Annulus: A ringlike structure around the stipe of the mushroom (Fig. 21).

Plate XXII

Fig. 104. Enclosure slip.

FOREST INSECT & DISEASE SURVEY SAMPLING FORM

1. INSECT 2. DISEASE

LOCATION

COLLECTION POINT (be specific) — NEAREST POST OFFICE

LOCALITY (use Forest Dist. or Div. or Drainage Div. or Political Sub-Div. or FIDS Dist.) [2]

UTM GRID DESIGNATION [5] — PLOT OR SAMPLE AREA NO. [12] — ELEVATION [14]

STAND EXAMINED

16 DESCRIPTION	17 HISTORY	18 ASPECT	19 MATURITY
1. Nursery	1. Undisturbed	1. North	1. Seedling (nursery)
2. Ornamentals	2. Clear cut	2. Northeast	2. Transplant (nursery)
3. Plantation (Nat. Sp.)	3. Selective cut	3. East	3. Seedling (forest)
4. Plantation (Exot. Sp.)	4. Burned	4. Southeast	4. Sapling
5. Shelterbelt	5. Insect damaged	5. South	5. Young growth
6. Hedgerow	6. Disease damaged	6. Southwest	6. Semi-mature
7. Woodlot	7. Animal damaged	7. West	7. Mature
8. Natural forest	8. Climate damaged	8. Northwest	8. Over-mature
9. Treed swamp	9. Wind damaged	9. Flat	20 AGE STRUCTURE
0. Scattered individuals	0. Water damaged		1. Even 2. Two 3. Uneven
	-. Unknown		

21 BASAL AREA (Circle code of nearest no. of sq. ft.) 1. (33) 2. (66) 3. (99) 4. (132) 5. (165) 6. (198) 7. (221) 8. (254) 9. (287) 0. (320) -. (353) +. (386)

FOREST SECT. [22] — COVER OR SUB-TYPE [25] — DOMINANT SPECIES [29]

30 HEIGHT OF DOMINANT TREES (Circle code of nearest ht. in ft.) 1. (0.5) 2. (1.5) 3. (3) 4. (7) 5. (15) 6. (30) 7. (45) 8. (70) 9. (100) 0. (140) -. (180) +. (210)

TREES SAMPLED

TREE SPECIES [31] — NO. OF TREES SAMPLED [34]

36 STATUS		37 TREE CLASS		
1. Living	6. Rec. dead fallen	1. Dominant	4. Suppressed	7. Fringe
4. Rec. dead stndg.	7. Old dead stndg.	2. Codominant	5. Undergrown regen.	8. Open
5. Rec. dead cut	8. Old dead fallen	3. Intermediate	6. Understory tree	9. Old vet.
	9. Manufactured			

DATA ON INSECT(S) OR DISEASE(S)

38 SAMPLING TECHNIQUE Qualitative	Quantitative	39 POPULATION LEVEL OR INCIDENCE	40 COLLECTION SOURCE	
1. Beating	2. Beating	1. Negative	1. Flower	7. Branch
3. Hand picked	4. Hand picked	2. Trace	2. Fruit	8. Stem
5. Traps	6. Traps	3. Low	3. Buds	9. Butt
7. Ground observation	8. Ground observ.	4. Moderate	4. Old foliage	0. Root
9. Aerial observation	0. Aerial observ.	5. High	5. New foliage	-. Duff or soil
-. Photography	+. Photography	6. N.A.	6. New shoot	+. N.A.

SAMPLE UNIT NO. — NUMBER OF UNITS [41] — DAMAGE & HAZARD INDEX [46]

COUNT PER UNIT — AV. COUNT [43]

GENERAL

FIDS NO. (See codes on cover) [47] — LAND OWNERSHIP (See codes on cover) [49] — DAY [50] — MO. [52]

COLLECTOR

ADDRESS

REMARKS & SYMPTOMS

1

Apothecium, pl. Apothecia: Cuplike structure containing asci (Fig. 19).

Ascospore: Spore produced in an ascus (Fig. 16).

Ascus, pl. Asci: Sack-like structure containing a definite number of ascospores, usually eight (Figs. 16 and 19).

Asexual reproduction: reproduction not involving nuclear fusion.

Asphyxiation: death caused by lack of oxygen.

Atrophic symptoms: symptoms resulting from growth reduction of affected tissues, e.g., dwarfed needles (Figs. 99 and 100).

Bacterium, pl. Bacteria: typically one-celled microorganisms which have no chlorophyll, and multiply by simple division.

Basidium, pl. Basidia: a club-shaped structure at the tip of a hypha, bearing (usually) four basidiospores (Figs. 17, 20 and 21).

Basidial stage: the fifth and last stage in the life cycle of rust fungi, producing 4 bandiospores (Fig. 28).

Basidiospore: a spore produced on a basidium (Figs. 17, 20 and 21).

