8 Habitat of Wood Fungi

Microbial damages to trees and wood can be differentiated into damage to the living tree, to felled and stored wood and in outside use, and to wood in indoor use.

Such grouping is however rather for didactical reasons. There are many overlappings: For example *Daedalea quercina* is occasionally found as wound parasite on living oaks, frequently on stumps, more rarely on timber in outdoor use, like sleepers or bridge timber, and sometimes also on buildings (half-timbering and windows). *Stereum sanguinolentum* causes as well the "wound rot" of spruce trees (Butin 1995) as the red streaking of stored coniferous wood (v. Pechmann et al. 1967).

8.1 Fungal Damage to Living Trees

This chapter belongs to the field of "forest pathology" and only gives an overview. For further reading see Tattar (1978), Schwerdtfeger (1981), Sinclair et al. (1987), Hartmann et al. (1988), Schönhar (1989), Butin (1995), Schwarze et al. (1997), and Nienhaus and Kiewnik (1998). Defense mechanisms of the trees are described by Blanchette and Biggs (1992) (also Chap. 8.2.1).

The tree can be already damaged on its flowers, seeds, and seedlings by fungi that belong to the Oomycetes, Deuteromycetes, or Ascomycetes. Among the more frequently occurring fungi on flowers or inflorescences are host specific *Taphrina* species that affect alder catkins, or female flowers of poplar, and *Thekopsora areolata* damaging spruce inflorescence (Butin 1995).

Seeds can be damaged by non-specific molds of the genera *Alternaria*, *Fusarium*, *Penicillium*, and *Trichothecium*. Among the specialists that can cause internal rotting of seeds are *Rhizoctonia solani* on beechnuts and *Ciboria batschiana* on acorns. Conedera et al. (2004) list several parasitic fungi that colonize chestnuts.

Heat damage in seedlings is often followed by secondary infections by *Alternaria*, *Fusarium*, and *Pestalotia* species. *Thelephora terrestris*, *Helicobasidium brebissonii*, *Rosellinia minor* and *R. aquila* can smother seedlings or young plants. Seedling rots are among the most common diseases in the forest nursery. Important fungi on conifer seedlings are *Phytium debaryanum*, *Phy-*

tophthora species, *Fusarium* species, *Rhizoctonia solani*, and *Macrophomina phaseolina*. The Shoot tip disease of conifer seedlings is caused by *Strasseria geniculata*, *Botrytis cinerea*, and *Sphaeropsis sapinea*. Sirococcus shoot dieback of spruce is caused by *Sirococcus strobilinus*, particularly on *Picea pungens* and *Pinus contorta*. *Meria laricis* causes the Meria needle-cast of young larch. The

Table 8.1. Some leaf diseases caused by fungi (compiled from Butin 1995)

Disease	Causal fungus	Classification
Needle-cast of Douglas fir	*Rhabdocline pseudotsugae* Sydow	Rhytismatales (A)
	Phaeocryptopus gauemannii (Rohde) Petrak	Dothideales (A)
Lophodermium needle blight of spruce	*Lirula macrospora* (R. Hartig) Darker	Rhytismatales (A)
Spruce needle reddening	*Lophodermium piceae* (Fuckel) Höhn.	Rhytismatales (A)
Spruce needle rust	*Chrysomyxa* species	Uredinales (B)
Rhizosphaera needle browning of spruce	*Rhizosphaera kalkhoffii* Bubák	Coelomycetes (D)
Lophodermium needle-cast of pine	*Lophodermium seditiosum* Minter, Staley & Millar	Rhytismatales (A)
Lophodermella pine needle-cast	*Lophodermella sulcigena* (E. Rostrup) Höhn.	Rhytismatales (A)
Naemacyclus needle-cast of pine	*Cyclaneusma minus* (Butin) DiCosmo, Peredo & Minter	Rhytismatales (A)
Dothistroma needle blight of pine	*Mycosphaerella pini* E. Rostrup ap. Munk	Dothideales (A)
Pine needle rust	*Coleosporium* species	Uredinales (B)
Larch needle-cast	*Mycosphaerella laricina* (R. Hartig) Neger	Dothideales (A)
Herpotrichia needle browning of Silver fir	*Herpotrichia parasitica* (R. Hartig) E. Rostrup	Dothideales (A)
Silver fir needle blight	*Hypodermella nervisequia* (DC.) Lagerb.	Rhytismatales (A)
Silver fir needle rust	*Pucciniastrum epilobii* (Pers.) Otth	Uredinales (B)
Black snow mold	*Herpotrichia juniperi* (Duby) Petrak	Dothideales (A)
White snow mold	*Phacidium infestans* P. Karsten s.l.	Helotiales (A)
Keithia disease of *Thuja*	*Didymascella thujina* (E. Durand) Maire	Rhytismatales (A)
Giant leaf-blotch of sycamore	*Pleuroceras pseudoplatani* (Tubeuf) Monod	Diaporthales (A)
Powdery mildew of maple	*Uncinula tulasnei* Fuckel, *Uncinula bicornis* (Wallr.) Lév.	Erysiphales (A)
Tar spot of maple	*Rhytisma acerinum* (Pers.) Fr.	Rhytismatales (A)
Cristulariella leaf spot of maple	*Cristulariella depraedans* (Cooke) Höhn.	Hyphomycetes (D)
Birch leaf rust	*Melampsoridium betulinum* (Pers.) Kleb.	Uredinales (B)
Beech leaf anthracnose	*Apiognomonia errabunda* (Roberge) Höhn.	Diaporthales (A)
Oak leaf browning	*Apiognomonia quercina* (Kleb.) Höhn.	Diaporthales (A)
Oak mildew	*Microsphaera alphitoides* Grif. & Maubl.	Erysiphales (A)
Taphrina gall of alder	*Taphrina tosquinetii* (Westend.) Magnus	Taphrinales (A)
Leaf browning of hornbeam	*Gnomoniella carpinea* (Fr.) Monod	Diaporthales (A)
	Asteroma carpini (Lib.) Sutton	Coelomycetes (D)
Apiognomonia leaf browning of lime	*Apiognomonia tiliae* (Rehm) Höhn.	Diaporthales (A)
Poplar leaf blister	*Taphrina populina* Fr.	Taphrinales (A)
Marssonia leaf-spot of poplar	*Drepanopeziza punctiformis* Gremmen	Helotiales (A)
Septotinia leaf blotch of poplar	*Septotinia populiperda* Waterman & Cash ex Sutton	Helotiales (A)
Poplar and willow leaf rust	*Melampsora* species	Uredinales (B)
Anthracnose of plane	*Apiognomonia veneta* (Sacc. & Speg.) Höhn.	Diaporthales (A)
Leaf blotch of Horse chestnut	*Guignardia aesculi* (Peck) Stew.	Dothideales (A)

A ascomycete, *B* basidiomycete, *D* deuteromycete

Table 8.2. Some fungal damages to buds, shoots, and branches (compiled from Butin 1995)

Disease	Causal fungus	Classification
Cucurbitaria bud blight of spruce	*Gemmamyces piceae* (Borthw.) Cassagrande	Dothideales (A)
Grey mold	*Botryotinia fuckeliana* (de Bary) Whetzel	Helotiales (A)
Sphaeropsis shoot-killing of pine	*Sphaeropsis sapinea* (Fr.) Dyko & Sutton	Coelomycetes (D)
Pine twisting rust	*Melampsora pinitorqua* E. Rostrup	Uredinales (B)
Brunchorstia dieback of conifers	*Gremmeniella abietina* (Lagerb.) Morelet	Coelomycetes (D)
Shoot shedding of pine	*Cenangium ferruginosum* Fr.	Helotiales (A)
Juniper rust	*Gymnosporangium sabinae* (Dickson) Winter	Uredinales (B)
Kabatina shoot killing of Cupressaceae	*Kabatina thujae* Schneider & Arx	Coelomycetes (D)
Pollaccia shoot blight of poplar	*Venturia macularis* (Fr.) E. Müller & Arx	Dothideales (A)
Myxosporium twig blight of birch	*Myxosporium devastans* E. Rostrup	Coelomycetes (D)
Marssonina leaf and shoot blight of willow	*Drepanopeziza sphaerioides* (Pers.) Höhn.	Helotiales (A)

A ascomycete, *B* basidiomycete, *D* deuteromycete

Beech seedling disease is due to *Phytophthora cactorum*. Other *Phytophthora* species attack chestnuts. *Rosellinia quercina*, *Cylindrocarpon destructans* and *Fusarium oxysporum* lead to root damage in young oaks.

Forest canopy fungi were investigated by Stone et al. (1996). A total of 344 different morphotaxa of endophytic fungi were isolated from leaves of *Theobromae cacao*. Most common were *Colletotrichum* sp., *Xylaria* sp. and *Nectria* sp. Inoculation of sterile leaves of young cocoa trees with these endophytes reduced subsequent damage by a parasitic *Phytophthora* sp. (Kull 2004).

Many species of fungi are capable of causing leaf diseases. Hardwood leaf diseases showing superficial fungal growth, or swollen, raised, or dead leaf areas, may be grouped simplistically into leaf spot, blotch, anthracnose, powdery mildew, leaf-blister, and shot-hole. Conifers may show needle spot, cast, blight, and rust (Tattar 1978; Stephan 1981; Butin and Kowalski 1989; Stephan et al. 1991). Table 8.1 only lists some fungi causing leaf diseases. Details on a specific disease may be read in Butin (1995).

Some fungal damages to buds, shoots, and branches are listed in Table 8.2.

8.1.1 Bark Diseases

Some bark diseases caused by fungi are listed in Table 8.3.

Three bark diseases are described in detail.

8.1.1.1 Beech Bark Disease

Beech bark disease (Fig. 8.1) has been known in Europe since about 1849 and was imported to North America (Shigo 1964; Parker 1974; Schütt and

Table 8.3. Some bark diseases (compiled from Butin 1995, supplemented from Jung and Blaschke 2005)

Disease	Causal fungus	Classification
Phacidium disease of conifers	*Phacidium coniferarum* (Hahn) DiCosmo	Helotiales (A)
Spruce bark disease	*Nectria fuckeliana* Booth	Hypocreales (A)
Crumenulopsis stem canker of pine	*Crumenulopsis soraria* (P. Karsten) Groves	Helotiales (A)
Pine stem rust (Resin-top disease)	*Cronartium flaccidum* (Alb. & Schwein.) Winter	Uredinales (B)
	Endocronartium pini (Pers.) Hiratsuka	Uredinales (B)
White pine blister rust	*Cronartium ribicola* J.C. Fischer	Uredinales (B)
Larch canker	*Lachnellula willkommii* (R. Hartig) Dennis	Helotiales (A)
Beech canker	*Nectria ditissima* Tul.	Hypocreales (A)
Beech bark disease	*Nectria* species	Hypocreales (A)
Black bark scab of beech	*Ascodichaena rugosa* Butin	Rhytismatales (A)
Fusicoccum bark canker of oak	*Fusicoccum quercus* Oudem.	Coelomycetes (D)
Chestnut blight	*Cryphonectria parasitica* (Murrill) Barr	Diaporthales (A)
Dothichiza bark necrosis and dieback of poplar	*Cryptodiaporthe populea* (Sacc.) Butin	Diaporthales (A)
Canker stain of plane	*Ceratocystis fimbriata* (Ellis & Halstead) Davidson f. *platani* Walter	Ophiostomatales (A)
Stereum canker rot of Red oak	*Stereum rugosum* (Pers.) Fr.	Aphyllophorales (B)
Pezicula canker of Red oak	*Pezicula cinnamomea* (DC.) Sacc.	Helotiales (A)
Coral spot	*Nectria cinnabarina* (Tode) Fr.	Hypocreales (A)
Sooty bark disease of sycamore	*Cryptostroma corticale* (Ell. & Ev.) Gregory & Waller	Hyphomycetes (D)
Sudden oak death	*Phytophthora ramarum* (Werres, De Cock & Man in't Veld)	Pythiales (O)

A ascomycete, *B* basidiomycete, *D* deuteromycete, *O* oomycete

Lang 1980; Eisenbarth et al. 2001). It develops particularly on trees older than 60 years of European *Fagus sylvatica* and American beech *F. grandifolia* by a disturbance of the water regime due to a abiotic/biotic factor complex: moist site, dry summer, participation of the Beech scale, *Cryptococcus fagisuga* (Lunderstädt 2002) and either one of two bark-killing Ascomycetes, in Europe *Nectria galligena* and in North America *N. coccinea* var. *faginata* (Mahoney et al. 1999), and possibly of mycoplasmas. Classical pathogenesis is an often short-lived mass reproduction of the Beech scale, which causes subcortical changes and subsequent infestation with *Nectria*. Xylem breeding *Trypodendron domesticum* and *Hylecoetus dermestoides* may follow. The larval galleries may be subsequently colonized by white-rot fungi. The susceptibility to the disease is biotically effected, whereby the physiological condition of the tree and its genetic potential determine the efficacy of the damaging agents (Beech scale, *Nectria* spp., beetles, white-rot fungi). The outbreak and/or healing can be controlled by the site conditions (Braun 1977; Lunderstädt 1992).

The fungus invades the bark that was previously altered by the feeding activity of the Beech scale. A red-brown to blackish (bark tannic substances) slimy liquid may ooze from the bark tissue (Wudtke 1991). Under the bark

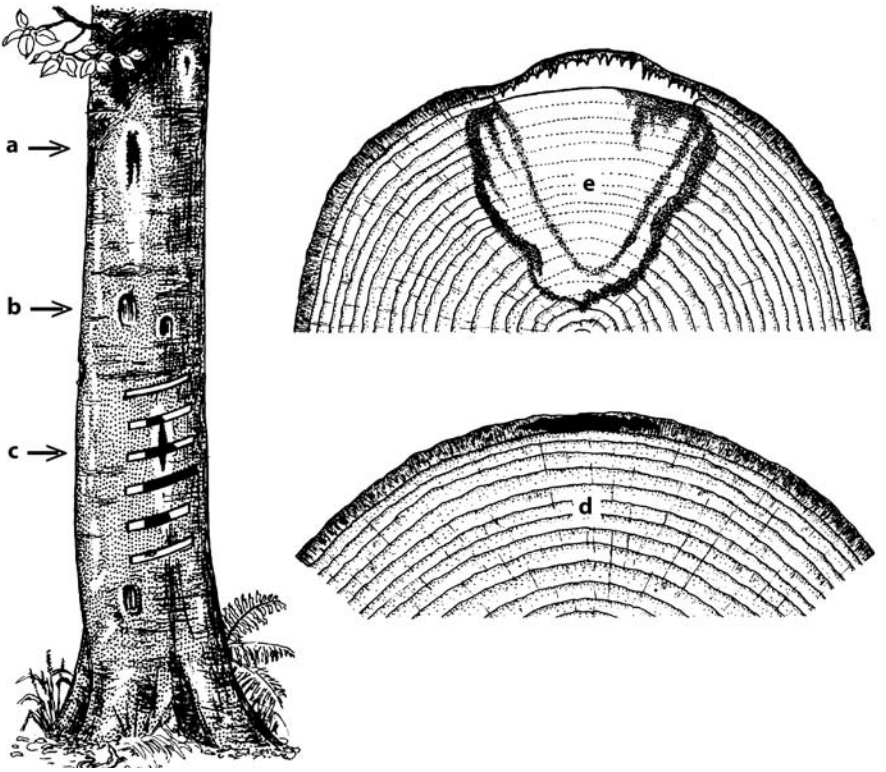

Fig. 8.1. Beech bark disease. *a* tarry spots on the bark, *b* occluded bark lesions, *c* determination of extent of necrosis by scoring the bark with a timber scribe, *d* early stage of necrosis, *e* late stage with incipient white rot (from Butin 1995, by permission of Oxford University Press)

develop dark regions with dead cambium to over 1 m in extension. Small necroses with exposed wood may be closed by callus formation, which leads to a T-shaped fault in the xylem. Tylosis formation causes wilting. Massive invasions can result in tree dieback. Larger necroses form infestation gates for white-rot fungi (*Bjerkandera adusta*, *Fomes fomentarius, Fomitopsis pinicola, Hypoxylon* species, *Stereum hirsutum*) (Eisenbarth et al. 2001).

8.1.1.2 Chestnut Blight

The Chestnut blight (chestnut bark canker) (Fig. 8.2) is caused by the ascomycete *Cryphonectria parasitica* (Halmschlager 1966; Heiniger 1999). The pathogen was imported on Asian rootstock to New York in 1904 and caused lethal cankers on more than 3.5 billion susceptible American chestnut trees, *Castanea dentata*, across 9 million acres of the eastern US, being there at that

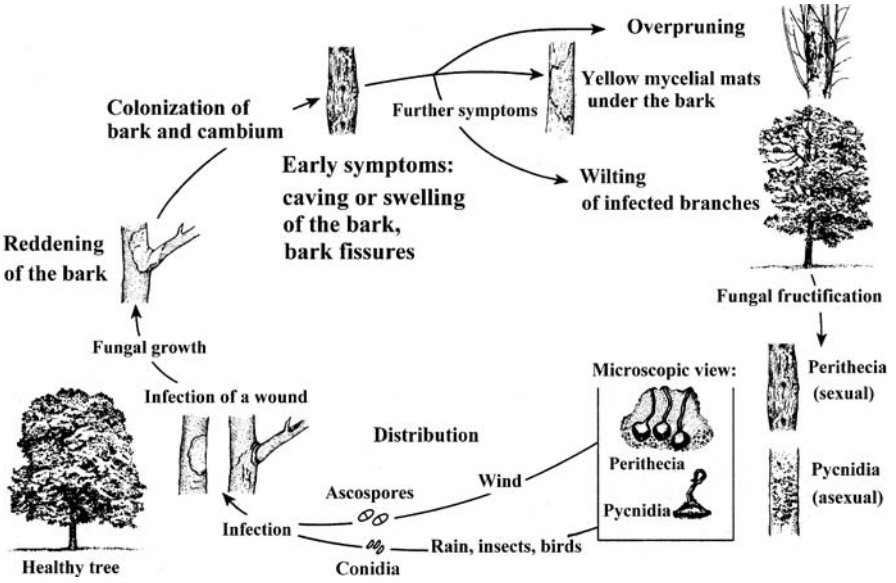

Fig. 8.2. Pathogenesis of Chestnut blight by *Cryphonectria parasitica* (translated from Heiniger 1999, with permission of Swiss Federal Institute for Forest, Snow and Landscape Research)

time the most important hardwood species. The disease appeared in Europe first in 1938 in Genoa in the European chestnut sites (*Castanea sativa*) of Italy, then in southern France, Spain, Switzerland (1948), Germany (1992), and Eastern Europe. The fungus penetrates as a spore by means of wind, rain, insects, or birds through wounds into the bark until the cambium. Then reddish-brown bark spots that break to longitudinal fissures, branch-surrounding necroses, wilt, and death of the affected branch or crown region occur. One- to 2-mm-large, orange-yellow-ochre pustules (conidiomata, ascomata) develop on the bark.

