Diseases of Forest and Ornamental Trees

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DISEASES OF FOREST AND ORNAMENTAL TREES

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Preface

In recent years public interest in trees and their diseases has greatly increased, partly because attention has been drawn to them by the losses caused by Dutch elm disease. The increasing numbers of arboricultural officers, consultants and tree surgeons as well as our foresters need a new book on the tree diseases of Britain, incorporating information acquired since the publication of the late T. R. Peace's *Pathology of Trees and Shrubs with Special Reference to Britain.* Peace's comprehensive work, published by the Clarendon Press, Oxford, in 1962, is now out of date and out of print.

The present book deals with the diseases found in Britain on forest and ornamental trees. Most of these diseases also occur elsewhere, and in our account we have therefore drawn on all the available literature, though we have had to be selective, and our interpretations are inevitably coloured by the fact that our experience of tree diseases has been mainly in the British Isles. We generally comment on diseases (and pests) alien to Britain only in the section on plant health legislation. We describe diseases of fruit trees such as the apple, pear and cherry only in so far as they affect ornamental forms of the fruit tree genera and species. These diseases are already treated at greater length in texts on diseases of orchard trees.

The depth and length of the treatment given to individual diseases varies, and in general reflects both the importance of the disorders concerned and the information available about them. In many cases we have divided the diseases into those occurring mainly in the nursery and those important chiefly after the nursery stage. In other cases this has not been possible or useful, and then, for the sake of uniformity, we have grouped all under one main heading as 'nursery and post-nursery' diseases.

Our aims have been wide: we have tried to make the book useful to forest and general plant pathologists, foresters and forest managers, arboriculturists and tree surgeons, staffs of parks and gardens, staff and students of universities and other places of further education and of research stations, and to all those generally interested in trees. Where possible we have provided information on symptoms, factors affecting disease expression, host range and resistance, and brief descriptions of causal organisms. We have not provided a lengthy introduction to mycology, bacteriology and virology, but in the case of bacterial and fungal diseases have usually supplied enough bacterial or mycological detail to enable the professional pathologist to make a diagnosis based on this and the other material given. Further information must be sought in the more extensive bacterial and mycological (and virological) texts cited in the bibliographies.

Name changes of both disease organisms and their hosts cause problems in practical fields such as forestry, arboriculture and plant pathology. We have generally attempted to apply current names to pathogens and to trees. In the case of pathogens we give the better known synonyms when we use what to some may be unfamiliar names. In the case of trees we usually supply the common names now used in Britain as well as the current scientific names.

Control measures are suggested for many diseases; in some cases, however, no control measures are as yet available. A good many diseases are too minor in their effects for control measures to be required. If it appears necessary to attempt the control of any of these lesser diseases, the general measures discussed in chapter 1 may be applied. Mention is made of many fungicides and bactericides. New chemicals are continually being introduced and old ones withdrawn, however, and the reader wishing to use these materials is advised to consult the latest issue of the *List of Approved Products and Their Uses For Farmers and Growers*, which is revised annually and published for the Ministry of Agriculture, Fisheries and Food by Her Majesty's Stationery Office.

The introductory chapter on symptoms, diagnosis and control of diseases is intended mainly for the student, the beginner, and the general reader. In the rest of the book the diseases are grouped chiefly under their host genera. Most of the diseases with a wide host range (including the disorders caused by nonliving agents such as frost or air pollution), however, are described in separate chapters. In a few cases organisms affect several hosts but are far more important on one than on any of the others; they are then described under the main host. The decay fungi (many of which also have a wide host range) are also drawn together in one chapter.

Many of our colleagues have made valuable comments on the text. Among them we must especially mention the late Dr S. Batko (who helped particularly by translating literature from many languages), Dr W. O. Binns, Dr C. M. Brasier, Dr J. N. Gibbs, Mr B. J. W. Greig, Dr D. Lonsdale, Mr J. D. Low, Mr W. J. McCavish, Dr D. B. Redfern, Mr R. G. Strouts, and the late Mr C. W. T. Young. Miss Mary Trusler greatly helped by printing photographs, and Mr J. Williamson drew figure 25.