Blight: a common name for a number of different diseases typified by sudden leaf damage and often by general wilting of flowers and stems.

Blue sapwood stain: a deep seated blue, black, or gray discolouration confined mostly to sapwood (Fig. 84).

Boreal forest: northern forest.

Brown cubical rot: A rot in which the causal fungi generally made a more concentrated attack on cellulose than lignin. The brown friable residue splits along rectangular planes in the advanced stage of decay (Fig. 65).

Callus: Tissue that develops at the margins of wounds and tends to cover them.

Cambium: The actively dividing layer of cells which lies between xylem and phloem tissues (Fig. 30).

Canker: An area of diseased tissue, often sunken, on a living host stem or branch.

Causal agent: The cause of a disease.

Cellulose: The chief substance in the cell walls of woody plant parts.

Chlorophyll: The green material in plants, which in the presence of sunlight converts carbon dioxide and water into sugar.

Chloroplast: A small chlorophyll-bearing component of the plant cell.

Chlorosis: yellowing of normally green tissue.

Conidium, pl. Conidia: an asexual spore formed usually at the top of a specialized hypha (Fig. 18).

Conidiophore: a specialized hypha on which conidia are produced (Fig. 18).

Context: part of the interior of a basidiomycete fruit body (Fig. 20).

Decay: the process by which sound wood is destroyed by the action of fungi.

Disease agent: The cause of a disease.

Drought: Serious water deficiency.

Facultative parasitism: The ability of normally saprophytic organisms to parasitize, i.e., to live on living material.

Facultative saprophytism: The ability of normally parasitic organisms to live on dead material.

Fruit body: a fungus structure containing or bearing spores: conk, mushroom, apothecium etc. (Figs. 19, 20, 21 and 22).

Fungus, pl. Fungi: a multicellular organism lacking chlorophyll and usually reproducing by means of spores.

Gall: a permanent swelling in plants involving abnormal amounts of tissue (Fig. 61).

Hardpan: a compacted or cemented soil horizon.

Heart rot: a rot characteristically confined to the heartwood (Figs. 65, 72, 74 and 80).

Heartwood: the inner layers of wood which, in the growing tree contain only a very few living cells (Fig. 30).

Hemicellulose: a component of the cell walls of woody plant parts.

Higher plants: plants that produce seeds.

Host: an organism on or within which another organism feeds and develops.

Hymenium: the spore-bearing layer of a fungus fruit body (Figs. 19 and 21).

Hyperparasite: an organism that is parasitic on another parasite.

Hypertrophic symptoms: symptoms resulting from excessive growth (Fig. 93).

Hypha, pl. Hyphae: a single thread of mycelium (Fig. 13).

Immunity: having qualities which do not permit infection.

Incubation period: the time between inoculation and the development of visible symptoms.

Infection: the initiation of a disease.

Infectious: Capable of causing an infection.

Infection court: a suitable place for infection to occur, e.g., natural opening, wounds, etc.

Ink spot: leaf disease of poplars (Fig. 42).

Inoculation: the placing of inoculum on or in the host.

Inoculum: infectious material.

Lamella, pl. Lamellae: gill of a mushroom (Fig. 21).

Lenticel: A bark opening through which gaseous exchange between the atmosphere and the intercellular spaces of the bark is effected.

Lesion: an area of diseased tissue.

Lignin: a principal component of the cell walls in woody plant parts.

Meristem: tissue made up of cells each of which is capable of division, giving rise to new cells; meristematic adj. of meristem.

Micro-organism: organisms difficult or impossible to see with the naked eye, e.g., bacteria and many fungi.

Molds: fungi with conspicuous mycelium or spore masses found growing over the surface of many materials.

Mycelium, pl. Mycelia: a mass of fungus hyphae.

Necrotic symptoms: symptoms produced by the death of plant cells (Fig. 49).

Nucleus: The central organized body of a plant cell.

Obligate parasitism: inability of a pathogen to live on anything but living tissues.

Obligate saprophytism: inability of a pathogen to live on anything but dead material.

Parasite: an organism which lives at the expense of another, usually invading it and causing disease.

Parasitism: the process of invasion and colonization of one organism by another, i.e., one plant living at the expense of another living plant.

Parenchyma: plant tissue comprised of thin-walled cells which function primarily in the storage and distribution of food materials (Fig. 31).

Pathogen: an organism capable of causing disease.

Pathogenicity: capability of causing disease.

Periderm: protective layer of bark.

Perithecium, pl. Perithecia: flask-like fruit body of ascomycetes.

Phellogen: bark cambium giving rise to the periderm (Fig. 30).

Phenology: the science that deals with the time and sequence of the development of plants.

Phloem: inner bark tissue which functions in the transport of elaborated foods from the leaves (Fig. 30).