The disease in Europe does not run however as intensively as in the USA probably due to lesser aggressive fungal strains. The reduced pathogenicity is caused by *Cryphonectria*-hypovirus 1 that infests the fungus, that is, it becomes lesser virulent and only produces superficial cankers, which soon heal up. The virus is also found in the natural *C. parasitica* populations in Japan and China, but not in the North American populations. To limit the distribution of the fungus in non-infested countries, there are official regulations (European and Mediterranean Plant Protection Organization) (Heiniger 2003).

Breeding experiments are performed between *C. dentata* and resistant Asian species. There are also attempts on a biological control based on vegetative pairing of hypo-virulent fungal isolates with virulent strains. Infested sites are inoculated with hypo-virulent isolates that can transfer the virus in the

pathogen if both belong to the same vegetative compatibility group (Haller-Brem 2001). There are biotechnological attempts for transgenic chestnut trees (Gartland and Gartland 2004).

8.1.1.3 Plane Canker Stain Disease

The Plane canker stain disease (plane tree canker) (Fig. 8.3) is caused by the ascomycete *Ceratocystis fimbriata* f. sp. *platani* (Wulf 1995). The disease was for the first time observed on *Platanus* species in 1926 in the eastern USA and occurred in the 1940s in Europe [France, Italy, Spain, Switzerland, Turkey; Clerivet and El Modafar (1994)]. About 80% of the city-trees along motorways became destroyed until 1950 in the USA. Marseille lost over 1,500 100-year-old plane trees in 12 years. The fungus penetrates through wounds predominantly after pruning, more rarely by insects, into the bark of the stem and the branches and leads to cambium dying and elliptical bark necroses. Later, it colonizes the outer sapwood with bluish-brown discoloration. Excretion of toxins by the fungus and tyloses effect wilting of individual crown portions. Thus, the fungus both produces a bark and a wilt disease (Butin 1995). The trees die usually within 3–6 years. Reproduction organs are predominantly found on

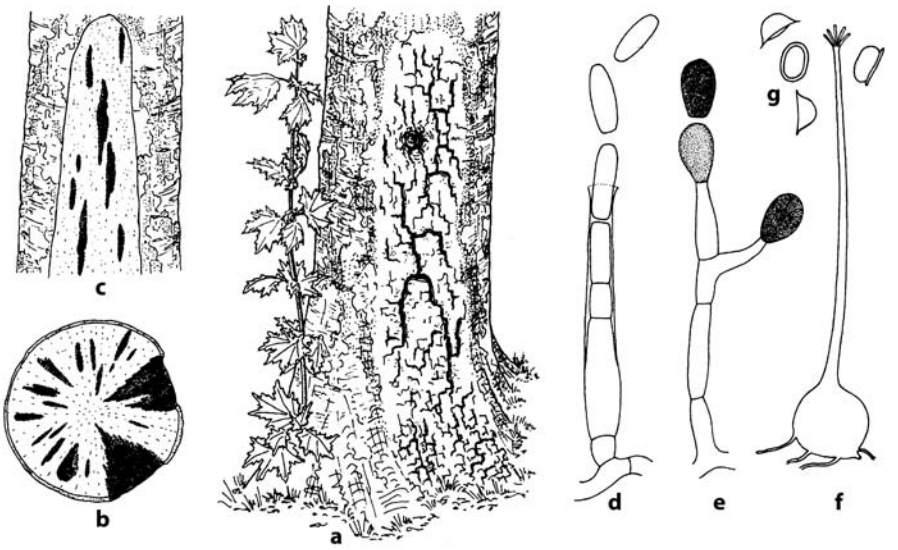

Fig. 8.3. Plane canker stain disease. *a* Symptoms on plane, *b* stem cross section showing stained wood, *c* tangential stem section showing the stain as streaks, *d* phialide with conidia of the *Chalara* anamorph, *e* conidiophore with chlamydospores, *f* perithecium, *g* ascospores (from Butin 1995, by permission of Oxford University Press)

cut sections of debranched or felled trees: perithecia with ascospores and three different anamorphs, e.g., *Chalara*. Necroses can by secondarily colonized by other fungi (*Chondrostereum purpureum*, *Schizophyllum commune*).

Transfer may be reduced by hygienic measures like removal of infested trees. National and EC regulations have to be considered.

8.1.2 Wilt Diseases

Diseases that affect the vascular system of a plant are called wilt diseases. A fungus causes moisture stress that leads to wilting, killing of large branches and even entire trees (Tattar 1978). Two important wilt diseases caused by fungi are Dutch elm disease and Oak wilt.

8.1.2.1 Dutch Elm Disease

Dutch elm disease ("elm dying") (Fig. 8.4) is caused by the ascomycetous fungus *Ophiostoma ulmi* s.l. (Gibbs 1974; Rütze and Heybroek 1987; Sinclair et al. 1987; Ouellette and Rioux 1992; Butin 1995; Harrington et al. 2001; Kirisits et al. 2001; Nierhaus-Wunderwald and Engesser 2003). The pathogen is composed of two separate species or three subgroups: the non-aggressive (NAG) subgroup, referred to as *O. ulmi*, and the two races, Eurasian (EAN) and North American (NAN), of the aggressive subgroup, referred to as *O. novo-ulmi* (Brasier 1999). The disease was probably imported from East Asia around 1917 over France into the Netherlands in 1919 (NAG), where 1920/21 the first comprehensive investigations took place, so that the disease was called Dutch elm disease. In 1923, it had arisen for the first time in England, 1930 via veneer wood in the USA, 1934 in almost all European countries and 1939 in the former Soviet Union (Heybroek 1982). Between 1940 and 1960 it receded, but again a new aggressive eastern race (EAN), probably from Romania/Ukraine, spread westward over the whole of Europe and eastward to middle Asia. Assumably after the import to North America, there the aggressive western race (NAN) shall have developed and imported to Great Britain (Röhrig 1996).

The wood loss in an economical view is very great. Altogether, hundreds of millions of decade- to centuries-old elm trees in Europe, North America, and in parts of Asia were destroyed. About 25 million elms died since the 1970s in England (Wörner 2005), and in Utrecht and Amsterdam, half of all the elms died.

Scolytid bark beetles are the principal agents of the long-distance transmission introducing the pathogen into healthy trees during adult feeding. In Europe, the principal vectors are *Scolytus scolytus* and *S. multistriatus*, but also

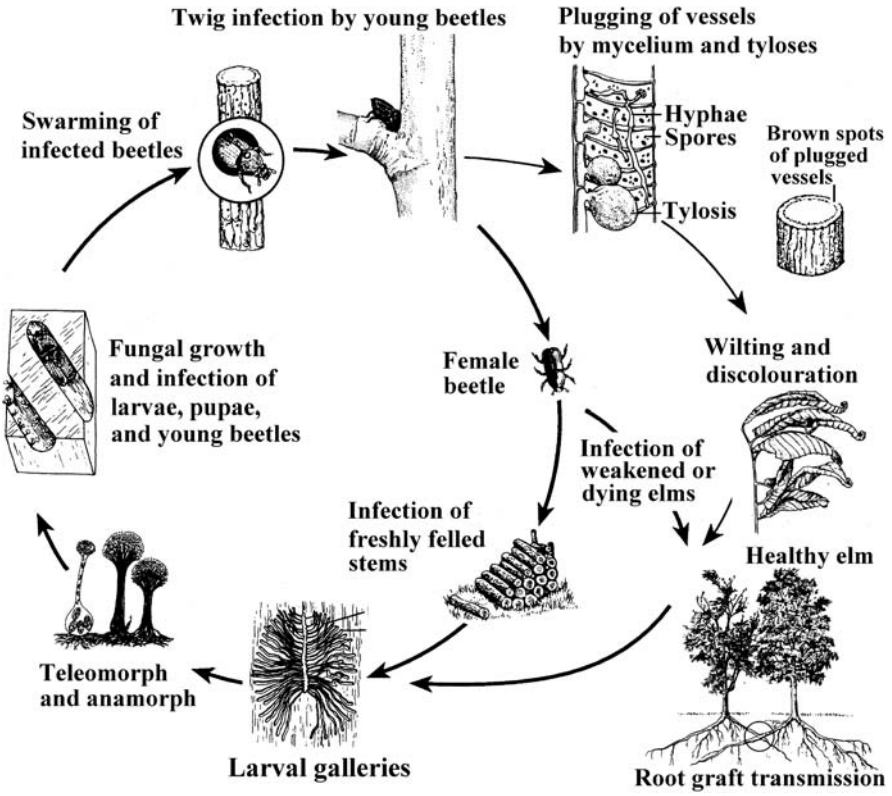

Fig. 8.4. Pathogenesis of Dutch elm disease (translated from Nierhaus-Wunderwald and Engesser 2003, with permission of Swiss Federal Institute for Forest, Snow and Landscape Research)

other vector species are recognized (Wingfield et al. 1999). In North America, vectors are the imported *S. multistriatus* and the American elm bark beetle *Hylurgopinus rufipes*. The females select almost exclusively diseased, dying, or already dead elms for their breeding galleries. The larvae take up the pathogen, which is passed on alive via the pupa to the young beetle. The young beetles contaminated with spores (conidia or ascospores) infect healthy trees in twig crotches of small branches during maturation feeding. Since this bark is too thin for oviposition, the beetles leave the healthy tree and use the thick-barked parts of diseased elms for their breeding galleries. The change between the stem of infected elms and the branches of healthy trees makes the *Scolytus* beetles effective vectors (v. Keyserlingk 1982). Root graft transmission via connections from adjacent trees is the major cause of elm death in urban areas.

The principal reaction compounds developing in elms following invasion by the fungus are cadinane sesquiterpenoids [mansonones, elm phytoalex-

ins; e.g., Meier and Remphrey (1997)]. Barrier zones containing starch-filled parenchyma and swollen ray parenchyma have also been observed. During pathogenesis, the fungus develops within the xylem vessels with associated tyloses and vessel plugging, ultimately resulting in the wilt syndrome (Smalley et al. 1999), promoted by fungal toxins (cerato-ulmin) (Brasier et al. 1990). A branch cross section shows dark spots in the earlywood, which form brownish longitudinal strips in the tangential plane. An infection with a non-aggressive strain can be buried by new annual rings (chronic form); an aggressive strain grows through the annual ring borders (acute form), and the tree can die within 2 years.

The use of pheromones as an attractant does not cover all beetles. Fungal inhibitors such as benomyl only result in a dilatory effect. There were attempts of a biological control with the bacterium *Pseudomonas syringae* van Hall and with *Trichoderma* species (Aziz et al. 1993). Mansonones inhibited the growth of *O. ulmi* in *vitro*. Control measures are felling of infected or weakened trees as well as debarking and burning the bark and thicker branches in order to reduce the beetle population. In view of resistance to the pathogen, the major sources of genes for resistance are possessed by Asiatic elms. The responses of the European and North American elms vary depending on the individual subgroups of the pathogen. Classical breeding for resistance by selection of individuals from native populations have been made since the 20s, and hybrid elms have been bred, incorporating natural resistance from Asian elms. There are indications, which are based on DNA techniques, that most of the English elms, *Ulmus minor* var. *vulgaris*, are clones deriving from an Italian tree exported by the Roman agronomist Columella from Latium via Spain to England. That would explain the observed small genetic diversity within the English elms and thus their high susceptibility to the pathogen (Wörner 2005). Currently, two biotechnological approaches are pursued: Double-stranded RNA viruses, known as d-factors, may have the potential to reduce aggressivity if introduced into a fungal population at large in sufficient quantities to become established and spread through fungal populations. Transgenic *Ulmus procera* trees have been produced using *Agrobacterium rhizogenes* (Riker et al.) Conn and *A. tumefaciens* as mediator, demonstrating that a variety of exogenous genes can be expressed in regenerant elms (Gartland and Gartland 2004).

8.1.2.2 Oak Wilt Disease

The North American oak wilt (Fig. 8.5; Rütze and Liese 1980, 1985a; Sinclair et al. 1987) is a vascular disease that is endemic among oaks in the USA and caused by the ascomycete *Ceratocystis fagacearum*. It was recorded for the first time in Minnesota in 1928, Wisconsin in 1942, already in 1979 in 21 US states east of the Great Plains and is now also found in Texas and Tennessee. The

fungus can both infect red oaks (*Quercus falcata* var. *pagodaefolia, Q. rubra, Q. shumardii*) and white oaks (*Q. alba, Q. bicolor, Q. macrocarpa, Q. michauxii, Q. muehlenbergii*). Red oaks become systematically infected and die quickly, mostly within the year of first wilting symptoms and sometimes within a few weeks after infection. The economically more important white oaks are more resistant and show the damage often being restricted to just a few branches. The lower susceptibility of the white oak is attributed to smaller earlywood vessel diameter, more intensive tylosis formation resulting in a slower spread of the fungus in the tree and the ability to "bury" infected tissue by a new annual ring.

The infection usually occurs via root graft transmissions between the diseased and healthy trees (Fig. 8.5a), so that the distribution is low with 1 to 2 m (maximum 8 m) per year. Local spreading via root grafts can be inhibited by ditches. The fungus invades the vessels of the youngest two annual rings and stimulates the adjacent parenchyma cells to tylosis formation. Thus, wilt and defoliation occur in the undersupplied crown regions. Additionally, wilt toxins are produced. The leaves become flabby and discolor, are light green from the edge, and later bronze-brown in red oak and pale-light brown in white oak. After tree death, the hyphae grow inward in the sapwood as well as outward

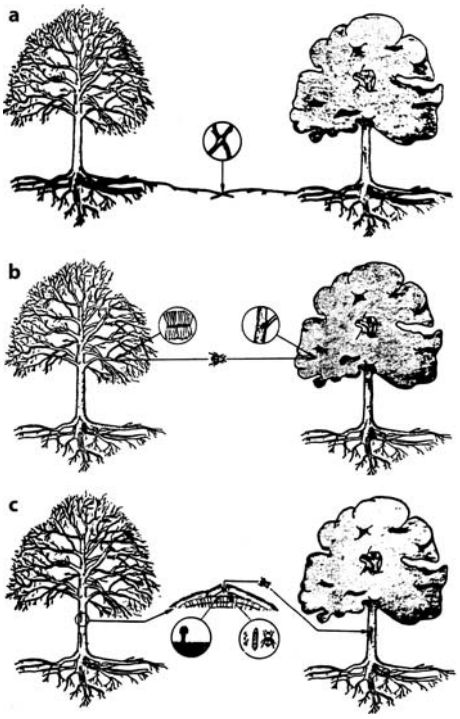

Fig. 8.5. Transmission of the Oak wilt fungus, *Ceratocystis fagacearum*, via root-grafts (**a**), during maturation feeding of bark boring beetles (**b**), and from sporulating mat by sap feeding nitidulids (**c**) (from Rütze and Parameswaran 1984)

through the cambium under the bark. In the cambial layer particularly in red oak, 5 to 8-cm-large sporulation mats (usually conidia) develop from May to October, which cause bark detachment and fissure by means of pressure cushions.

There are two different ways for long-distance transmission by insects (about 100 m/year): First, oak bark beetles (*Pseudopityophthorus* spp.) breed in dying or dead oaks, and the young beetles transfer the pathogen during the maturation feeding on shoots and twigs of healthy oaks (Fig. 8.5b). Since asexual spores do not develop in the larval galleries, this transmission way has only less significance. Second, sap beetles, particularly Nitidulidae, are attracted by the smell of the sporulating mats and transmit infectious material to healthy trees into fresh wounds, attracted by their smell (Fig. 8.5c) (Appel et al. 1990). The nitidulids effect that the bipolar heterothallic fungus is dikaryotized and develops ascospores, if conidia with contrary mating factor were introduced from other sporulation mats. Since wounds are infectious only a few days in healthy oaks, this infection way has also less significance. Furthermore, the subcortical mats of *C. fagacearum* were observed to be rapidly overgrown by *Graphium pyrinum* Goid. (anamorph of *Ophiostoma piceae)*. This colonization reduces the chance of contamination of the insect vectors with spores of the pathogen and is likely to contribute to the low efficacy of insect transmission (Rütze and Parameswaran 1984).