The book owes much to the decision of the publishers to illustrate many of the diseases in colour. Many of the photographs are from the collection of the Forestry Commission, to whom special thanks are therefore due. These and the other illustrations are separately listed and acknowledged elsewhere. Fuller acknowledgement of black and white illustrations from sources outside our own collections and those of the Forestry Commission are as follows. Figures 3, 4, 27, 98: B. J. W. Greig. Figures 47, 85: W. B. Grove (1913), *British Rust Fungi*, Cambridge University Press, Cambridge. Figures 51, 54, 60, 83: R. Hartig (1894), *Text-book of the Diseases of Trees*, Macmillan, London. Figure 63: D. B. Redfern. Figure 5: G. A. Salt (1974), *Trans. Br. mycol. Soc.*, **63**, 339–51. Figures 7, 8, 61, 77, 78, 81, 84: K. F. Tubeuf (1895), Pflanzenkrankheiten, Springer, Berlin. Figure 10: J. H. Western (1971), *Diseases of Crop Plants*, Macmillan, London.

Figure 48: M. Wilson and D. M. Henderson (1966), *British Rust Fungi*, Cambridge University Press, Cambridge. Figures 9, 86, 88: H. Wormald (1955), *Diseases of Fruits and Hops*, Crosby Lockwood, London. Figure 67: C.M. Braiser.

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Contents

1 General introduction

Disease is a disorganisation of the normal physiological activity of the tree caused by some adverse agent which gives rise to characteristic symptoms. Hence a diseased tree differs from a healthy one in recognisable ways, and the pathologist must first of all become familiar with the appearance and characteristics of healthy trees. Thus in cold weather the foliage of nursery plants of western red cedar (*Thuja plicata*) may turn from green to bronze (plate 39). This colour change is normal and reversible, and the affected plants are not diseased. Nevertheless, if the temperature becomes sufficiently low, the foliage of these plants is killed, but they then become an irreversible glossy black. Similarly, the fungus *Didymascella*

thujina may attack and kill the scale leaves of *Thuja* seedlings. The affected plants show the small fruit bodies of the fungus (plate 40) and are diseased, and their growth is reduced; if enough scale leaves are destroyed the plants die. Again, the bark of London plane (*Platanus* x *acerifolia*) peels off the tree in a typical pattern, but this is a normal phenomenon, whereas the breaking up of the bark in the late stages of beech bark disease (figure 56) is an indication of severe and irreparable damage by *Nectria coccinea* and other associated fungi.

CAUSES OF DISEASE

The agents that cause diseases may be nonliving or living. Among the nonliving agents are climatic factors such as high or low temperatures, drought and lightning, soil factors such as poor soil aeration and the lack of essential nutrients, and injurious chemicals such as atmospheric pollutants and misplaced herbicides. Damage by these agents is associated with some discrete event or series of events, such as an emission of some polluting chemical, or with the absence of some necessary element (as in the case of nutrient deficiency disorders). Disorders caused by nonliving agents are not infectious so they cannot spread from tree to tree.

The living pathogens include the fungi (the most important), the bacteria, and the semiparasitic mistletoes. The viruses, which are ultramicroscopic and can reproduce only in their host cells, are also included here. Some disorders formerly regarded as virus diseases now appear to be caused by mycoplasmas or by mycoplasma-like organisms. The mycoplasmas are now considered to be small bacteria. Those affecting plants are still little known. The diseases caused by these living pathogens are infectious and can spread from tree to tree by means of their own spores or other disseminules either alone or with the aid of one or more vectors.

Many fungi cause diseases of trees (and of other plants). The true fungi (excluding the slime moulds) are divided into five main subdivisions. The first two, the Mastigomycotina and the Zygomycotina, were formerly grouped together as the Phycomycetes. These fungi are microscopic, one-celled or formed of mainly nonseptate threads (*hyphae*) which in aggregate are described as *mycelium*. Most, if not all, the fungi in these groups that attack trees are classified in the Peronosporales, of the order Oomycetes, which form a class of the Mastigomycotina. Included here are species of *Phytophthora* and other downy mildews.