Photosynthesis: the building up in green plants of plant foods from carbon dioxide and water. The energy for this process is obtained from sunlight acting on chlorophyll.

Pigment: any colouring matter in the cells and tissues of plants.

Pileus: the cap of a mushroom (Fig. 21).

Polygonal: having the form of a polygon which is a plane figure with several angles and sides.

Primary inoculum: the first inoculum which reaches the host in the growing season.

Promycelium, pl. promycelia: an outgrowth of a rust telispore, which bears basidiospores (Fig. 28).

Punk knots: rotted knots where the wood has been replaced by masses of fungus material.

Pycnial stage: first stage in the life cycle of rusts in which pycniospores are produced (Fig. 24).

Pycniospore: a spore borne in a pycnium.

Pycnium, pl. Pycnia: flasklike fruit body containing pycniospores (Fig. 24).

Ray cells: the cells of wood rays (Fig. 31).

Red belt: winter drying of conifers in mountainous areas producing bands of reddened trees at specific elevations (Fig. 7).

Red heartwood stain: a pronounced reddish colouration, induced by fungi in the heartwood of conifers (Figs. 70 and 82).

Resinosis: an abnormal flow of resin or pitch from conifers (Figs. 50 and 52).

Resistance: ability to suppress or retard the activity of a pathogen.

Resupinate: flat (Figs. 64, 73, 75, 81, 83 and 89).

Rhizomorph: a strand of fungus hyphae.

Root necrosis: death of roots.

Saprophyte: an organism which lives on lifeless organic matter.

Saprot: a rot occurring in sapwood.

Sapwood: the outer portion of a woody stem (Fig. 30).

Sclerotium, pl. Sclerotia: a hard mass of fungus tissue, resistant to unfavourable conditions.

Secondary inoculum: inoculum produced during the growing season.

Septum, pl. septa: the cross wall in a hypha (Fig. 13).

Sessile: having no stem.

Sexual reproduction: reproduction involving the union of two nuclei.

Sign: visible portion of a pathogen on a diseased host, e.g., spores, mycelia, fruit body.

Sinker: part of the dwarf mistletoe "root system".

Sporangium, pl. Sporangia: an organ producing asexual spores (Fig. 15).

Spore: a small fungus structure functioning as a seed, but differing in that a spore does not contain an embryo (Fig. 14).

Sporophore: any structure which bears spores.

Spring wood: the less dense portion of an annual ring produced at the beginning of the growing season (minor portion of a growth ring).

Stain fungi: fungi that cause wood discolouration but little or no decay (Fig. 84).

Stigma: that part of a flower which receives the pollen for effective fertilization.

Stipe: a stalk (Fig. 21).

Stipitate: stalked.

Stoma, pl. Stomata: a small opening on the surface of a leaf permitting gaseous exchange.

Stroma, pl. Stromata: a dense mass of fungus hyphae containing or bearing fruit bodies (Fig. 22).

Suberin: a waxy or fatty substance occurring in bark and other plant tissues.

Substrate: the material on which an organism lives and often obtains its nourishment.

Summerwood: the denser portion of an annual ring produced during the latter part of the growing season (the outer portion of a growth ring).

Sunscald: heat injury to bark and cambium resulting from exposure to intense sunlight.

Susceptible: non-resistant, i.e., permitting the attack of a pathogen.

Symbiont: the participants in symbiosis.

Symbiosis: the relationship of two dissimilar organisms living together in close association, which is harmless or helpful to the two organisms.

Symptom: any reaction of a host plant to disease.

Tar spots: a disease causing black crusts on leaves (Fig. 29).

Telial stage: a late stage in the life cycle of rusts in which teliospores are produced (Figs. 27, 55, 57 and 60).

Telium, pl. Telia: rust fruit body producing teliospores.

Teliospore: thick-walled rust spore giving rise to basidiospores.

Trachea, pl. Tracheae: a conducting element in the xylem of broadleaved trees.

Tracheid: a conducting and supporting element in xylem of coniferous trees (Fig. 31).

Uredial stage: a stage in the life cycle of rusts in which uredospores are produced (Figs. 26, 54 and 57).

Uredospore: a rust spore.

Uredium, pl. Uredia: rust fruit body producing uredospores (Figs. 26, 54 and 57).

Vascular diseases: diseases affecting the conductive system of plants (xylem, phloem).

Virus: ultra microscopic particles capable of causing disease.

Viscin: a sticky substance present in the berries of dwarf mistletoe.

White rot: a rot caused by any fungus which destroys lignin more readily than cellulose (Fig. 71).

Wilt: a disease symptom in plants caused by water deficiency.

Witch's broom: excessive branching in parts of trees as the result of disease.

Wood fibers: elongated, thick-walled cells.

Wood ray: ribbon-shaped strand of tissue extending in a radial direction across the grain (Figs. 30 and 31).

Xylem: the woody tissues of plants.

XII. INDEX