Since 1951, the import of unpeeled oak logs from North America to Germany was allowed according to a plant protection order, if the wood derives from healthy areas ("white counties"), in accordance with the plant protection department of the US Department of Agriculture. It had however to be considered that also the European oaks, although usually white oaks (*Quercus petraea* and *Q. robur*), are more susceptible from nature and that the European oak bark beetle *Scolytus intricatus* is more aggressive in its transmission behavior than the North American species. In order to prevent the import of the fungus (Gibbs et al. 1984), oak wood became subject to specific treatment requirements under Council Directive 77/93/EC including bark removal, kiln drying, etc. Since such wood cannot be converted to veneers, those measures would have equaled practically an import stop for oak logs and the endangerment of the European veneer industry. Thus, experiments were performed in a cooperative venture between the Federal Research Center for Forestry and Forest Products Hamburg and the Universities of Minnesota and West Virginia on log fumigation with bromomethane (methyl bromide) as a means of ensuring that the logs were free from *C. fagacearum* (Liese et al. 1981; Schmidt 1988). The European community permitted by EEC Plant protection guidelines of 1978 the import of unpeeled oak logs if they were disinfected before export with 240 g bromomethane per m^3 of wood for 3 days at a minimum temperature of 3 °C in plastic tents (Rütze and Liese 1983). The use of bromomethane has fallen off considerably since the Montreal Conference of 1997 because of its

destruction to the ozone layer. Log fumigation needs an exemption. In Europe, to monitor that sufficient bromomethane fumigation of the oaks has been carried out, the TTC test (Brunner and Ruf 2003) is suitable. The test is based on the fact that the gas kills not only the oak wilt fungus but also the living cells of oak sapwood. These cells would survive for several months in logs that are not treated with gas. Increment cores of the whole sapwood are treated with a 1% solution of 2,3,5-triphenyl-2H-tetrazolium chloride (colorless), which discolors dark red to triphenylformazan in contact with living cells by their dehydrogenase activity (Rütze and Liese 1985b).

Fumigation with bromomethane has also been applied to four pathogenic fungi in larch heartwood (Rhatigan et al. 1998). Due to the pending restrictions of bromomethane for phytosanitation in general, the potential substitution by sulfuryl fluoride and iodomethane was investigated (Schmidt et al. 1997c, Unger et al. 2001).

There are privileges of the import regulations for the fewer endangered white oak: no fumigation during winter months, however immediate debarking and burning of the bark as well as immediate wood processing. Since the wood of both oak groups is hardly or not at all to differentiate by appearance, a color test is suitable: When sprayed on the heartwood of any species of white oak a sodium nitrite solution produces a blue-black color within a few minutes, whereas the color is a reddish brown in red oak (Willeitner et al. 1982).

The possible oak wilt transmission to Europe was discussed several times in connection with the increasing illness of European oaks (Siwecki and Liese 1991). These damages develop however due to a complex effect of abiotic factors (dryness and pollutants as predisposing factors, severe winter frost as acute stressor) and biotic influences (leaf-eating insects, nematodes, phytoplasmas, and *Armillaria* spp. as weakness parasites, other *Ceratocystis* species, other fungi.) The literature on the role of pathogens in the present oak decline in Europe has been compiled by Donaubauer (1998).

8.2 Tree Wounds and Tree Care

8.2.1 Wounds and Defense Against Discoloration and Decay

Initiation for discolorations and decay are predominantly wounds that are frequently caused by animals chewing, branch breaking, pruning, mechanized wood harvest, construction injury, and motor traffic (Tattar 1978).

Rots in living trees might occur fast or result from processes of many years, which frequently remain hidden for a long time, until fruit bodies appear, or the tree is broken, thrown by the wind, or felled.

After wounding, tree-own discolorations (deposition of heartwood substances) develop by living cells, followed by microbial stain and finally by wood rot (Shigo and Hillis 1973; Hillis 1977; Shortle and Cowling 1978; Bauch 1984; Rayner and Boddy 1988; Fig. 8.6).

Depending on the fungus and tree species, brown, white, or even soft-rot decay can develop in the tree. Sapwood and/or heartwood can be colonized. Fungi may be saprobionts of parasites. Development and spread of decay are influenced by the tree species, which can be susceptible, like birch or poplar, or exhibits natural durability in its heartwood due to inhibiting accessory compounds.

It has to be distinguished between passive mechanisms, which are already present before damage, and active defense mechanisms, which trees trained in the course of their phylogenetic development to limit wounds, infections, and senile damages (Blanchette 1992; Duchesne et al. 1992; Rayner 1993).

After the xylem is wounded, two defense functions have to be differentiated: First, the tree must avoid an interruption of the transpiration stream by air embolism, and second, limit the spread of invaded microorganisms (Liese and Dujesiefken 1996).

When a softwood tracheid is injured, its lumen is filled with air at ambient pressure. Thus, a pressure drop exists across the pit membranes of the water-containing neighboring tracheids. Their tori are therefore pulled against their pit borders, and the air-blocked tracheid is thus sealed off from the water-conducting tracheids (Zimmermann 1983). Conifers protect themselves from

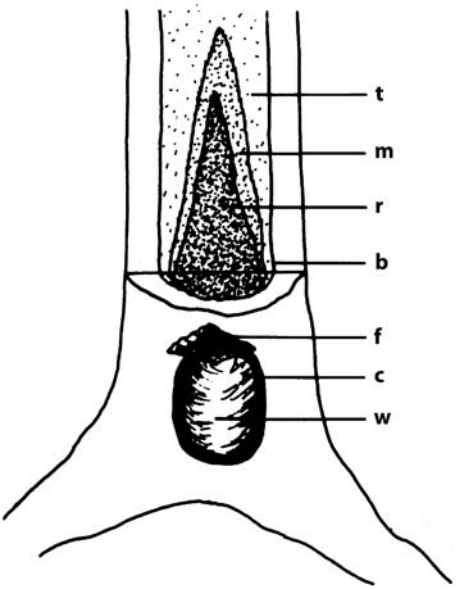

Fig. 8.6. Model of successive changes in the stem wood after prior injury to the bark. *w* wound, *c* callus margin, *f* fruit body, *b* barrier zone, *r* rot, *m* microbial wood discoloration, *t* tree-own wood discoloration (after Shigo 1979)

wounds and penetrating microorganisms by phenolic compounds, terpenoids, and resin (Tippett and Shigo 1981).

In hardwoods, the defense reactions depend on physiologically active parenchyma cells. The water-conducting system is protected against damage by tyloses, plugs or membranes, and phenolic substances or suberin are deposited on the cell wall or in the lumen (Schmitt and Liese 1993).

For the graphic understanding of the spatial cut off within a tree, Shigo developed the CODIT model (Fig. 8.7; Shigo and Marx 1977; Shigo 1984), which stands for "compartmentalization of decay in trees". The model means that the tree protects itself from penetrating microorganisms by four inhibiting walls and that the spatial expansion of discoloration and decay is determined by the anatomical structure of the wood. The axial "walls 1" with the weakest partitioning effect are formed by the closure of the vessels and pits above and underneath a wound by gums and tyloses. The tangential "wall 2" stem-inward occurs by the annual ring borders and by the sapwood/hardwood boundary. The radial "walls 3" are caused by the lateral wood rays. The most effective compartmentalization is by "wall 4", also termed barrier zone, formed by the cambium after the injury with increased parenchyma content.

The CODIT model interprets the tree-own reactions as compartment formation against microorganisms. It seems, however, more biological that the tree protects itself first from penetrating air, particularly since wood fungi can only settle the tissue if air is present. With changed definition, the term CODIT has been expanded by Liese and Dujesiefken (1989, 1996): the D does not only stand for decay, but also for damage and covering desiccation as well as dysfunction.

The histological changes that occur in wood and bark as wound reactions in hardwoods are schematically shown in Fig. 8.8.

The parenchyma cells die at the surface of the damaged wood area. The tissue beneath the wound plane also dies, without mobilizing reserve materials,

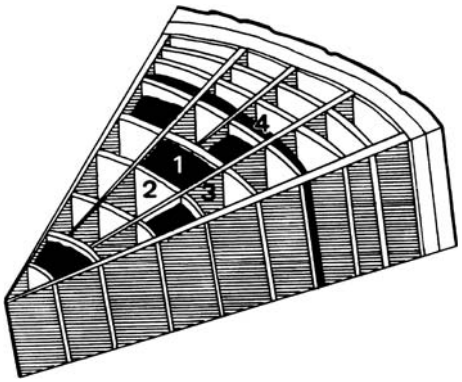

Fig. 8.7. CODIT model with walls *1* to *4* (after Shigo 1979)

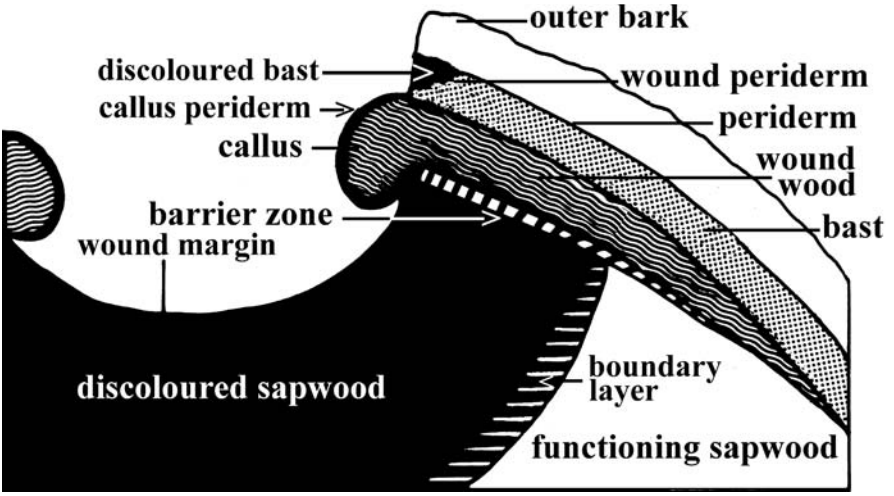

Fig. 8.8. Changes in the xylem and phloem of hardwoods after wounding (after Liese and Dujesiefken 1989)

since the defense reactions in the wood begin temporally retarded. In this bright zone of about 1 cm, the vessels remain open, and the lumina do not contain inclusions. With increasing distance to the wound, reserve material is mobilized, and the vessels are closed. In beech, the degeneration of the parenchyma is limited, as parenchyma cells in the wounded area are divided by transverse walls and limit the damage by suberization of the wound-near compartments (Schmitt and Liese 1993).

A closure by tyloses (Schmitt and Liese 1994) only takes place in tree species, which possess pit sizes of at least 8 µm. Trees without tyloses, like lime and maple, can prevent air embolism by blocking the vessels with plugs. In birch, the ladder-shaped vessel openings are closed on one side by membranes, and parenchyma cells excrete fibrillar material in neighboring vessels and fibers (Schmitt and Liese 1992a).

The tissue behind the wound area, which is discolored by means of accessory compounds and which contains died parenchyma cells and vessels out of function, had been termed protection wood. As it is colonized however frequently by fungi, it obviously does not possess increased durability. The healthy wood outside this area shows microscopically in an area of a few millimeters mobilization of reserve material and vessel closure, but no fungi, so that the actual protective layer obviously lies outside of the visible discoloration.

Also in the phloem the parenchyma dies at the wound surface and the tissue beneath is set out of function. A wavy-shaped wound periderm, which attaches the periderm of the young callus bark to the outer bark, develops in

the transition of the discolored to the functional phloem (Trockenbrodt and Liese 1991).

The cambium reacts to the damage at the wound margin with intensified cell formation (callus) to overwall the opened wood body (Stobbe et al. 2002a). The wound wood, which is later formed outside the callus, effectively limits discoloration and decay outward.

8.2.2 Pruning

Forest tress are pruned to produce high-class timber, trees in urban areas are pruned for safety reasons and along motorways and power-lines for clearance. Each cut causes a wound, which leads in the exposed wood to discoloration and decay (Fig. 8.9).

Until the 80s in Germany, the flush cut had been regarded as the correct method when removing a branch back at the stem. Studies on the pruning of hardwoods carried out by Shigo and staff (Shigo 1989) caused confusion. Comparing the effects of different cut locations of a total of 750 pruning wounds on 115 street and park trees led to the Hamburg Tree Pruning System (Dujesiefken and Stobbe 2002), which is integrated since 1992 into the German rules and regulations for tree care methods. The recommendations

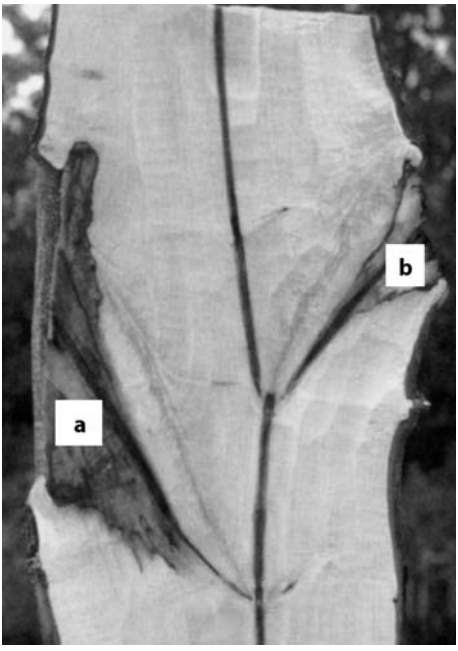

Fig. 8.9. Discoloration reaching far into the stem of horse chestnut 9 years after flush cut pruning (**a**); reduced discoloration after a branch collar cut (**b**) (from Dujesiefken and Stobbe 2002)

for branches without branch collar are also part of the European Tree Pruning Guide. According to the branch attachment (branches with or without a collar), the cut has to be done outside the stem so that the branch bark ridge is not damaged. Flush cuts have to be avoided. When pruning dead branches, the distinctive swelling at branch base must remain at the stem. Regardless of the time of year and the tree species, radical tree pruning, e.g., a drastic removal of crown parts, should not be done. If possible, branches greater than 5 cm in diameter of weak compartmentalizing trees (e.g., *Aesculus*, *Betula*, *Malus*, *Populus*, *Prunus*, *Salix*), and greater than 10 cm of strong compartmentalizing trees (e.g., *Carpinus*, *Fagus*, *Quercus*, *Tilia*) should only be reduced partially rather than completely.

For organizational reasons and due to nature protection laws, pruning is usually done during the dormant season. However, wounding of maple, birch, beech, oak, ash, lime tree and spruce showed on the basis the intensity of the wood discolorations that injuries should be avoided in hardwoods during the dormant stage and in spruce from late summer to winter due to different wound reactions (Lenz and Oswald 1971; Armstrong et al. 1981; Dujesiefken et al. 1991; Schmitt and Liese 1992b).

8.2.3 Wound Treatment

In the 50s and 60s, large stem wounds were shaped out and filled with concrete. Since concrete and wood shrink and extend differently under weather influence, shakes develop, water penetrates and leads to rot. Since the 70s, the cleaned wounds were treated with wound dressings or with wood preservatives. Disinfection of the opened wood body with ethanol or alcoholic iodine solution before wound treatment did not led to a prevention of discoloration and decay in beech and ash (Dujesiefken and Seehann 1995). The use of wood preservatives was disputed for tree care measures, as they are not developed for the protection of tree wounds. The treatment of artificial wounds with wood preservatives resulted in beech in more intensive discolorations behind the wound area than at wounds, which were only treated with wound dressings. Wound dressings belong to the plant preservatives. In Germany, they must be tested according to efficacy and environmental compatibility to become licensed (Balder 1995).

Alternatively, cavities can be foamed with polyurethane (Dujesiefken and Kowol 1991). Figure 8.10 shows reduced discoloration in a beech tree after filling the wound with polyurethane.

Currently, traffic wounds on street trees are covered by black plastic wraps, which promote the development of a surface callus overgrowing the wound area (Fig. 8.11).

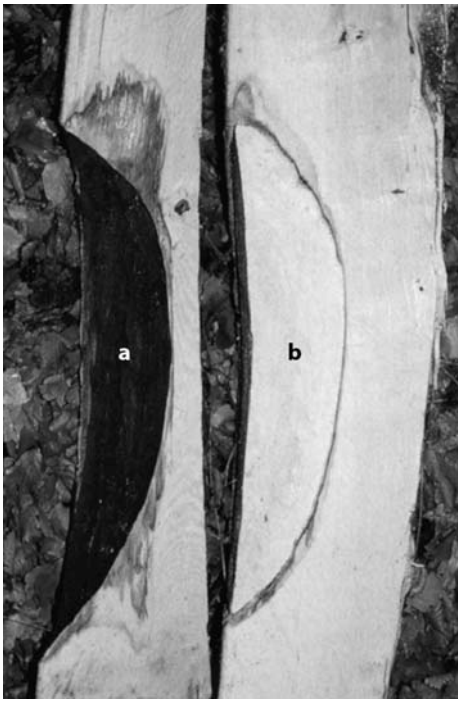

Fig. 8.10. Discoloration of beech at the control wound protected with wound dressing (**a**) and at the cavity filled with polyurethane (**b**) (from Dujesiefken and Kowol 1991)

8.2.4 Detection of Tree and Wood Damages

To investigate trees with regard to microbial damage, particularly to detect decay, discolorations, cavities, shakes and generally pathological changes, as well as to determine wood quality in felled timber, construction wood and wood-based composites, numerous methods are available. Inspection methods were described by McCarthy (1988, 1989), Zabel and Morrell (1992), Niemz et al. (1998), Londsdale (1999), Harris et al. (1999), Unger et al. (2001). Methods can be classified as destructive, nondestructive, or near-nondestructive. They reach from technically simple procedures like using increment bore tools to expensive equipment like computer tomography (Habermehl and Ridder 1993; Habermehl 1994) as well from subjective visual inspection to objective molecular techniques. In view of tree care, noninvasive or less destructive methods are preferable (Niemz et al. 1999; Kaestner and Niemz 2004). Modern techniques for nondestructive characterization and imaging of wood were reviewed by Bucur (2003) and comprise ionizing radiation computed tomography, thermal imaging, microwave imaging, ultrasonic imaging, nuclear magnetic resonance and neutron imaging. Some methods are preferentially used for trees, others for lumber, some may be used on the spot, others are pure laboratory tech-

Fig. 8.11. Use of a plastic wrap to improve the development of a surface callus. **a** Fresh, cleaned wound. **b** Wound covered with a black plastic wrap. **c** After 9 weeks nearly half of the wound covered with a bright surface callus tissue (from Stobbe et al. 2002b)

niques, and some of the latter are capable to identify the causal agent. Due to some overlapping in their use, the methods are listed together in Table 8.4. Limits of ultrasonic evaluation of wood defects have been shown by v. Dyk and Rice (2005). There is a great bulk of references on the various techniques; thus, only examples are given in Table 8.4.