In the third and fourth subdivisions, the hyphae that make up both the vegetative body and the fructifications are septate (that is, they are divided into segments by cross walls). The fruit bodies are generally relatively large, and readily visible to the naked eye or with the aid of a hand lens. In the first of these two groups, the Ascomycotina (Ascomycetes), the sexual spores are borne inside sac-like or tubular *asci*. In a few the fruit body containing the asci is very simple, consisting of little or nothing more than an ascal layer (*hymenium*), as in the case of *Taphrina populina*, the cause of popular leaf blister (plate 28). In others

(if we confine ourselves to those causing diseases in trees) the asci are enclosed in more or less globular, flask-shaped, saucer-shaped, or boat-shaped fruit bodies. Included here are, for example, the powdery mildews (such as the oak mildew, *Microsphaera alphitoides*), with small, globular fruit bodies (*cleistothecia*) (plate 29), the *Nectria* species (including *N. cinnabarina*, with small, bright red, flask-shaped *perithecia*) (plate 14), *Lachnellula willkommii*, the cause of larch canker (with small, disc-shaped *apothecia* with a white outer wall and a bright orange hymenial disc) (plate 23), and the *Lophodermium* species associated with needle cast in pines, with a boat-shaped *hysterothecium* opening by a slit (figure 37).

In the second of these groups, the Basidiomycotina (Basidiomycetes), the sexual spores are borne outside usually club-shaped *basidia*. Of the three classes of the Basidiomycotina, only two contain pathogens. The first, the Hemibasidiomycetes, includes the Uredinales (the rusts), such as species of *Cronartium*, *Coleosporium* and *Melampsora*. The rusts often exhibit complex life histories, which in their most complete form involve the production of a series of spore types. Some of these spores arise on one host, while others form on a second, alternate host, which may be necessary for the completion of the life cycle. These spore forms and their associated fructifications are described below.

(1) *Spermatia*: small sex-cells produced in minute *spermogonia*, embedded in the leaves or stems.

(2) *Aecidiospores*: produced in *aecidia*, which are often cup-shaped or cylindrical (figure 38), like those of *Coleosporium tussilaginis* on needles of pines, or blister-like, like those of *Peridermium pini* on pine stems (plate 12).

(3) *Uredospores*: produced in *uredosori*, small, often yellow or brown pustules; the uredosori of *C. tussilaginis* occur on *Senecio*, *Tussilago*, and other members of the Compositae.

(4) *Teleutospores*: produced in *teleutosori* which often resemble the uredosori and follow them on the same leaves (as they do in the case of *C. tussilaginis*). In some rusts the spores in these sori are massed together into small columns that stand up above the leaf surface like minute bristles. This is so in *Cronartium ribicola*, the white pine blister rust, the teleutosori of which occur on the leaves of the black currant and other species of *Ribes* (figure 43). In species of *Gymnosporangium*, the teleutosori form as large, gelatinous, cushion-shaped or horn-like bodies (figure 47).

The second of these groups among the Basidiomycotina, the Hymenomycetes, includes the Agaricales (plate 17) (the toadstools, such as *Armillaria mellea* and similar forms) and the Aphyllophorales, important among which are the pore-bearing bracket fungi, with many wood-decay organisms such as *Heterobasidion annosum* (*Fomes annosus*) (plate 18).

Finally, the fifth subdivision of the fungi is the Deuteromycotina (Deuteromycetes, the Fungi Imperfecti), an artificial assemblage consisting mainly of asexual forms of ascomycetes and of fungi with no known affinity with other groups. The fruit bodies of these fungi often superficially resemble those of

ascomycetes, but they contain asexual spores instead of asci with ascospores.

For further information on the fungi, reference should be made to standard mycological texts such as those of Webster (1977) and Burnett (1977).

The few bacteria known to cause diseases of trees are species of *Agrobacterium*, *Pseudomonas*, *Erwinia* and *Xanthomonas*. Further details on these are available in the texts of Dowson (1957) and Stapp (1961).

A recent summary of the diseases caused in trees by the viruses and the mycoplasma-like organisms has been prepared by Cooper (1979).

SYMPTOMS OF DISEASE

Symptoms of disease may be found on any part of the tree, on the leaves, on the stems and branches, and on the roots.

SYMPTOMS ON LEAVES

Colour changes

Browning and death The leaves may be partly or completely killed, when they usually turn brown (or sometimes black). This death of leaves may have many causes. It may be due to drought, or to wind damage, or frost, or sometimes to air pollution. Fungi may also sometimes destroy leaves in this way. Thus in severe attacks *Lophodermium* spp. may kill the needles of young pines in the nursery, and *Meria laricis* may similarly affect nursery plants of European larch. The leaves of broadleaved trees may also be killed and become brown. Thus secondary spread of *Ceratocystis ulmi* (the cause of Dutch elm disease) through root systems may produce rapid browning and death of the crown of the tree. Primary spread by insect vectors in its later stages also leads to leaf death. Sometimes leaf browning may be marginal only, as is often the case with leaves scorched by wind.

Other colour changes In some cases browning and death of leaves may be replaced or preceded by other colour changes. As already noted, severely cold-damaged fronds of *Thuja plicata* die and turn glossy black.

Nursery plants (and sometimes plantation trees) may change colour when affected by mineral deficiencies (plates 5, 6, 7, 8). Thus plants deficient in nitrogen tend to be pale green, while those short of potash may become pinkish, purplish or sometimes yellow. Magnesium deficiency is indicated by a bright yellow colour which on the leaves of broadleaved trees occurs mainly between the veins. Pines on very alkaline sites often become yellow at about 10–15 years of age, and then gradually die. This is due to a complex deficiency disorder called lime-induced chlorosis. The same disease may also affect other trees (including broadleaved ones), though usually less markedly.

Virus diseases may also cause yellowing of leaves. This yellowing may take the form of a more or less regular mottle or mosaic, or it may follow the leaf veins ('vein clearing'), or appear as lines or rings (figure 76).

Some wilt diseases that block the vessels (and at least some of which produce toxins) may cause the foliage of parts of the crown to become yellow or red. Thus one of the earliest primary symptoms of Dutch elm disease, caused by *Ceratocystis ulmi*, is a yellowing of the foliage of isolated branches of the tree. Eventually (as noted above) the affected leaves die and become brown. Leaves in parts of the crown of willows affected by watermark disease (caused by the bacterium *Erwinia salicis*) turn bright red.

Some rusts may cause a yellowing of leaves; an example is provided by *Chrysomyxa* spp. which produce yellow bands on diseased spruce needles (plate 19).

Leaf distortion and reduction

A more or less general distortion of leaf shape may be caused by hormone weed killers such as 2,4,D.

Some fungi may also cause leaf distortion. Among these are the various species of *Taphrina*, including *T. deformans* which gives rise to leaf curl in peaches and almonds (plate 55), and *T. populina* which causes leaf blister in poplars (plate 28).

Many root disease fungi reduce the size of leaves. Pine trees attacked by *Heterobasidion annosum* (*Fomes annosus*) at first have short, sparse needles, which eventually fall as the tree dies.

Some virus diseases may cause the distortion of leaves and the production of small outgrowths (enations) from their surfaces.

General mould growths

Fungal attack may show itself as a more or less general mould growth. *Botrytis cinerea*, the common grey mould, appears as a greyish, sparse or more woolly growth of mould (plate 4) (often with small sporing heads and sometimes with rounded black fungal aggregates called *sclerotia*) on the leaf surface. The oidial stages of powdery mildews, such as oak mildew (*Microsphaera alphitoides*), form a powdery white (or at first yellowish or brownish) cover on the leaf surface (figures 50, 89).

Fungal fructifications

More clearly marked fungal fruit bodies may also be found on leaves (usually on spots or areas of dead or dying leaf tissue). The fungus *Rhytisma acerinum* forms large thickened black stromata ('tar spots') on the leaves of sycamore (plate 26).

Examination of the concave surfaces of the blisters on poplar leaves affected by the leaf blister disease mentioned earlier will reveal a golden-yellow lining consisting of a layer of the asci of the ascomycete *Taphrina populina* (plate 28).

Other, more distinctive ascocarps produced on leaves include, for example, the cleistothecia (cleistocarps), perithecia, hysterothecia and apothecia described above.