The earliest nondestructive evaluation of trees is the visual inspection of the tree condition (growth, foliation, wilt) and occurrence of wounds, resin excretion, necrosis, canker, or fruit bodies. Visual inspection is also applied for lumber, poles, and wood in indoor use. Fruit bodies might serve to identify the causal agent. This visual inspection is by definition neither objective nor sure. Olfactory detection is done by the use of sniffer dogs that detect dry rot (Koch 1991), molds, or termites (Zabel and Morrell 1992).

Table 8.4. Inspection methods for fungal activity and wood quality in trees and timber

Method	Procedure	Advantage, disadvantage	Reference
Optical	Visual	Non-destructive, in situ, subjective	
	Endoscopy	Hidden spaces in buildings, bore holes may be required	Janotta (1995)
	Rhizoscopy	Root system	Seufert et al. (1986)
	Light microscopy	Simple, destructive	Schwarze et al. (1997), Anagnost (1998)
	Electron microscopy	Accurate, photographic record, destructive	Liese (1970), Daniel (2003)
	IR/NIR/FTIR spectroscopy	Laboratory method, printed record	Körner et al. (1992), Schwanninger et al. (2004)
	UV microspectrophotometry	Laboratory method, 3D wood topochemistry	Koch and Kleist (2001)
	Raman spectroscopy	Laboratory method, wood topochemistry	Röder et al. (2004)
Spectrometrical	GC-MS	Laboratory method, MVOC's, mold and rot detection	Keller (2002), Blei et al. (2005)
	MALDI-TOF MS	Laboratory method, fungal identification	Schmidt and Kallow (2005)
Acoustic	Speed of ultrasound (Impulse hammer)	Non-destructive, in situ, density of sound wood must be known	Rust (2001), Niemz et al. (2002)
	Acoustic emission	Non-destructive, in situ	Noguchi et al. (1992)
Electrical	Electrical resistance, conductivity		Shigo et al. (1977), Kučera (1986)
	(Shigometer, Vitamat)	Less destructive, in situ, handy devices	Larsson et al. (2004)
	Nuclear magnetic resonance	Non-destructive, not transportable, expensive	Müller et al. (2002)
	Radar	Ground penetrating radar for root investigation, in situ	Barton and Montagu (2004)
	Microwaves	Non-destructive	Takemura and Taniguchi (2004)
Mechanical	Increment cores	Handy instruments, low cost, destructive	Niemz et al. (1998)
	Needle penetration (Pilodyn)	Handy instruments, low cost, nearly non-destructive	Niemz and Kučera (1999)
	Drill resistance (Resistograph)	Portable instruments, printed data plots, destructive	Rinn (1994), Isik and Li (2003)
Thermographic	Heat radiation	Non-destructive, handy instruments, resolution insufficient	Niemz et al. (1998)
Radiographic	X-ray, γ-ray computed tomography	Non-destructive, in situ, expensive	Habermehl (1994)
Calorimetric	Isothermal microcalorimetry	Laboratory method, non-destructive	Xie et al. (1997)
Microbiological	Culturing to pure culture	Laboratory method, fungal identification	
Biochemical	CO_2	Laboratory method, fungal activity	Kirk and Tien (1986)
	ATP	Laboratory method, fungal activity	McCarthy (1983), Bjurman (1992a)
	Chitin	Laboratory method, fungal quantification	Nilsson and Bjurman (1998)
	Ergosterol	Laboratory method, fungal quantification	Pasanen et al. (1999), Dawson-Andoh (2002)
	pH-value	Non-destructive, fungal activity, brown/white rot differentiation	Peek et al. (1980)
	Sniffer dogs	Non-destructive, detection of dry rot, molds	Koch (1991), Keller et al. (2004)
Molecular	Protein gel electrophoresis	Laboratory method, fungal identification	Schmidt and Kebernik (1989), Vigrow et al. (1989)
	Immunology	Laboratory method, early decay, fungal identification	Vigrow et al. (1991a,b), Clausen (1997a)
	DNA-based methods	Laboratory method, fungal identification, objective	White et al. (2001), Schmidt (2000)

The type and intensity of a biological attack can be recognized by different macromorphologic changes of the wood tissue. Typical discolorations occur on and inside wood that is colonized by molds, blue stain, and red-streaking fungi. Brown- and soft-rotten woods differ in color and shape of the brown and soft-rotten cubes, and white-rotten wood between simultaneous and white pocket rot.

Various mechanical and physical wood changes occur when wood-inhabiting microorganisms colonize wood. Wood mass (weight) loss is a commonly used measure of decay capability. The basic calculation is: [(weight before − weight after): weight before] ×100%. The extent of decay in a specimen that was sampled from attacked wood can be determined the same way, if its dry weight is compared to that of a comparable healthy control: mass loss ML (%) = $[(DW_1 - DW_2) : DW_1] \times 100$ (DW_1 = dry weight of control, DW_2 = dry weight of decayed sample).

Mass loss of wood samples exposed to fungi is likewise used to determine the efficacy of wood preservatives and to examine the natural durability of wood species. There is a permanent discussion if fungal pure cultures or artificial mixed cultures should be used in laboratory tests (Kolle flask method, soil-block test, vermiculite method) or if soil contact decay tests are preferable. Laboratory tests are reproducible as they are based on defined test fungi. Field stake tests result in a severe exposure condition as the natural microbial composition may contain microorganisms that degrade wood, biodegrade organic wood preservatives or modify inorganic preservatives making them more susceptible to leaching (Nicholas and Crawford 2003). In Europe, the Kolle flasks method with malt extract agar and defined wood blocks of 5 × 2.5 × 1.5 cm in size from Scots pine sapwood and European beech is used for Basidiomycetes according to the standard EN 113 (Fig. 7.5; Table 7.6). In this method, specified isolates of certain fungal species, e.g., *Coniophora puteana* Ebw. 15, have to be used. The wood decay capacity of the test organisms is, however, erroneously named "virulence", although it concerns fungi and not viruses. Soft-rot fungi tests are performed in plastic containers with vermiculite (grainy substance of aluminum iron magnesium silicate) as moisture and nutrient depot. The standard soil block test AWPA E10 uses either 14-mm or 19-mm wood cubes that are exposed to white- and brown-rot fungi that were previously inoculated onto wood wafers on top of a sterile moist soil bed in a bottle. Soil bed testing based on the methodology described in the European Pre-standard ENV 807 uses 100 mm_{long} × 10 mm_{rad} × 5 mm_{tang} specimens that are exposed to the naturally soil-inhabiting microorganisms (v. Acker et al. 2003). Field stake tests use stakes or posts of the selected wood species that are half buried vertically in soil and inspected for decay at intervals. Wood assembly above-ground tests (post-rail, L-joint, lap-joint), all including some type of joint that effectively traps rainwater, simulate decking, door frames or joinery (Zabel and Morrell 1992; Nicholas and Crawford 2003).

The degree of wood decay can be quantified by changes in wood strength properties, modulus of rupture, work to maximal load in bending, maximal crushing strength, compression perpendicular to the grain, impact bending, tensile strength parallel to the grain, toughness, hardness, and shear strength (Wilcox 1978; Zabel and Morrell 1992; Nicholas and Crawford 2003).

Isothermal microcalorimetry has been used to determine the activity of fungi after exposure to high and low temperature, oxygen depletion, and drying (Xie et al. 1997).

Different stainings detect fungal hyphae and spores in woody tissue (Erb and Matheis 1983; Krahmer et al. 1986; Weiß et al. 2000). Treatment with safranine and astra blue stains lignified wood areas red and lignin-free parts blue, and thus differences between sound and decayed wood may become visible. Light-microscopic degradation patterns have been summarized (Schwarze et al. 1997). There is a key to identify wood decays based on light microscopic features (Anagnost 1998).

Transmission (TEM) and raster electron microscopy (REM) result in detailed views of the cell wall decay by the various groups of fungi (Liese 1970; Daniel 1994). UV microspectrophotometry (UMSP) characterizes lignin and phenolic compounds in situ, determines their content semiquantitatively in the various layers of the wood cell wall (Koch and Kleist 2001), and has also been applied to measure lignin content after microbial wood attack (Bauch et al. 1976; Schmidt and Bauch 1980; Kleist and Seehann 1997; Kleist and Schmitt 2001). General wood quality, microbial activity in wood, and composition in fossil specimens may be quantified by chemical analyses of the wood cell wall components, by UV and IR spectroscopy, and by gas chromatography/mass spectrometry of lignin components (Faix et al. 1990, 1991; Nicholas and Crawford 2003; Schwanninger et al. 2004; Uçar et al. 2005).

Biochemical methods to quantify microbial activity comprise assay of chitin as component of the fungal cell wall (Braid and Line 1981; Vignon et al. 1986; Jones and Worrall 1995; Nilsson and Bjurman 1998) and ergosterol as fungal membrane component (Nilsson and Bjurman 1990; Pasanen et al. 1999; Dawson-Andoh 2002).

Molecular methods to detect and identify fungi, like protein gel electrophoresis, immunology, and DNA-based techniques, are described in Chap. 2.4.2.

8.3 Tree Rots by Macrofungi

There is a broad spectrum of macrofungi (macromycetes) affecting trees. Most fungi belong to the Homobasidiomycetes (Table 2.12). About 20 species have greater economic importance. Among them, the Agaricales are represented

by *Armillaria*. The other important fungi belong to the Aphyllophorales and there predominantly to the Polyporaceae sensu lato ("polypores": Ryvarden and Gilbertson 1993, 1994). These polypores are summarized by the practical forester as "tree polypores" (Table 8.5; Seehann 1971). Fungi occurring on park and urban trees have been compiled e.g., by Seehann (1979), Wohlers et al. (2001), Wulf (2004) and Dujesiefken et al. (2005). Fungi affect predominantly older hardwoods and conifers of all climate zones. Infection occurs through wounds (wound parasites). Weakened trees may be more susceptible to fungi (weakness parasites). However, samples of dead wood from weakened spruces of different damage classes from forest dieback sites did not show differences in decay experiments with *Heterobasidion annosum*, *Trametes versicolor* (Schmidt et al. 1986), *Coniophora puteana*, *Gloeophyllum abietinum* and *Oligoporus placenta* (Liese 1986), compared to healthy trees.

Fungi either penetrate via the roots (root rots) or the stem (stem rots). Root-decay Basidiomycetes are e.g., *Armillaria* species, *Heterobasidion annosum*, *Meripilus giganteus*, *Phaeolus schweinitzii*, and *Sparassis crispa*. Among the Ascomycetes, *Rhizina undulata* (Pezizales) attacks the roots of spruce, pine and larch, and *Kretzschmaria deusta* (Xylariales) invades injured roots of beech, horse chestnut, elm, lime tree, maple, and plane causing white rot in the root and the stem (Butin 1995; Schwarze et al. 1995b; Baum 2001). Some common stem-decay Basidiomycetes in Europe (Butin 1995) and the USA (Zabel and Morrell 1992) are listed in Table 8.5. Most English names derive from Käärik (1978), Larsen and Rentmeester (1992) and Rune and Koch (1992).

Fungi may attack the heartwood (heart rots) and effect thus a considerable strength and volume reduction of the tree xylem. They cause either brown or white rot in a several years of development, whereby all combinations between hardwoods and conifers as well as brown rot and white rot occur. However, also a soft-rot decay pattern may develop in the standing tree. Tree decay fungi have great economical importance, since a great part of the wood body can be devaluated, and felling of infected trees may be necessary. After felling, windthrow, or death of the tree, some fungi continue growth as saprobes in the wood for several years, then however usually die, that is, typically they do not endanger structural timber. The variously sized fruit bodies (basidiocarps, basidiomata) are either pileate, shelf-shaped, bracket-like, coral-like, or resupinate (see Fig. 2.17). Shape and size of the pores are distinguishing features (Breitenbach and Kränzlin 1986; Ryvarden and Gilbertson 1993, 1994; Krieglsteiner 2000). Beside fungi with annual fruit bodies, species with perennial basidiomes produce new hymenial layers each year and may become very large, hard and woody (see Fig. 8.15a).

Daedalea quercina, *Fomes fomentarius*, *Phellinus igniarius*, *Laetiporus sulphureus*, *Piptoporus betulinus*, *Polyporus squamosus*, and *Meripilus giganteus* occur predominantly on hardwoods. *Heterobasidion annosum*, *Phaeolus*

Table 8.5. Some stem-decay Basidiomycetes

	Rot
Amylostereum areolatum (Chaill.: Fr.) Boidin	white
Armillaria mellea (Vahl: Fr.) Kummer, Honey fungus, and further *Armillaria* species	white
Bjerkandera adusta (Willd: Fr.) P. Karsten, Smokey polypore	white
Chondrostereum purpureum (Pers.: Fr.) Pouzar, Silver-leaf fungus	white
Climacocystis borealis (Fr.: Fr.) Kotl. & Pouzar	white
Coniophora arida (Fr.: Fr.) P. Karsten	brown
Coniophora olivacea (Fr. Fr.) P. Karsten	brown
Daedalea quercina (L.: Fr.) Fr., Maze-gill	brown
Daedaleopsis confragosa (Bolton: Fr.) J. Schröter	white
Fistulina hepatica (Schaeffer: Fr.) Fr., Beef-steak fungus	brown
Fomes fomentarius (L.: Fr.) Kickx, Tinder fungus	white
Fomitopsis pinicola (Sw.: Fr.) P. Karsten, Red-belted polypore	brown
Ganoderma adspersum (S. Schulzer) Donk,	white
Ganoderma applanatum (Pers.) Pat.	white
Ganoderma lipsiense (Batsch) G.F. Atk., Artist's conk	white
Ganoderma lucidum (Curtis: Fr.) P. Karsten	white
Grifola frondosa (Dicks.: Fr.) S.F. Gray	white
Heterobasidion annosum (Fr.: Fr.) Bref., Root rot fungus	white
Inonotus dryadeus (Pers.: Fr.) Murr.	white
Inonotus hispidus (Bull.: Fr.) P. Karsten	white
Laetiporus sulphureus (Bull.: Fr.) Murr., Sulphur polypore	brown
Meripilus giganteus (Pers.: Fr.) P. Karsten, Giant polypore	white
Oligoporus stipticus (Pers.: Fr.) Kotl. & Pouzar	brown
Onnia tomentosa (Fr.: Fr.) P. Karsten	white
Phaeolus schweinitzii (Fr.: Fr.) Pat., Dye polypore	brown
Phellinus chrysoloma (Fr.) Donk	white
Phellinus hartigii (Allesch. & Schnabl) Pat.	white
Phellinus igniarius (L.: Fr.) Quélet, False tinder fungus	white
Phellinus pini (Brot.: Fr.) A. Ames, Ochre-orange hoof polypore	white
Phellinus pomaceus (Pers.: Fr.) Maire	white
Phellinus robustus (P. Karsten) Bourdot & Galzin	white
Pholiota squarrosa (Pers.: Fr.) Kummer	white
Piptoporus betulinus (Bull.: Fr.) P. Karsten, Birch polypore	brown
Pleurotus ostreatus (Jacq.) Kummer, Oyster mushroom	white
Polyporus squamosus (Hudson: Fr.) Fr., Scaly polypore	white
Resinicium bicolor (Alb. & Schwein.: Fr.) Parm.	white
Schizophyllum commune Fr.: Fr., Split-gill	white
Sparassis crispa Wulfen: Fr.	brown
Stereum rugosum (Pers: Fr.) Fr.	white
Stereum sanguinolentum (Alb. & Schwein.: Fr.) Fr., Bleeding Stereum	white
Trametes hirsuta (Wulfen: Fr.) Pilát	white
Tyromyces caesius (Schrader: Fr.) Murr., Blue cheese polypore	brown
Tyromyces stipticus (Pers.: Fr.) Kotl. & Pouzar	brown
Xylobolus frustulatus (Pers.: Fr.) Boidin, Ceramic parchment	white

schweinitzii, *Phellinus pini,* and *Sparassis crispa* inhabit softwoods. Species of *Armillaria* attack both tree groups.

In the following, some common tree fungi are described, mostly in note form. For details see Seehann (1971, 1979) and textbooks e.g., by Butin (1995), Breitenbach and Kränzlin (1986, 1991), Rayner and Boddy (1988), Jahn (1990), Ryvarden and Gilbertson (1993, 1994), Krieglsteiner (2000), and Schwarze et al. (2004).

8.3.1 *Armillaria* Species, Honey Fungi

The genus *Armillaria* (Fr.: Fr) Staude comprises worldwide about 40 species. The rather similar fungi form rhizomorphs in the soil and beneath the tree bark, the mycelium shines in the dark, the secondary mycelium is diploid and normally clampless (Marxmüller and Holdenrieder 2000). There are exannulate and annulate species (Shaw and Kile 1991; Guillamin et al. 1993). In Europe, five intersterility groups that had been referred to as A, B, C, D, E (Korhonen 1978b) within the annulate *Armillaria mellea* complex were assumed until the 1980s to be polymorphic members of the species *Armillaria mellea* ("*Armillaria mellea* complex"). In the 90s, the groups were assigned to five biological species (Guillaumin et al. 1993; Nierhaus-Wunderwald 1994; Holdenrieder 1996):

A = ***Armillaria borealis*** Nordic honey fungus,
B = ***Armillaria cepistipes***,
C = ***Armillaria ostoyae*** Dark honey fungus,
D = ***Armillaria mellea*** s.s. Honey fungus,
E = ***Armillaria gallica*** Marxm. & Romagn.