Among the basidiomycetes, the rusts give rise to various fructifications on leaves. These fruit bodies have also been listed above.

Finally, various small, asexual, so-called imperfect fructifications (fruit bodies of the Deuteromycotina, including asexual stages of ascomycetes) may be found on leaves. Many look like small black perithecia (when they are called *pycnidia*), but they contain asexual spores instead of asci.

SYMPTOMS ON STEMS AND BRANCHES

Splits in bark and wood

Splits in the bark and wood are often due to drought or frost damage. In the later stages of beech bark disease (associated with *Nectria coccinea*) the bark of affected trees may break into pieces and eventually fall off (figure 60).

Watery exudations

Sap may exude from cracks in tree trunks. Continuing, often foul-smelling, sap flowing from the bark of broadleaved trees may indicate the bacterial disorder wetwood (plate 11). Such exudations may also be caused by *Phytophthora* species, as in the case of the bleeding canker sometimes found on the horse chestnut (figure 88).

Exudations of bacterial slime

Wetwood exudations may often become slimy through the activities of bacteria and yeasts, and are then known as slime fluxes. In some bacterial diseases (notably in the case of bacterial canker of poplar, caused by *Xanthomonas populi*) thick bacterial slime may exude from small cracks in the bark of young stems and branches.

Resin flows

Resin may sometimes exude through the bark of conifers and flow down the trunk. Such resin flows often indicate root damage by fungi such as *Phytophthora* spp., *Armillaria mellea* or *Heterobasidion annosum* (figure 17). Resin may also exude from the stem cankers produced on pines by *Cronartium* spp. and other fungi (figure 42).

Distortions and malformations

In some seasons plant stems (including small branches of trees) may become wide, flattened and strap-like. This growth abnormality is known as *fasciation*.

Cold damage insufficient to cause death may distort the growth of tree shoots. Distortion of tree shoots may also be caused by fungi. Thus the pine twisting rust, *Melampsora pinitorqua* (a race of *M. populnea*), causes a twisting of the pine shoots (mainly of Scots pine) on which it grows (figure 40). The ends of the shoots of elms affected by Dutch elm disease often bend to form 'shepherds'

crooks' which provide a useful diagnostic feature after leaf fall (figure 68).

Some fungi may cause the production of dense groups of adventitious shoots called 'witches' brooms'. An example is the witches' broom of birch caused by *Taphrina betulina* (figures 58, 59). Some viruses (and some mites) can also give rise to similar malformations on some trees.

Very marked distortions of stems of young trees may be caused by the honeysuckle (*Lonicera periclymenum*). This damage is mechanical since the honeysuckle is not a parasite.

Chemical distortion, especially of rather soft shoots, may follow applications of hormone weed killers.

Cankers

Sometimes a disease agent kills part of the cambium and the adjacent bark. The cambium around the lesion then produces new tissue which grows inwards to cover the dead area. If no further damage occurs, the canker will be occluded, and enveloped by the stem tissues. Often, however, further annual damage occurs, accompanied by further growth, and a large, swollen canker results. Such cankers are caused on poplar by the bacterium *Xanthomonas populi* (figure 75). Rough-surfaced cankers are produced on ash by another bacterium, *Pseudomonas savastanoi* f. *fraxini* (plate 31).

Other cankers are caused by fungi. Among these is the canker of larch caused by *Lachnellula willkommii* (figures 45, 46). Rusts of the genus *Cronartium* also give rise to cankers on pine trunks and branches. Among these rusts are *Cronartium ribicola*, the white pine blister rust, and *Peridermium pini* (an aecidial form of *C. flaccidum*).

General fungal growths

Grey mould (*Botrytis cinerea*), already mentioned in connection with leaves, may also produce lesions (often sunken) on twigs, and on stems of nursery plants. On these lesions it produces its mycelium, with masses of sporing heads, and sometimes its black sclerotia.