Based on the verification of isolates by mating tests between monospore cultures, between diplonts and haplonts (Buller phenomenon), and by somatic compatibility tests, morphological variation of the fruit bodies of the five annulate European species was recently shown in color plates with suitable characters for species identification (Marxmüller and Holdenrieder 2000). In North America, nine annulate species are known (Anderson and Ullrich 1979; Anderson et al. 1980; Bruhn et al. 2000). The six species in Australasia (Kile and Watling 1983) are incompatible with European and North American species. In Africa, a subspecies of *A. mellea* was found (Agustian et al. 1994).

Occurrence: The *Armillaria* species differ in host preference, pathogenicity (primary parasite, opportunist attacking weakened plants, destructive agent of non living tissue resulting in heart wood rot), geographical distribution, type and frequency of rhizomorphs, and in cultural characteristics such as mat morphology and optimum temperature (Rishbeth 1985, 1991; Shaw and Kile 1991; Guillaumin et al. 1993; Marxmüller and Holdenrieder 2000; Schwarze

and Ferner 2003; Prospero et al. 2003). The damage, *Armillaria* root disease (Hartig 1874, 1882), occurs in conifers and hardwoods, particularly spruce, pine, maple, poplar, oak, in plantations of fruit, vine, flowers, ornamentals, and tropical cash crops (Seehann 1969; Schönhar 2002a; Schwarze and Ferner 2003). The fungi occur also on stumps, piles, etc., and even in sprinkled wood (Metzler 1994).

Physiology: Parasite, saprobe, white rot; slow growth in the laboratory;

Characteristics: in pine and spruce, resin excretion; white, fan-like mycelial mats and brown-black, inside white rhizomorphs (0.25–4 mm; Schmid and Liese 1970; see Fig. 2.7) between bark and wood (Hartig 1874; Fig. 8.12a); wood colonized by living mycelium shining in the dark; clampless;

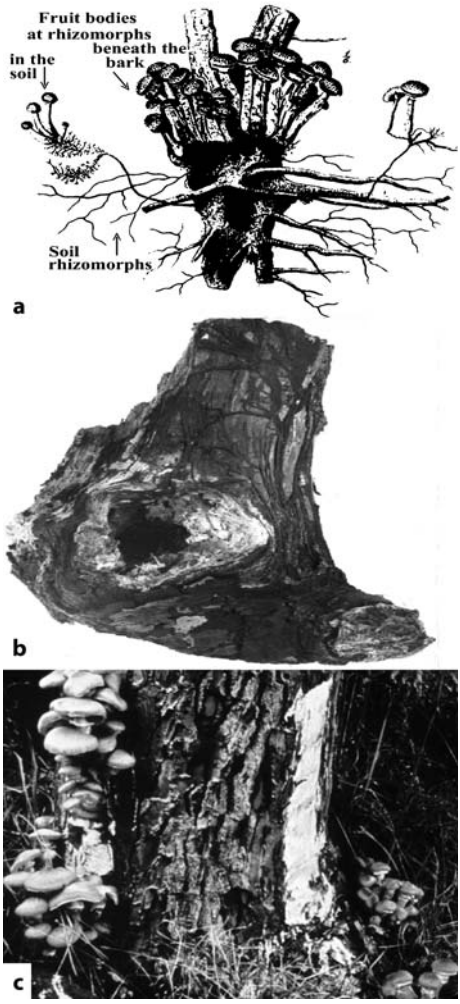

Fig. 8.12. *Armillaria mellea*. **a** Fruit bodies and rhizomorphs (translated from Hartig 1874); **b** White-rotten stump with rhizomorphs after removing the bark. **c** Fruit bodies and white mycelial sheet beneath the bark (photo W. Liese)

Fruit body (Fig. 8.12c): central stipe (to 15 cm), cap 5–15 cm in diameter; annual, in groups on stumps and at the root collar in late autumn; upper surface (*A. mellea*): small, yellow-brown scales on honey-yellow ground (Honey fungus); gill surface: cream-white to brownish-red gills; monomitic; clamps only at the basidium basis; pileus with white ring; young edible, danger of sickness when insufficiently cooked or overmatured;

Significance: The *Armillaria* fungi, which are feared by the foresters, belong to the most important and cosmopolitan pathogens inside and outside the forest. They can attack almost all species of hardwoods and conifers of all ages (Hartig 1874; Schönhar 1989; Livingston 1990; Klein-Gebbinck and Blenis 1991; Gibbs et al. 2002). They live as saprobes in the soil on dead wood remainders and on stumps. The transition to the parasitic phase occurs, if the tree is weakened by stress (other parasites, wetness, dryness, pollution), so that forest damage sites showed increased occurrence of *Armillaria*. The infection occurs by rhizomorphs (Fig. 8.13). Solla et al. (2002) showed that *A. mellea*

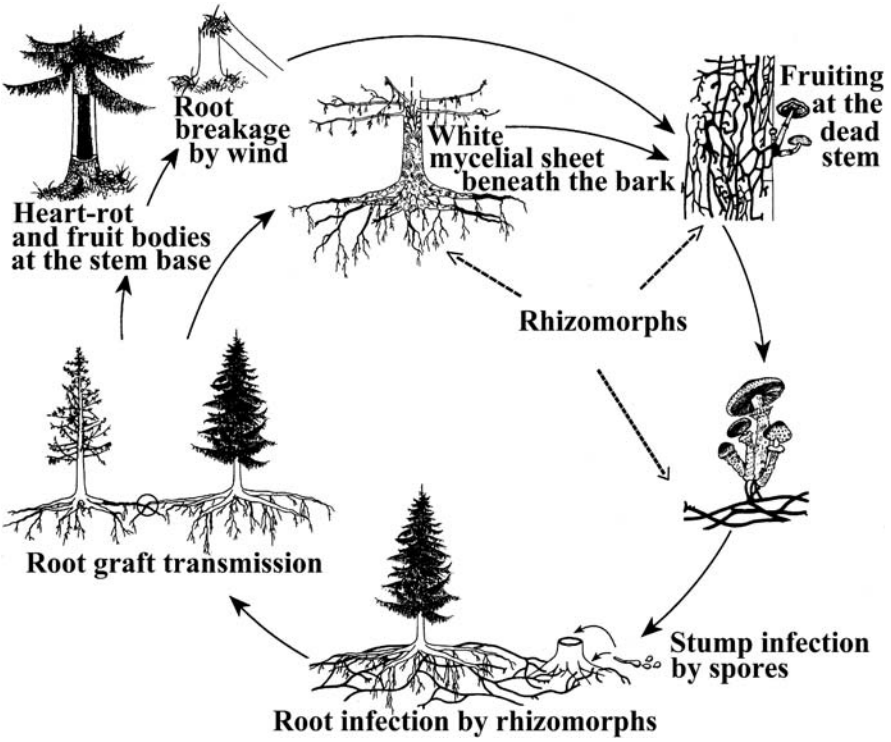

Fig. 8.13. Development and transmission of *Armillaria* root disease (translated from Nierhaus-Wunderwald 1994, with permission of Swiss Federal Institute for Forest, Snow and Landscape Research)

and *A. ostoyae* penetrated *Picea sitchensis* root bark without prior wounding, but neither species formed rhizomorphs. The rhizomorphs grow in the soil from tree to tree and serve for nutrient translocation and infection. If the tree does not succeed in defending the fungus by histological or chemical barriers (Woodward 1992a; Wahlström and Johansson 1992), the fungus spreads between bark and xylem in the cambial region. The sap stream is interrupted, and toxic metabolites are excreted by the fungus. If the whole cambium is colonized around the stem, the tree dies rapidly ("cabium killer"). Beside the parasitic way of life, the fungus can spread via the wood rays in the heartwood of the root and stem basis (butt rot). *Armillaria* species and *Heterobasidion annosum* showed an increased occurrence in forest dieback sites (Kehr and Wulf 1993).

A direct control of *Armillaria* spp. (e.g., Fox 1990) is practically impossible, particularly since the fungus occurs almost everywhere in the soil. In Oregon, the upper ground layer was colonized over an area of about 9 km^2 by only one mycelial clone of *A. ostoyae*, whose age was supposed to be 2,400 years. In England, a clone of *A. gallica* of about 500 years of age covered an area of 9 ha. In France and Germany, clone diameter reached about 200 m in diameter (Marxmüller and Holdenrieder 2000).

Armillaria is more frequent on soils with balanced microclimate and high air humidity at ground level as well as on nutrient-rich soils of about pH 5. Since young conifers are particularly susceptible on former hardwood soils, old stumps and roots should be rooted out before planting conifers to limit the vitality of the fungus, which, during its saprobic phase, depends on easily degradable nutrients (Butin 1995). Isolation of infected tree groups by 30 to 50-cm-deep ditches is usually unsuccessful. *Armillaria*-infected plants in gardens and parks should be promptly removed. The resistance of the plant hosts can be increased by suitable soil preparation, good planting, and tree care. Douglas fir, Sitka spruce, fir and larch are lesser susceptible species. The application of chemicals within the root range is strenuous and therefore only suitable for valuable garden and park trees (Schönhar 1989).

Pinosylvin from *Pinus strobus* inhibited mycelial growth of *A. ostoyae* (Mwangi et al. 1990). Growth rate, spread and survival of rhizomorphs decreased by several bacteria, particularly *Pseudomonas fluorescens* Migula (Dumas 1992), *Trichoderma* species (Dumas and Boyonoski 1992), wood-inhabiting Basidiomycetes (Pearce 1990) and mycorrhizal fungi (Kutscheidt 1992).

8.3.2 *Heterobasidion annosum* s.l. Root Rot Fungus, Fomes Butt Rot

From the Root rot fungus, several intersterility groups have been distinguished, which differ in relation to distribution, fruit body morphology and host tree (Korhonen 1978a). In Europe, three groups have been referred to as P-group

(pine), S-group (spruce), and F-group (fir) (Holdenrieder 1989; Siepmann 1989; Capretti et al. 1990; Stenlid and Karlsson 1991; Korhonen et al. 1992). In North America occur the P- and S-type. The Asian forms are lesser characterized (e.g., Dai and Korhonen 1999). The three European forms show significant differences in their distribution and host preference and have been attributed to three distinct species (Niemelä and Korhonen 1998; Korhonen and Holdenrieder 2005):

Heterobasidion annosum s.s. corresponds to the European P-type of *H. annosum* s.l. and may named pine root rot fungus, as it typically occurs in pine forests. In addition, the fungus attacks *Juniperus communis*, *Picea abies*, *P. sitchensis*, *Pseudotsuga menziesii*, *Larix decidua*, *L. x eurolepsis*, and *L. kaempferi*. The distribution area covers the whole of Europe except for the most northern forests and possibly the great parts of Siberia.

Heterobasidion parviporum (European S-type of *H. annosum* s.l.; Spruce root rot fungus) occurs in Europe nearly exclusively on *Picea abies*, but as it seems, it is not found in Western Europe. In Russia, it attacks also *Abies sibirica* and in East Asia further *Picea* and *Abies* species.

Heterobasidion abietinum (European F-type of *H. annosum* s.l.; Fir root rot fungus) occurs in fir forests from the Pyrenees to South Polonia and the Caucasus, particularly on *Abies alba*, but also on *A. borisii-regis*, *A. cephalonica* and *A. nordmanniana*.

The three closely related species can be differentiated by cultural studies, mating tests and DNA techniques. The hymenium of *H. parviporum* has small pores (up to 5 pores/mm) and the upper side shows short hairs, while *H. annosum* s.s. has bigger pores and a bald upper side. The features of *H. abietinum* often overlap with those of the two former species, but its occurrence on firs is a suitable clue (Korhonen and Holdenrieder 2005). Hybridization of the species occurs in the laboratory. A natural hybrid between S- and P-type has been found in North America, but generally, hybrids occur more easily between forms from different continents. Regarding the evolution of *H. annosum* s.l., the origin of *H. parviporum* and *H. abietinum* seems to be East Asia, as there occurs a form that showed high compatibility with all three species. Assumably, *H. annosum* s.l. spread from the eastern Himalayas and has thereby increasingly differentiated via different routes: *H. abietinum* arrived in Europe via the South Asian conifer forests, *H. parviporum* via northern Asia, and the American S-type reached North America over the Bering Strait. Not much is known on the P-types (Korhonen and Holdenrieder 2005). Molecular analyses have shown a close relation of the genus *Heterobasidion* to the Russulales.

The following description concerns *H. annosum* s.l.

Occurrence: common in Europe, North America; predominantly conifers; in heartwood and rootwood of spruce, larch and Douglas fir; in pine restricted to the root area due to greater resin content; broad host range of over 200 woody plants (Heydeck 2000); largest diameter of a genet smaller than 30 m, only in

single cases up to 55 m; maximum age of an individual genet around 200 years (Queloz and Holdenrieder 2005);

Physiology: white rot, root rot, butt rot, so-called red rot due to reddish discoloration of the wood; at initial decay preferential lignin degradation, later simultaneous white rot (Peek and Liese 1976); parasite and saprobe;

Characteristics: anamorph *Spiniger meineckellus* (A.J. Olson) Stalp. (Fig. 8.14C) on agar and fresh wood samples at high relative humidity: club-shaped thickened conidiophore after spore dispersal like a morning star ("Brefeld conidia" as identification feature: Brefeld 1889); flask-shaped increase of the stem basis of spruce by cambial irritation; resin excretion;

Fruit body (Fig. 8.14A): annual to enduring crusty brackets in autumn, often resupinate (1 cm thick, 3–20 cm wide) in rows and roofing tile-similar, usually fused, at the stem basis and on flat-running roots, frequently covered by needle litter; yearly a new pore layer; fresh: tough, old: hard and woody; upper surface: bumpy-wrinkled, brown, often zonate, leathery-crusty, white-yellowish margin; pore surface: white-cream with circular-angular pores (4–5/mm); dimitic; bipolar.

Significance: The fungus is one of the most important pathogens in coniferous forests of temperate regions (Hartig 1874, 1878; Rishbeth 1950, 1951; Zycha et al. 1976; Hallaksela 1984; Tamminen 1985; Benizry et al. 1988; Schönhar 1990; Woodward 1992a, 1992b; LaFlamme 1994; Woodward et al. 1998; Heydeck 2000; Greig et al. 2001; Gibbs et al. 2002; Korhonen and Holdenrieder 2005), which causes substantial damage particularly in older forests. The infection occurs by germinating spores or by mycelium that is already present in roots or soil. Several infection ways are possible: by basidiospores (also conidia) via stump infection (Redfern et al. 1997), by mycelial growth through root graft transmission from diseased to healthy roots (Hartig 1878; Schönhar 2001), or via spores [germinable about 1 year: Brefeld (1889)], which are washed into the soil by rain and germinate on the roots. The fungus penetrates into older roots through wounds and into young uninjured roots through the thin bark (Rishbeth 1951; Peek et al. 1972a, 1972b; Lindberg and Johansson 1991; Lindberg 1992; Solla et al. 2002). The hyphae penetrate into sound spruce roots via the pit channels of the thick-walled stone cork cells. The walls of the following thin-walled stone cork cells and the sponge cork cells are degraded. The fungus colonizes the tracheids from the bark rays via the wood rays. The tracheids are degraded by enzymes and perforated by microhyphae (Peek and Liese 1976). Embryos of *Pinus* spp. showed three days after artificial inoculation intercellular penetration of hyphae through the epidermis and into the cortex (Nsolomo and Woodward 1997). Infection of spruce seeds of 4–7 days of age showed that infective structures on the root surfaces were evident 24 h after inoculation. Internal colonization of cortical tissues started after 24–48 h and reached the endodermis within 72 h. Severe destruction of stelar cells occurred 12–15 days postinfection (Asiegbu et al. 1993). Infection of nonsuberized and

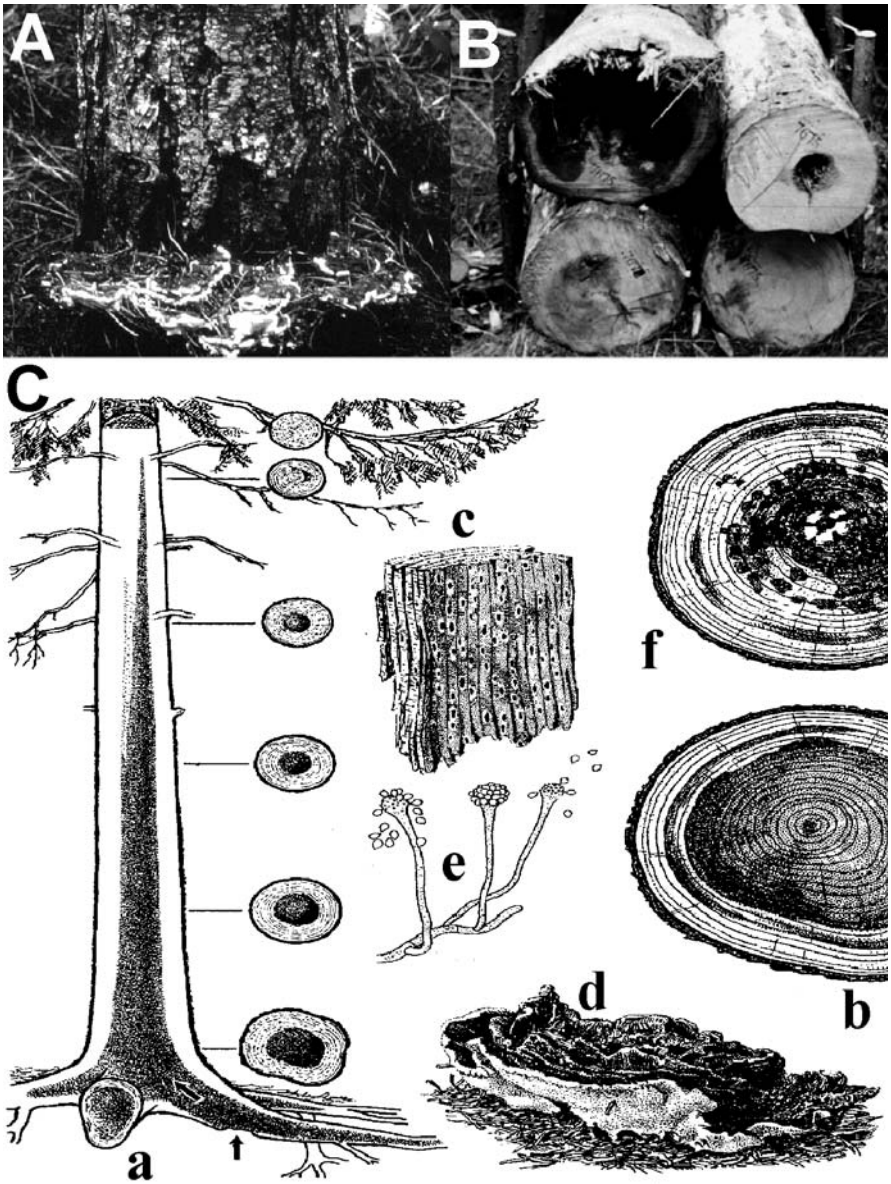

Fig. 8.14. Fomes root rot by *Heterobasidion annosum*. **A** Fruit bodies at the stem basis. **B** Sequent sections of a stem showing the different color and decay zones (photos W. Liese); **C** Pathogenesis, *a* longitudinal section through a spruce with heart rot, with stem cross sections, *b* cross section through a stem at an early stage of disease, *c* a late stage in the wood decay, *d* fruit bodies, *e* Brefeld conidiophores with conidia, *f* a heart rot caused by *Armillaria* sp. shown for comparison (from Butin 1995, by permission of Oxford University Press)

young suberized roots of spruce seedlings showed host reaction to delimit the infection by the formation of a necrotic ring barrier in the outer cortex. In cases where the inner cortex became infected, hyphae accumulated just before the endodermis, which acted as a new barrier. Only in nonsuberized roots, the stele was almost completely digested within 3 days after inoculation (Heneen et al. 1994a). In woody roots 2–4 mm in diameter, fungal infection was restricted to the remnant cortex cells and the rhytidome after an incubation period of 20 days; accumulation of granular materials prevailed in the infected periderm cells, which enclosed degenerated hyphae, both leading to the conclusion that the rhytidome acts as a successful barrier to infection of the inner parts of the root for at least 20 days following inoculation (Heneen et al. 1994b). Stem infections are rare and limited to wounds at the root collar (Schönhar 1990). Main infection is by airborne basidiospores that germinate on fresh stump surfaces. Infection of neighboring trees occurs by vegetative mycelia via root contacts. Once established in the root system, the fungus can remain active for about 60 years. The fungus spreads into trees of the next generation from infected stumps (Vasiliauskas and Stenlid 1998).

The significance of the fungus is not only based on its parasitic capability to kill living roots, but it is at the same time causal agent of "red rot", which ascends in the heartwood (heart rot) of the stem and is economically usually more serious. In Europe, on average, a 10% stem wood devaluation is counted for spruce by "red rot". In Scotland, the fungus is responsible for 90% of losses due to rot (Blanchette and Biggs 1992). The yearly damage in Germany amounts to € 56 million (Dimitri and Tomiczek 1998) and in the EU countries to about € 500 million (Woodward et al. 1998). "Red rot" increased in forest dieback sites.

The parasitic phase of the fungus develops first as root rot. In pine, the fungus predominantly grows stemwards in the root cambium area, until it is stopped by resin formation and a bark wound periderm. Large root parts die off. In the less resinous spruce, fir, larch and Douglas fir, fungal activity shifts, as soon as the mycelium reaches roots of more than 2 cm in diameter, into the root interior, that is, side roots and thus also the infected tree remain alive. Only if all roots are colonized, the mycelium also grows into the cambium and kills the tree.

The saprobic phase begins with penetration in the heartwood. Sapwood colonization occurs only after felling due to reduction of moisture content and particularly due to inhibition by the living sapwood (Shain and Hillis 1971). The effects of heartwood colonization depend on the tree species. In pine, the fungus spreads usually only insignificantly in the stem, but the tree dies due to the root damage. In larch, the mycelium grows in the heartwood/sapwood area and reaches likewise only low stem height. In spruce, the fungus climbs up in the stem 25–40 cm/year (Stenlid and Redfern 1998). Likewise, the Douglas fir stem can be colonized. The infected wood shows first a "1. color zone" (grey-

violet striping), then a "bright hard rot" (light brownish, wood still firm), later a "dark hard rot" (brownish-red, only wood structure remaining) and finally a "soft rot" (Fig. 8.14B; Zycha 1964), where the wood is fibrously dissolved and interspersed with small, white spindle-like nests with a black center of manganese deposits (Fig. 8.14C) (Hartig 1978; see Chap. 7.2).

Imperiled for *H. annosum* are first plantings on formerly agriculturally used pasture soils and arable lands ("field-dying", German: "Ackersterbe"). Conifers on base-rich and compacted ground, and on sites with very variable moisture content suffer more from the disease than those on acidic, more open soils with a more uniform water supply (Butin 1995; Schönhar 1997; Heinsdorf and Heydeck 1998). The inhibition of acidophilic, antagonistic mycorrhizas may play a role. A direct control is difficult, and only preventing measures are used (Schönhar 1990, 2002b). Rooting out and removing the infected stumps as well as isolating the infected sites by ditches are difficult and not always successful (Schönhar 1989). The most effective measure is to perform thinnings during the wintertime, as spore infection decreases during frost (Korhonen and Holdenrieder 2005). In not-yet-infected first plantings, the stumps which are the starting point for a propagation of the fungus via root grafts, have been coated on the fresh surface with carbolineum, which however delays the stump decomposition. Immediate treatment of the fresh surface with a sodium nitrite solution prevented spore germination of *H. annosum*. As chemical, also urea (Schönhar 2002b) and boron compounds are used (Pratt 1996). Originally in the U.K and later in Scandinavia and further European countries, a spore solution of the antagonistic fungus *Phlebiopsis gigantea* is immediately applied to the fresh stump surface of pines (Meredith 1959; Rishbeth 1963; Schwantes et al. 1976; Lipponen 1991; Gibbs et al. 2002) and spruce (Korhonen et al. 1994; Holdenrieder et al. 1997). There are spore preparations, which are specifically suited for spruce, but generally, *P. gigantea* is more suitable for pines. The wood can be automatically inoculated with spores through holes in the saw blade of the harvester (Metzler et al. 2005). The antagonist overgrows the stump cross surface, so that *H. annosum* cannot colonize it by spores. Thus, an infection of neighboring trees over root grafts is prevented. Further antagonists to *H. annosum* are treated by Holdenrieder and Greig (1998) and compiled by Woodward et al. (1998).

Root graft transmission can be reduced by far planting faces and admixture of hardwoods. Lesser sensitive hardwoods as well as fir or larch should be selected for particularly endangered sites instead of spruce and pine. In vitro, mycelial growth was inhibited by stilbenes, flavonoids and lignans (Zycha et al. 1976; Shain and Hillis 1971; Yamada 1992). Breeding attempts with the aim of red-rot resistant tree clones were performed, but did yet not reach a practical use. Recent resistance research mainly deals with the genetic mechanisms of resistance and the physiology of defense reactions (Korhonen and Holdenrieder 2005). Viruses in the root rot fungus, which are morphologically similar to the

Cryphonectria-hypovirus (Chap. 8.1.1.2), only reduced spore germination of the fungus.

8.3.3 *Stereum sanguinolentum*, Bleeding Stereum, Bleeding Conifer Parchment

Occurrence: conifers, particularly spruce; as saprobe causing red streaking discoloration (see Fig. 6.4a);

Significance: white rot, most important fungus involved in "Wound rot of spruce" (Butin 1995); 2/3 of about 20% of annual harvest of fir wood with fungal damage affected by wound rots, particularly by *S. sanguinolentum* (Schönhar 1989); wounds often due to mechanized wood harvest or bark damage by game; infection of the opened wood body by spores; also transmission of mycelial fragments by woodwasps (*Sirex* spp.); small and superficial wounds often closed by resin excretion; extension of white rot in the outer stem wood with reddish discoloration; fast rot extension (20 cm/year) in the first years after infection; rot spreads more rapidly after injuries at the root collar than after wounding the stem or small roots; injured roots of less than 2 cm in diameter and wounds in more than 1-m distance of the stem foot hardly lead to stem rot.

To prevent wound rot by *S. sanguinolentum*, tree harvest should be done carefully and injuries treated with a wound dressing. *Amylostereum* species may be also involved in wound decay of spruce and other conifers, *A. areolatum* and *A. chailletii*, both also being associated with woodwasps (Vasiliauskas 1999).

8.3.4 *Fomes fomentarius*, Tinder Fungus, Hoof Fungus

Occurrence: common, circumboreal, south to North Africa, through Asia to eastern North America; mostly hardwoods, common on birches in the north and on beeches in the south, also on oak, lime tree, maple, poplar, and willow, rarely on alder and hornbeam, exceptionally on softwoods (Schwarze 1994, 2001);

Fruit body (Fig. 8.15a): perennial (over 30 years, increase in early summer to autumn), thick, large (to 50 cm in diameter), hard brackets, mostly solitary; often high at the stem; firmly attached to the bark; upper surface: light brown to blackish-grey, bulging-zonate; pore surface: flat, cream-brownish hymenium with white margin; circular pores (4–5/mm); trimitic; soft-tough trama beneath a 1 to 2-mm-thick hard crust; 1–3 new hymenial layers per year; up to 240 million spores per cm^2 hymenium and hour; tetrapolar. In former times (e.g., in Haitabu), the trama was soaked with salpetre for tinder production.

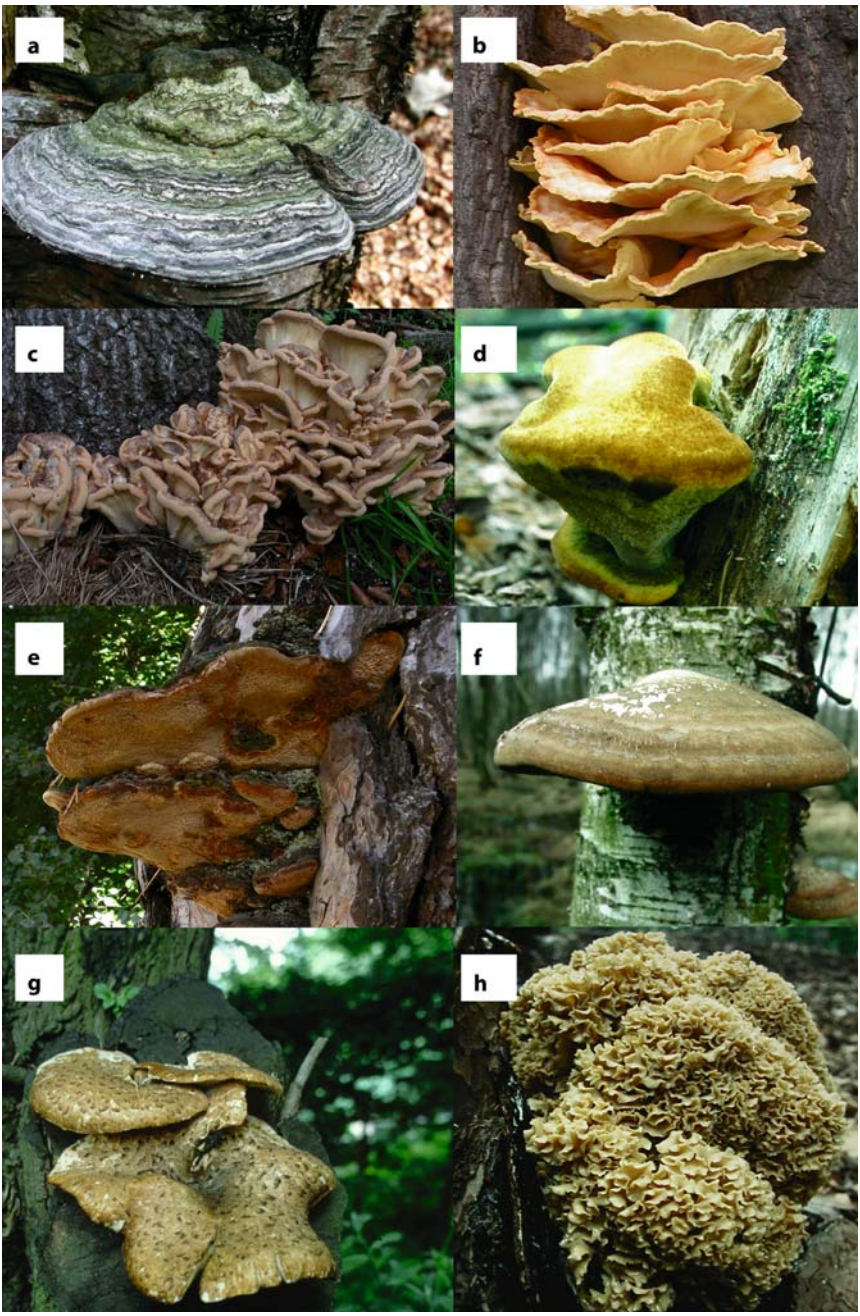

Fig. 8.15. Fruit bodies of tree decay fungi. **a** *Fomes fomentarius*. **b** *Laetiporus sulphureus*. **c** *Meripilus giganteus*. **d** *Phaeolus schweinitzii*. **e** *Phellinus pini*. **f** *Piptoporus betulinus*. **g** *Polyporus squamosus*. **h** *Sparassis crispa* (photos T. Huckfeldt)

A part of a fruit body was found at the "Ötzi" mummy. Still, around 1890, about 50 t of trama per year were sampled in the Bavarian, Bohemian and Thuringian forests for fire igniting, as styptic, and for the production of hoods, gloves and trousers (Hübsch 1991; Scholian 1996).

Significance: one of the most remarkable "large polypores"; infection of weakened and old trees via bark wounds or branch breakings; natural member in the biocoenosis of birch and beech forests; simultaneous white rot with black demarcation lines; at final stage, danger of windthrow; involved in the final decay of beech bark-diseased trees; saprobe on thrown or felled trees for several years ("Verstocken").

8.3.5 *Laetiporus sulphureus*, Sulphur Polypore, Giant Sulphur Clump

Occurrence: cosmopolitan, Europe, western North America, northeast Asia; preferentially on hardwoods with colored heartwood, like oak and robinia, also apple, beech, cherry, elm, lime tree, maple, pear, plum, poplar, willow, rarely on conifers; common on park and urban trees (Schwarze 2002);

Fruit body (Fig. 8.15b): annual (summer to autumn), conspicuous (upper surface: sulfur-yellow to reddish) wavy-velvety brackets (15–40 cm); pore surface: sulfur-yellow with angular pores (3–4/mm); single or in clusters; fresh: succulent-soft, later: inflexible, chalk-like, straw-colored to grey; dimitic; eaten in North America;

Significance: infection of the stemwood usually via wounds; brown rot in the heartwood; yellowish mycelium in broad, bind-like strips along the tears and shakes that develop in the wood; sapwood usually not attacked; infected trees alive for many years till broken or thrown by storm; rarely saprobic, e.g., on wooden boats.

8.3.6 *Meripilus giganteus*, Giant Polypore

Occurrence: circumboreal in the northern hemisphere, but nowhere common; usually hardwoods, particularly horse chestnut, beech, lime and oak; often on park and urban trees (Seehann 1979; Schwarze 2003);

Fruit body (Fig. 8.15c): annual (summer to autumn) on stumps of freshly felled trees and at the basis of standing trees; often apparently growing from the ground, but always in contact to wood; large and pileate with fan-shaped to spatulate pilei from a common base; aggregates to 1 m in diameter and 70 kg fresh weight; upper surface: cream-white to yellow-brown zonate; pore surface: cream to yellow-orange-brown pores (3–5/mm), rapidly blackish when bruised or cut; monomitic; eaten in Japan;

Significance: white rot in damaged roots of usually older trees, weakened due to compressed soil, asphalting, salting, and by wounds due to building operations or road traffic; fruit bodies indicate a heavily destroyed root system leaving only little time to the trees for surviving; stem hardly infected. Tree care in the urban area reduces the damage.

8.3.7
Phaeolus schweinitzii, Dye Polypore, Velvet Top Fungus

Occurrence: circumglobal, in European conifer forests north to 70 °N in Finnmark, Norway, particularly pine, Douglas fir, also spruce and larch, rarely on hardwoods (Ryvarden and Gilbertson 1993);

Fruit body (Fig. 8.15d): annual (late summer), easy-passing; at the stem basis or on the soil on hidden roots; stipitate, short, central, upward more thick, cylindrical to knotty stipe, first with spinning-top-like, later with several tile-like caps (to 40 cm); on the cross cuts of felled trees with lateral stipe; frequently including plant residues or small branches during ripening; upper surface: when young orange, later yellowish-brown, old often black; yellow-brown margin; woolly; pore surface: angular pore (1–2/mm) layer at first orange, later greenish to rusty brown, discolors with pressure red-brownish; monomitic;

Significance: brown rot, major cause of butt rot in the heartwood of old pine and Douglas fir; frequently in conifers forests on former hardwood soils (Schönhar 1989); first on roots and in stem wounds, later in the stem heartwood, less ascending the stem (butt rot); decayed wood and laboratory cultures with turpentine smell; saprobe on dead trees, stumps and logs for several years.