The honey fungus, *Armillaria mellea*, will often be found on dead or diseased trees as a thick sheet of creamy or whitish mycelium under the bark at the base of the trunk. At a later stage the fungus produces a network of flattened, bootlace-like *rhizomorphs*, also under the bark (figure 15). These rhizomorphs have a black outer surface, but have a white and (unlike roots) structureless tissue within. *A. mellea* also forms rhizomorphs in the soil. These are similar to those described above, but are round in section. They grow out from infested stumps and roots, and may attack the roots of surrounding trees and shrubs (and sometimes other plants).

Fungal fructifications

When these occur, they are very valuable in diagnosis. Examples among the basidiomycetes are the honey-coloured toadstools of *Armillaria mellea*, which in

autumn usually grow in tufts at the bases of affected trees or on the ground around them (plate 17).

The bracket-shaped root and butt-rotting fungus *Heterobasidion annosum* also occurs at the bases of diseased trees and on infested stumps (plate 18). Another butt-rotting polypore, *Phaeolus schweinitzii* (plate 64) (the velvet-topped fungus), also usually occurs on the ground or at the stem base (but may also be found higher up the trunk), while yet another, *Polyporus squamosus* (the Dryad's saddle), causes a top rot and so fructifies near the top of the tree trunk, often on wounds caused by the loss of branches, for example.

Also among the basidiomycetes, species of *Cronartium* produce large, blister-like, cream or white aecidia filled with orange spores on the cankers caused by these rusts on the stems and branches of pines (plate 12, figure 42).

The fruit bodies of ascomycetes may also be found on trunks and branches. Sheets of the small, red, flask-shaped perithecia of *Nectria coccinea* may grow on the trunks of beech trees affected by beech bark disease.

Reddish-brown stromata containing the embedded perithecia of *Cryptodiaporthe castanea* may be found in cracks in the bark of coppice shoots of sweet chestnuts affected by Cryptodiaporthe canker.

Cup-like or disk-like apothecia of other ascomycetes also occur, like those of *Lachnellula willkommii* on the cankers caused by this fungus on larch (plate 23).

Asexual fruit bodies, imperfect stages of ascomycetes, or the fructifications of Deuteromycetes (Fungi Imperfecti) may also be found. Thus the pink, cushion-like imperfect stage of *Nectria cinnabarina* is common on twigs attacked by this fungus or colonised by it saprophytically (plate 14). Again, the pycnidial stage of *Cryptodiaporthe castanea*, *Fusicoccum castaneum*, occurs around the edges of the perithecial stroma.

Other plant growths

Algae, mosses, liverworts, ferns and lichens often grow on tree trunks and branches, but these growths are purely epiphytic. Plants of mistletoe (*Viscum album*) seen on some trees, however, are semiparasitic.

Internal symptoms

Some symptoms may be hidden inside the twigs, branches or trunks, either as stains, or rots, or as characteristic rings.

The bacterium *Erwinia salicis* causes rusty or inky stains inside the stems of cricket bat willow and other willows (plate 57). Usually after felling, various fungi cause a blue stain of the wood of pines. *Verticillium dahliae* (and the less common *V. albo-atrum*), the cause of verticillium wilt, may give rise to a brown or greenish stain in the stems of affected trees (plate 27) (as it does in the case of many other hosts, including the tomato).

In the early stages of attack many root-rot and butt-rot fungi also cause inky or rusty stains. Later the affected wood usually becomes soft and rotten, and

may then occupy the centre of the stem, surrounded by a stained zone. Some of these fungi cause white rot, others a brown rot. Typical white rot fungi are *Armillaria mellea* and *Heterobasidion annosum*. The first of these causes a soft, wet, stringy rot in a conical zone usually reaching about 60 cm into the butt (figure 17). The second produces a rot with small white pockets of fungal mycelium, and the rot usually reaches much further up the trunk, to a level of about 300–400 cm (figures 29, 30, 31).

Phaeolus schweinitzii, on the other hand, is one of the brown rot fungi. It breaks the wood for a long distance up the trunk into brown, cubical blocks (figure 97), often separated by thin, yellow sheets of mycelium, and the affected wood smells of aniseed.

Rings of abnormal tissue produced by damaged cambium may be produced in twigs in the case of some disorders, and can be seen if the damaged twigs are sectioned and examined under a lens or a microscope. Such rings may be caused by frost (figure 2), drought or lightning.