8.3.8
Phellinus pini, Ochre-Orange Hoof Polypore

Occurrence: circumglobal, widespread in northeast Europe on pine, in North America and Asia on other conifers as well (Heydeck 1997; Frommhold and Heydeck 1988);

Fruit body (Fig. 8.15e): perennial (to 50 years), brackets only 5–20 years after infection near branch holes and stubs; often high at the stem of old trees (Naumann 1995), 5–12 cm; upper surface: zonate, rough, cracked, at first rust-brown, hirsute, later dark-brown-blackish, glabrous and encrusted; pore surface: yellow to grey-brown with round to angular/daedaleoid pores (1–3/mm); dimitic, bipolar;

Significance: infection of old (30–50 years) pine and larch at exposed heartwood (branch stubs, wounds); living sapwood usually not penetrated; often high at the stem (Hartig 1874; Liese and Schmid 1966); from deep-reaching

dead branches decay upwards and downwards in the stem; white-pocket rot, preference for latewood of *Pinus* and *Larix* (Liese and Schmid 1966; Blanchette 1980), pockets in some hosts concentrated in the earlywood bands ("laminated rot", ring shake); occurrence of transpressoria and formation of cavity-shaped decay pattern (Liese and Schmid 1966); local bark deepenings, outer sapwood resin-infiltrated (in former times wood used as resinous wood); in spruce, infection also via sapwood; wood still relatively firm at early decay; dying after tree felling.

8.3.9 *Piptoporus betulinus*, Birch Polypore, Birch Conk Fungus

Occurrence: circumboreal, north to Norwegian North Cape at 71 °N (Ryvarden and Gilbertson 1994); only birch; also in gardens and parks;

Fruit body (Fig. 8.15f): annual (summer to late autumn), but enduring; solitary and in groups; shell-shaped, fan-like brackets (8 – 30 cm); pilei pendent, dimidiate, or reniform; often several meters high on the stem; upper surface: dull-smooth, unzonate, young cream-white, later ochre-brown to grey-brown, old usually cracked; pore surface: white to cream-brownish circular to angular pores (3 – 5/mm); dimitic; some isolates bipolar (Stalpers 1978); fruit body previously used in Fennoscandia as a cushion for knives, which do not rust while standing in the fruit body;

Significance: weakness-parasite, host-specific on older and weakened (e.g., lack of light) birch; infection via wounds (branch breakage); brown rot; danger of windthrow.

8.3.10 *Polyporus squamosus*, Scaly Polypore

Occurrence: circumpolar in Europe (north to Finnmark at 70 °N), Australia, Asia, and America; hardwoods such as ash, beech, elm, horse chestnut, lime, maple, planetree, poplar, and willow (Schwarze 2005); frequently on urban and park trees;

Fruit body (Fig. 8.15g): annual (early summer); solitary or in groups from a branched base; usually laterally stipitate, with circle to fan-like cap (to 80 cm wide and 2 kg fresh weight); upper surface: yellow-ochre with concentrically arranged light to dark-brown, scale-like patches, smooth and sticky; pore surface: cream-yellowish with angular-oval pores (1 – 2/mm); whitish stipe (up to 10 cm) at the basis dark-brown to black-felty; dimitic; tetrapolar (Stalpers 1978); young edible;

Significance: white rot in the heartwood of living and dead hardwoods with black demarcation lines after penetration through wounds.

8.3.11 *Sparassis crispa*

Occurrence: rare in Europe; particularly pine, also Douglas fir, spruce and fir;

Fruit body (Fig. 8.15h): annual (summer to late autumn); solitary at the root area of living pines, lateral and at cross surface of stumps and fallen stems; hemispherical to cushion-shaped; resembling a large (up to 70 cm and 6 kg fresh weight) sponge, cauliflower, or coral (German: "Krause Glucke"); consisting of numerous, wavy, narrow upright-standing branches deriving from a fleshy stalk; frizzy, leaf-like branch-ends partly growing together, similar to Icelandic moss; surface: smooth, cream, later ochre, when old with brown margin, finally completely brown; hymenium on the outside, downward arranged side of the branches; monomitic; when young well edible mushroom (in Germany certified as market fungus) with whitish meat, spicy morel-similar smell and nut-like taste; fruit bodies also on agar cultures; some isolates tetrapolar (Stalpers 1978);

Significance: parasitically in roots of older pines, ascending to 3 m high with brown rot in the stem heartwood; decayed wood with turpentine smell; economically important wood losses in pine and Douglas fir (Heydeck 1994).

8.4 Damage to Stored Wood and Structural Timber Outdoors

After felling or falling of a tree, the living cells die some time later. The active defense systems do not function any longer. Some fungi that are already present in the stem can continue degradation by their now saprobic way of life, e.g., *Fomes fomentarius*. The exposed wood surfaces however rapidly dry, and new ecological conditions develop. Thus, the stem usually provides a new energy-rich substrate for rapid colonization by several saprobic organisms (Zabel and Morrell 1992).

Colonization and discolorations of the stem in the forest occur frequently within short time by bacteria, algae, slime fungi, molds, and blue-stain and red-streaking fungi. After longer exposure wood decays by brown, white and soft-rot fungi develop, which may be summarized as "decay of stored wood", or "colonization of fallen and cut wood" (Rayner and Boddy 1988). Among the Basidiomycetes are e.g., *Armillaria gallica*, *Bjerkandera adusta*, *Chondrostereum purpureum*, *Fomes fomentarius*, *Stereum* spp., *Schizophyllum commune* and *Trametes versicolor*. Several fungi are involved in the decomposition of the stumps remaining in the soil e.g., *Armillaria* spp., *B. adusta*, *C. purpureum*, *Daedalea quercina*, *Fistulina hepatica*, *Ganoderma* spp., *Gloeophyllum* spp., *Grifola frondosa*, *Heterobasidion annosum*, *Meripilus giganteus*, *Phaeolus schweinitzii*, *Phlebiopsis gigantea*, *Pleurotus ostreatus*, *Stereum* spp.,

S. commune and *T. versicolor*. On tree residues remaining in the forest (top, branches) grow e.g., *B. adusta*, *C. purpureum*, *Coniophora puteana*, *Gloeophyllum sepiarium*, *Stereum sanguinolentum* and *T. versicolor*. Forest-litter degrading Basidiomycetes were described by Frankland et al. (1982).

Damages on roundwood (logs, poles) and boards may occur during transport and inappropriate storage e.g., by *C. puteana*, *Fomitopsis pinicola*, *Gloeophyllum trabeum*, *Paxillus panuoides*, *Phlebiopsis gigantea*, *S. sanguinolentum* and *Trichaptum abietinum*. Wood chips are damaged by *B. adusta*, *Gloeophyllum* spp., *Phanerochaete chrysosporium*, *T. versicolor*, and by several Deutero- and Ascomycetes (molds, blue-stain and soft rot fungi). Several bacteria, yeasts, Deuteromycetes and Ascomycetes were found in stored annual plant residues, like sugarcane bagasse (Schmidt and Walter 1978).

Yeasts commonly colonize twigs, leaves, litter, and humus, are however also found on freshly sawn lumber (Mikluscak et al. 2005).

Structural timber that is used outdoors in ground contact, like sleepers, poles, posts, fences, bridges and garden furniture, is attacked by soft-rot fungi if it is insufficiently treated with wood preservatives. Among the Basidiomycetes occur e.g., *Antrodia vaillantii*, *H. annosum*, *Lentinus lepideus*, *Leucogyrophana pinastri*, *Oligoporus placenta*, *Phanerochaete sordaria*, *Phlebiopsis gigantea*, *Serpula himantioides*, *Sistotrema brinkmanni*, *Trametes versicolor* and *Trichaptum abietinum* (e.g., Lombard and Chamuris 1990; Morrell et al. 1996).

Mine timber was decayed by *A. vaillantii* and *C. puteana* as well as by *Armillaria* spp., *G. sepiarium*, *H. annosum*, *L. lepideus*, *L. pinastri*, *O. placenta*, *Paxillus panuoides*, *Schizophyllum commune*, *Serpula lacrymans*, *Stereum* spp. and *T. versicolor* (Eslyn and Lombard 1983). *Earliella scrabosa*, *Loweporus lividus*, *Rigidoporus lineatus,* and *R. vinctus* were isolated from gold mine poles in India (Narayanappa 2005).

Wood in fresh water, like in cooling towers, is often destroyed by soft-rot fungi. Among the Basidiomycetes, e.g., *Donkioporia expansa* and *Physisporinus vitreus* have been isolated from cooling-tower woods (v. Acker and Stevens 1996). The latter fungus degraded pine sapwood samples that showed a final moisture content of up to 320% u (Schmidt et al. 1996). Schwarze and Landmesser (2000) hypothesized that the preferential degradation of tracheidal pit membranes is associated with the adaptation of this fungus to very wet substrates. Wood in salt water below (not permanent) the sea level, as in harbor constructions, is predominantly attacked by Deuteromycetes and Ascomycetes and rarely by Basidiomycetes (Jones et al. 1976; Kohlmeyer 1977; Leightley and Eaton 1980). Basidiomycetes, like *Antrodia xantha*, *Daedalea quercina*, *Gloeophyllum sepiarium*, *Laetiporus sulphureus*, *Lentinus lepideus*, *Phlebiopsis gigantea*, *Schizophyllum commune* and *Xylobolus frustulatus* dominate in wood above the water level, like in docks, stakes or boats (Rayner and Boddy 1988).

Damages on stored and structural timber in outside use can be reduced or even avoided by means of protection measures against fungal activity described

in Chap. 6.4: winter felling, short and adequate storage of the fresh roundwood, wet storage, rapid drying, storage in a gas atmosphere (N_2/CO_2), and storage of cut timber in well-ventilated piles with protection against rain as well as chemical protection.

In the following, some common Basidiomycetes on wood in outside use are described, mostly in note form. For details see also Grosser (1985), Breitenbach and Kränzlin (1986, 1991), Zabel and Morrell (1992), Eaton and Hale (1993), Ryvarden and Gilbertson (1993, 1994), Bech-Andersen (1995), Butin (1995), Kempe (2003), Krieglsteiner (2000), and Weiß et al. (2000).

8.4.1 *Daedalea quercina*, Maze-Gill, Thick-Maze Oak Polypore

Occurrence: circumglobal and throughout Europe, North America, North and Central Asia, North Africa; in northern Europe only on oaks, in central and southern Europe also on *Acer*, *Carpinus*, *Castanea*, *Chamaecyparis*, *Corylus*, *Eucalyptus*, *Fagus*, *Fraxinus*, *Juglans*, *Juniperus*, *Populus*, *Picea*, *Prunus*, *Robinia*, *Sorbus*, *Tilia,* and *Ulmus* (Ważny and Brodziak 1981);

Fruit body (Fig. 8.16h): perennial, single or fused, broadly sessile, dimidiate, flat or ungulate, sometimes imbricate, sometimes nodular or deformed, large brackets (up to 30 cm wide and 8 cm thick) often high at the stem; hard and corky to woody; upper surface: grooved, uneven, covered with nodes, glabrous or somewhat pubescent, cream, ochraceous grey to brown; pore surface: sinuous, or daedaleoid to labyrinthine, or almost lamellate, pores 1–4 mm wide measured tangentially, walls up to 3 mm thick; monstrous fructification in the dark; trimitic; bipolar;

Significance: brown rot in the durable heartwood of oaks and other hardwoods; on wounded standing trees via exposed heartwood, dead branches, on stumps, fallen stems, on sleepers, poles, stakes, wooden bridges, mine timber; occasionally in buildings on weathered timber, like window sills and half-timbering.

8.4.2 *Gloeophyllum* Species, Gill Polypores

Three *Gloeophyllum* species are relevant to wood. The fungi have similar fruit bodies and life conditions (Hof 1981a, 1981b, 1981c; Grosser 1985; also Bavendamm 1952a), and are thus usually united as “wood gill polypores”. They are widespread in Europe, North America, North Africa, and Asia on conifers and hardwoods. *Gloeophyllum abietinum* is a somewhat southern species, *G. trabeum* a southern species.

Fig. 8.16. Fruit bodies of decay fungi on stored wood and on timber in outdoor use. *Gloeophyllum abietinum*. **a** Upper side. **b** Lower side. **c** Darkness fruit bodies; *Gloeophyllum sepiarium* **d** Upper side. **e** Lower side; *Gloeophyllum trabeum* **f** Upper side. **g** Lower side. **h** *Daedalea quercina;* **i** *Lentinus lepideus*; **j** *Paxillus panuoides*; *Schizophyllum commune* **k** Upper side. **l** Lower side. **m** *Trametes versicolor* (photos T. Huckfeldt)

Gloeophyllum abietinum, Fir Gill Polypore

Fruit body (Fig. 8.16a,b): perennial, pileate (2–8 cm wide), broadly attached, often in rows or tile-like, on timber lower side resupinate; upper surface hirsute to velutinate, in age zonate, scrupose to warted or smooth, rusty yellow, reddish-brown to dark grey and black when old, when young whitish-yellow-brown, wavy, sharp margin; hymenophore ochre-grey brown, wavy lamellae (8–13/cm, behind the margin) with anastomosing, serrate, mixed with poroid areas; monstrous fruit bodies in the dark (Fig. 8.16c); trimitic; bipolar;

Strands: only rarely on timber in laboratory culture, cream-ochre-dark brown; fibers to dark brown; no vessels.

***Gloeophyllum sepiarium*, Yellow-Red Gill Polypore**

Fruit body: (Fig. 8.16d, e) annual to perennial, pileate, broadly sessile, dimidiate, rosette shaped, often imbricate in clusters from a common base or fused laterally, to 7 cm wide, 12 cm long and 6–8 mm thick, margin slightly wavy; upper surface when young yellowish brown, then reddish brown and grey to black when old; scrupose, warted to hispid, finally zonate often differently colored; hymenophore with straight lamellae (15–20/cm, behind the margin), edges of lamellae golden brown in active growth, later umber brown, side surface of lamellae ochre-brown; usually mixed with daedaleoid to sinuous pore areas (1–2/mm); monstrous fruit bodies in the dark; trimitic; bipolar;

Strands: only rarely on timber in laboratory culture, white-cream; fibers yellow to brown, no vessels.

***Gloeophyllum trabeum*, Timber Gill Polypore**

Fruit body (Fig. 8.16f, g): annual to perennial, pileate, sessile, imbricate with several basidiomes from a common base or elongated and fused along wood cracks, to 3 cm wide, 8 cm long, 8 mm thick; upper surface soft and smooth, hazelnut to umber brown to grayish when old, weakly zonate to almost azonate, lighter margin; hymenophore semi-lamellate or labyrinthine to partly poroid (2–4/mm), rarely lamellate specimens with up to four lamellae/mm along the margin, ochre to umber brown; monstrous fruit bodies in the dark; dimitic; bipolar;

Strands: only on timber in laboratory culture, white-beige to yellow-orange-grey brown, below 1 mm thick; fibers yellow to brown; no vessels.

Significance: predominantly saprobic, *G. sepiarium* and *G. trabeum* exceptionally on living trees; belonging to the strongest brown-rot fungi of coniferous structural timber; often on stumps; broad moisture optimum (about 40 to 200% u; Table 8.7), on stored timber and on finished timber that is again moistened, like poles, posts, fences, sleepers and mining timber. The fungi are the most important destroyers of conifers windows (cf. Fig. 8.17) that had accumulated moisture due to inappropriate window construction and handling faults by the user (e.g., injuring of the lacquer layer by nails). For example, 3.5 million (7%) of wooden windows were partly or completely destroyed by fungi, predominantly by *G. abietinum*, in Germany between 1955 and 1965 (Seifert 1974). Fungi survive in the sun-warmed and dry window timber due to their heat and dryness resistance [*G. abietinum*: 5–7 years survival in dry timber: Theden (1972)]. Fungi cause (by means of substrate mycelium) decay first only in the wood interior ("interior rot"). The serious brown rot under the varnish layer is often only recognized if fruit bodies develop. Except on

window timber, the gill polypores occur in buildings after moisture damages or incorrect structure on roofing timbers, on façades, outside doors, balconies, and on timber in saunas and mines.

8.4.3 *Lentinus lepideus*, Scaly Lentinus

Occurrence: temperate zones, common in Europe, North America, former Soviet Union, India; conifers, particularly *Pinus*, also *Abies*, *Cedrus*, *Larix*, *Picea*, *Pseudotsuga*, *Tsuga;*

Fruit body (Fig. 8.16i): mainly eccentric, stipe (up to 7 cm long), pileus 5–15 cm wide; fleshy-tough to hard in age, initially convex, later applanate; upper surface: pale to cream or purplish brown, with brownish scales (name!) in radial orientation; lower surface: whitish to yellow-ocher, serrate gills; monstrose, sterile fruit bodies in the dark (Seehann and Liese 1981); dimitic (Kreisel 1969);

Significance: brown rot of heartwood, via wounds and dead branches in standing trees, on stumps, felled logs, serious damage on structural timbers outdoors in ground contact (poles, sleepers, fence posts, stakes, wooden bridges, harbor timbers) (Bavendamm 1952b), on mine timber; particularly dangerous due to resistance to heat, desiccation and coal tar oil (test fungus in EN 113 for tar oil and comparable compounds); degradation of pine heartwood (interior rot) in improperly impregnated (drying shakes developed after treatment) poles and sleepers; rarely in buildings, particularly in the cellar and on damp timber on the ground floor, on joist heads in contact with wet masonry, door posts, roof timber; pleasant smell of the fresh mycelium of Peru balsam.