A rather different type of ring may be found in the twigs of elms affected by Dutch elm disease (and occasionally by some other diseases). Here, sections of diseased twigs show a ring of brown dots in their outer wood (figure 69). If, instead of sectioning the twigs, their bark and outer wood are peeled away, these dots appear as brown streaks (figure 70).

Stem blisters

Cryptostroma corticale, the cause of the sooty bark disease of sycamore, raises the bark of affected trees into large blisters, which eventually break open to release the mass of brown, powdery spores that give the disease its common name (plate 32).

SYMPTOMS ON ROOTS

Symptoms on roots caused by root-rot and butt-rot fungi, such as *Armillaria mellea* and *Heterobasidion annosum*, are broadly similar to those caused in trunks by the same fungi. The roots of conifers attacked by *H. annosum* may exude resin (as happens with the trunks of some trees attacked by this fungus) and internally the roots show characteristic forms of rot.

The ascomycete *Rhizina undulata* (*R. inflata*) is associated with a root disease in conifers, especially in Sitka spruce. Its large, brown, hollow fruit bodies grow on the ground around diseased trees (figure 11), attached to the damaged roots, which also show characteristic lesions (figure 14).

Among the phycomycetes, *Phytophthora cambivora* and *P. cinnamomi* cause Phytophthora root rot in various broadleaved trees. In sweet chestnut the damaged roots may exude a blue, inky stain which seeps out into the soil. This stain gives rise to the name 'ink disease', but it is not in itself diagnostic.

DIAGNOSIS OF DISEASE

In the above account, the various symptoms have been isolated to draw attention to them. It must be emphasised, however, that the pathologist must usually look for symptoms as patterns or groups rather than individually, and the various symptoms added together give a picture of a given disease. The pathologist may also find clues pointing to the causes of various diseases and disorders by noting, for example, the relationships of affected trees to possible sources of air pollution or their position in frost hollows or areas of waterlogged land. He may also gain much in some cases from a study of local weather data, which will assist in the diagnosis of frost or drought damage, or damage by other adverse weather conditions. Growth changes (seen in studies of leader growth and of successive annual rings) may also provide valuable information, indicating, for example, when a decline in growth set in; it may then be possible to correlate the decline with some known adverse factor.

When dealing with diseases caused by living agents, laboratory work is usually needed to isolate and identify the organisms concerned. In the case of a new disease it is necessary to re-inoculate the isolated organism into specimens of the host plant to confirm that they do indeed produce the disease. As final confirmation they must then be re-isolated and rechecked.

Virus diseases require special techniques involving the use of test host plants and electron microscopy, for example.

LOSSES AND DAMAGE CAUSED BY DISEASE

It is usually impossible to make any precise assessment of the losses caused by tree diseases. Some diseases cause little appreciable damage, but others cause clearly visible loss of some kind or other.

Diseases such as anthracnose (*Marssonina salicicola*) (figure 79) of weeping willow make the tree look unsightly, a serious matter in the case of an ornamental tree of parks and gardens. Similarly, blue-stain fungi may give an unpleasant appearance to the wood of pine and so reduce its value and usefulness for many purposes (figure 44). The staining caused by watermark disease (*Erwinia salicis*) in the cricket bat willow (plate 57) renders the wood useless for the manufacture of cricket bats. A wood of high value then becomes virtually unmarketable.

In nurseries, species of *Phytophthora* may destroy plants; the number of dead plants may then be counted. Such a count, however, only estimates the minimum loss, as apparently healthy plants which leave an infected nursery may also be diseased. In many nurseries until recently it was impossible to grow plants of *Thuja plicata* because of the depredations of the needle blight fungus *Didymascella thujina*, though this blight may now be controlled by spraying with cycloheximide.

The stem rust *Cronartium ribicola* makes it virtually impossible to grow the valuable five-needled pine *Pinus strobus* at least on a commercial scale in Britain. So far this rust cannot be controlled (though much work on the breeding of resistant pines has been done in the USA). The fungus *Gremmeniella abietina* (*Brunchorstia pinea*), on the other hand, does not prevent the growing of