8.4.4 *Paxillus panuoides*, Stalkless Paxillus

Occurrence: mostly conifers;

Fruit body (Fig. 8.16j): annual, thin, small (2–12 cm), shell-shaped, bell-shaped, small eccentric stipe or attached, solitary or in groups, also tile-like; upper surface: pale-yellow to olive brown; lower surface: saffron-orange gills; monomitic; normal fructification in the dark (Kreisel 1961);

Significance: slowly growing, but serious brown rot; rarely at the basis of living pines, on stumps, stored wood, structural timber outdoors (sleepers, bridges, balconies), garden furniture, mine timber, rarely in buildings, associated with the *Coniophora* spp., on very moist places in cellars, cow-sheds, greenhouses.

8.4.5
Schizophyllum commune, (Common) Split-Gill

Occurrence: circumglobal, temperate to tropical, very common, predominantly hardwoods like *Fagus*, *Quercus*, *Tilia*, fruit woods, bamboos, straw, tea-leaves, coconut fibers;

Fruit body (Fig. 8.16k, l): annual, but durable, thin, small, shell-shaped (1–5 cm), dimidiate; usually in groups, leathery-tough; upper surface: grey-brown to flesh-colored becoming white with dryness, downy-woolly; lower surface: appearing as if gilled, hymenium covering fan-like arranged, at the beginning grey, later violet-brown pseudolamellae, which are lengthwise split and outwardly bent (Fig. 3.3d); hygroscopic movements of the split lamellae by being hard and rolled up in dry weather and being again flexible and sporulating after years of dryness when again moist; monomitic, tetrapolar (Raper and Miles 1958); formerly eaten in Assam, Congo, Peru and Thailand, and used as chewing gum in Hong Kong, Indonesia and Malaysia (Dirol and Fougerousse 1981); fructification also in culture;

Significance: white rot; as wound parasite on living trees after bark fire damage, on stumps, stored stems, frequently on beech as first colonizer; on stored and structural timber outdoors surviving dryness and exposition to sun by dryness resistance; in the tropics serious wood destroyer, fruit bodies often on imported timber; in vitro only little wood decay (Schmidt and Liese 1980).

8.4.6
Trametes versicolor, Many-Zoned Polypore

Occurrence: circumglobal, very common throughout Europe, dead wood of almost all hardwoods, particularly *Fagus*, also *Betula*, no attack of *Quercus*, *Castanea,* and *Robinia* (Jacquiot 1981), rarely conifers, also fruit woods after pruning;

Fruit body (Fig. 8.16m): annual, often reviviscent, hard-leathery, sessile or effused-reflexed, pilei dimidiate-substipitate, convex or imbricate, rarely resupinate, to 10 cm wide, often in large imbricate clusters, rarely solitary; upper surface: hirsute to tomentose, highly variable in color, with sharply contracted concentric zones of brown, buff, reddish or bluish colors (name!), often green by algae; lower surface: cream-white to ochraceus-yellow, angular to circular pores (4–5/mm); in the dark self-colored fruit bodies with totally white hirsute upper surface; trimitic; tetrapolar;

Significance: white-rot, often with black demarcation lines ("marble rot"); on wounded or dead standing trees, on stored stems, common on 4–6 years old hardwood stumps; rarely on sleepers, fence posts, garden timber; on mine timber; dryness resistance; used after World War II in the former East Germany

for the production of "myco-wood" for pencils, rulers, etc. (Luthardt 1963); test fungus in EN 113 for hardwood samples.

8.5 Damage to Structural Timber Indoors

8.5.1 General and Identification

The indoor wood decay fungi ("house-rot fungi") cause considerable economical damage in buildings. They may be considered to be the most important "wood fungi" as they deteriorate wood at the end of the economical series "forestry" – "timber harvest" – "storage" – "structural timber" – "indoor use". For Britain, it has been estimated that the cost of repairing fungal damage of timber in construction in 1977 amounted to £ 3 million per week (Rayner and Boddy 1988). An estimate for the former East Germany amounts to an avoidable damage in old houses of € 1.5 billion (Huckfeldt 2003). In the northern hemisphere, mainly coniferous wood is used as interior structural timber, in Germany particularly *Picea abies*. The most important wood-degrading fungi within buildings in Europe and North America are therefore fungi that cause brown rot in conifers. White-rot fungi, which preferentially attack hardwoods, are less common in buildings. Depending on the state of knowledge, formerly often only three more well-known species (groups) were called house-rot fungi in Europe: the True dry rot fungus, *Serpula lacrymans*, the cellar fungi *Coniophora* spp. (formerly only *C. puteana*) and the indoor polypores, formerly called "*Poria* group" (probably mainly *Antrodia vaillantii*). These three groups cause about 80% of the fungal wood damages in buildings. Recently, the Oak polypore, *Donkioporia expansa*, has also been accepted as important indoor rot fungus (Kleist and Seehann 1999). The Gill polypores (Falck 1909) may be included to the indoor species as they are common destroyer of painted coniferous window timber (Fig. 8.17) and also occur on damp roofing timber.

There are some evaluations on the frequencies of the various species involved in indoor wood decay. A survey of 1,500 buildings in New York State from 1947 to 1951 showed several fungi and *Hyphodontia spathulata*, *G. sepiarium*, *A. xantha*, and *G. trabeum* as most frequent isolations from decayed wood (Silverborg 1953). An investigation of 3,050 buildings in Poland showed 53.8% *S. lacrymans*, 22.4% *C. puteana* and 11.3% *A. vaillantii* (Ważny and Czajnik 1963). A survey of 1,200 biotic damages in buildings of the former East Germany over 21 years resulted in 34.8% *S. lacrymans*, 14.6% *Coniophora* spp., 13% soft rot and 8.7% "*Poria*" (Schultze-Dewitz 1985). An evaluation of 749 damages in Belgium between 1985 and 1991 revealed 59.4% *S. lacrymans*,

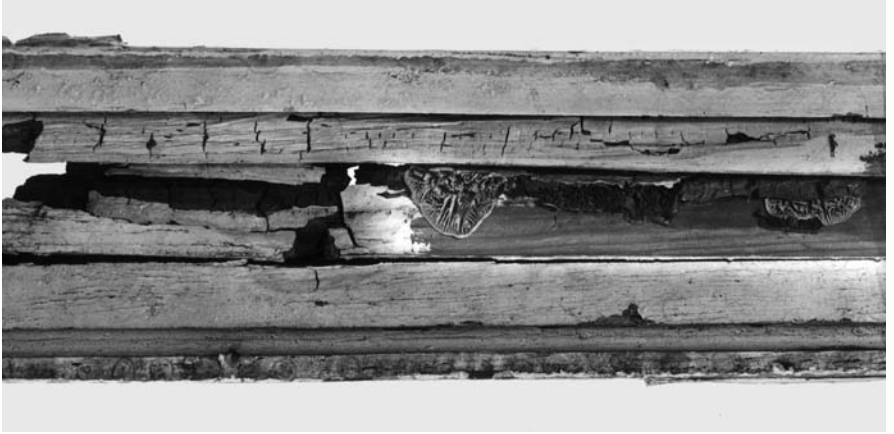

Fig. 8.17. *Gloeophyllum* sp. on window joinery. Fruit body and brown-rotten softwood

10.1% *C. puteana*, *C. marmorata*, 9.5% *Donkioporia expansa*, 2.3% *Antrodia vaillantii*, *A. sinuosa*, *A. xantha* and some further species (Guillitte 1992). An evaluation of a total number of 3,434 decay fungi in Norwegian buildings from 2001 to 2003 found as the most frequent fungi 18.4% *Antrodia* species, 16.3% *C. puteana*, 16.0% *S. lacrymans* and 2.9% *G. sepiarium* (Alfredsen et al. 2005). A recent survey over 4 years in 63 buildings in North Germany yielded 36 basidiomycetous species (Table 8.6). Supplemented by literature research, altogether about 70 different house-rot fungi have been reported (Huckfeldt and Schmidt 2005). However, those literature compilations might be uncertain due to the use of synonyms and the change in fungal nomenclature.

A survey of 5,000 cases of damage in multistorey houses revealed that all timbers without sufficient basic protection are endangered, but that there are different damage centers in a home: "*Poria*" and soft rot in the attic and upper floor, and *S. lacrymans* and *Coniophora* spp. on the ground and in the cellar (Schultze-Dewitz 1990).

Some of the less common indoor Basidiomycetes are listed in Table 8.6. Among them, *Lentinus lepideus* is particularly found in damp cellars, on the ground floor and in beam-ends in contact with wet masonry (Bavendamm 1952b). *Paxillus panuoides* occurs in cellars (Bavendamm 1953). *Daedalea quercina* affects structural oak-wood (windows, half-timbering). Falck (1927) mentioned for cellars *Polyporus squamosus* and Coggins (1980) also *Laetiporus sulphureus*, *Phlebiopsis gigantea* and *Trametes versicolor*. A description of the Dry rot fungus and other fungi in houses and on timber in exterior use has been compiled by Bech-Andersen (1995). Some of the more rare indoor species normally occur on trees or timber in outdoor use and are described in Chaps. 8.3 and 8.4. Further indoor damages are discolorations of window

Table 8.6. Species and frequency of house-rot fungi and accompanying fungi in buildings in northern Germany (from Huckfeldt and Schmidt 2005)

Species	Frequency
Serpula lacrymans	53
Coniophora puteana	7
Antrodia sp.	6
Antrodia xantha	5
Coprinus spp., three species	5
Donkioporia expansa	5
Asterostroma cervicolor	4
Antrodia sinuosa	3
Antrodia vaillantii	2
Coniophora marmorata	2
Dacrymyces stillatus	2
Diplomitoporus lindbladii [a]	2
Gloeophyllum trabeum	2
Lentinus lepideus	2
Leucogyrophana pinastri	2
Leucogyrophana pulverulenta	2
Paxillus panuoides	2
Trechispora farinacea	2
Asterostroma laxum [a]	1
Cerocorticium confluens [a]	1
Cerinomyces pallidus [a,b]	1
Gloeophyllum abietinum	1
Gloeophyllum sepiarium	1
Gloeophyllum sp.	1
Grifola frondosa [a]	1
Heterobasidion annosum	1
Hyphoderma praetermissum	1
Leucogyrophana mollusca	1
Oligoporus placenta	1
Oligoporus sp.	1
Phellinus contiguus	1
Phellinus pini	1
Pluteus cervinus [a]	1
Stereum rugosum	1
Trametes multicolor	1
Trichaptum abietinum	1
Volvariella bombycina	1
non-decay fungi:	
Peziza repanda	5
Reticularia lycoperdon	3
Cladosporium sp.	2
Fuligo septica	1
Ramariopsis kunzei	1
Scutellinia scutellata[a]	1

[a] For the first time proven to occur in houses
[b] First proof in Germany (Huckfeldt and Hechler 2005)

timber and outside doors by blue-stain fungi and molding in damp rooms (Chap. 6) (Frössel 2003; Hankammer and Lorenz 2003).

The common house-rot fungi are serious wood decayers. Among them, *S. lacrymans* is considered in Europe as most dangerous and most hardly controllable fungus due to its ability to transport nutrients and water. Traditionally, it is also supposed to possess some further specific features, which, however, do not all stand up to laboratory results. Nevertheless, in Germany, *S. lacrymans* has to be clearly differentiated from the other house-rot fungi in view of refurbishment. More far-reaching measures have to be performed in the case of its presence. Thus species identity should be known.

For identification, fruit bodies are preferentially used (Grosser 1985; Breitenbach and Kränzlin 1986; Jahn 1990; Ryvarden and Gilbertson 1993, 1994; Krieglsteiner 2000; Weiß et al. 2000; Kempe 2003; Bravery et al. 2003). A diagnostic key for fungi on structural timbers based on their fruit bodies is available in the internet and is to be completed in time (Huckfeldt 2002).

Some species only rarely fructify in buildings, or after isolation in laboratory culture, or do it never. However, some house-rot fungi form mycelial strands (cords). The classical strand diagnosis from Falck (1912) is old and includes only a few species. A diagnostic key including color photographs based on measurements in infected buildings and on wood samples in laboratory culture comprises several species (Huckfeldt and Schmidt 2004, 2006). An updated version is shown in Appendix 1. A recent textbook comprises photographs and identification keys for fruit bodies and strands of fungi occurring on wood in indoor and exterior use (Huckfeldt and Schmidt 2005).

If neither fruit bodies nor strands, but only vegetative mycelia are present, e.g., if only mycelium is found in buildings, or as it is the case for fungi cultured in the laboratory on agar, there are keys and books for mycelia (Nobles 1965; Stalpers 1978; Lombard and Chamuris 1990). However, some genera among the house-rot fungi are hardly or not at all distinguishable into species, like *Antrodia*, *Coniophora* and *Leucogyrophana*. Thus, molecular methods may be used (Chap. 2.4.2). Among the DNA-based techniques, species-specific ITS-PCR differentiated seven indoor wood-decay Basidiomycetes (Fig. 2.23, Table 2.9; Moreth and Schmidt 2000). The technique is meanwhile used in Germany for commercial identification of house-rot fungi. Sequencing of the internal transcribed spacer (ITS) of the ribosomal DNA (rDNA) and subsequent sequence comparison by BLAST with ITS sequences from correctly identified fungi deposited in the nucleotide databases is to date the best molecular tool for diagnosis (Table 2.8 and Fig. 2.22; Schmidt and Moreth 2002, 2003).

There is a great number of investigations on the physiology of house-rot fungi in text books (e.g., Jennings and Bravery 1991), monographs (e.g., Cockcroft 1981), and publications that may used in support of identification. Among the physiological parameters, growth rate and reaction to wood moisture con-

Table 8.7. Cardinal points of wood moisture content (% u) of some house-rot fungi for colonization and decay of wood (after Huckfeldt and Schmidt 2005)

Species	Minimum for colonization (moisture source 20–30 cm away)	Minimum for decay (mass loss above 2%)	Optimum for decay (mass loss above 10%)	Maximum for decay (mass loss above 2%)
Serpula lacrymans	21	26	45–140	240
Leucogyrophana pinastri	30	37	44–151	184
Coniophora puteana	18	22	36–210	262
Antrodia vaillantii	22	29	52–150	209
Donkioporia expansa	21	26	34–126	256
Gloeophyllum abietinum	20	22	40–208	256
Gloeophyllum sepiarium	28	30	46–207	225
Gloeophyllum trabeum	25	31	46–179	191

tent and temperature are important features. However, some of the older data suffer in so far as they derive from only vague or incorrectly identified fungi. Data that are based on genetically verified fungi are shown in Tables 2.2, 3.8–3.11, and 8.7.

Regarding the most important influence on wood decay, wood moisture, opinion has it that the indoor polypores need moisture above the fiber saturation range, which often occurs only after wetting with water, whereas the *Coniophora* spp. mostly attack wood, which was moisturized by vaporous water or by contact with damp material. The Dry rot fungus is halfway as it germinates on contact-wetted timber, but takes water from wet substrates by capillary mechanism and translocates water in its mycelium to timber for further growth (Schultze-Dewitz 1985).

In piled Scots pine sapwood samples placed on agar in 2-L Erlenmeyer flasks, a continuous wood moisture gradient developed within 6 weeks by diffusion from the agar via the lowest sample, which was water-saturated to the uppermost air-dried sample (Huckfeldt 2003). Table 8.7 shows that all fungi subsequently inoculated on the agar near the bottom wood sample degraded very wet wood. For example, *S. lacrymans* showed more than 2% wood mass loss in a sample of 240% final moisture content. The optimum moisture for decay (mass loss above 10%) varied among the species from 36 to 210% u. The minimum moisture for decay (mass loss above 2%) was slightly below fiber saturation and for *C. puteana* and *G. abietinum* significantly low at 22% u. Minimum moisture for wood colonization was for some fungi around 20% u, whereby the wood sample was 20–30 cm away from the agar as the water source (Huckfeldt and Schmidt 2005).

8.5.2
Lesser Common Basidiomycetes in Buildings

The following species description starts with some lesser common fungi and ends with the most serious European fungus, the True dry rot fungus *Serpula lacrymans*, in order of a transition to the remedial treatments. *Daedalea quercina*, *Gloeophyllum* species, *Lentinus lepideus* and *Paxillus panuoides*, which also occur in buildings, have been already described in Chap. 8.4. The following data are based on observations and measurements in attacked buildings and on genetically verified pure cultures on wood samples in the laboratory (Huckfeldt 2003; Huckfeldt and Schmidt 2005; Huckfeldt et al. 2005; Schmidt and Huckfeldt 2005), and were supplemented mainly from Grosser (1985), Breitenbach and Kränzlin (1986), Ryvarden and Gilbertson (1993, 1994), and Bravery et al. (2003).

8.5.2.1
Diplomitoporus lindbladii

Occurrence: circumpolar in the conifers zone, in Europe throughout the conifer forest regions, but rare in the Mediterranean region, North America, also on hardwoods;

Fruit body (Fig. 8.18a): annual to biannual, resupinate, becoming widely effused (a few decimeters), up to 6 mm thick, biannual basidiomes thicker, frayed margin, easily separable; upper surface white-cream, grey when old; pore surface with 2–4 circular-angular pores/mm, to 3 mm deep; trimitic; allantoid to cylindrical, hyaline spores (5–7 × 1.5–2 µm); bipolar;

Strands (Fig. 8.18b): on timber in laboratory culture, white, yellowing when dry, root-like, iceflower-like, similar to *A. vaillantii*; fibers similar to *A. vaillantii*, but soluble in 5% KOH;

Significance: white rot, indoors.

8.5.2.2
Asterostroma cervicolor and *A. laxum*

Fruit body (Fig. 8.18c): resupinate, sheet-like, thin, whitish to ochre or cinnamon, hardly distinguishable from mycelium; no pores; may be found on masonry; spores warty (*A. cervicolor*), without warts (*A. laxum*); monomitic;

Strands and mycelium (Fig. 8.18d): cream-brown, up to 1-mm-wide strands with a rough appearance, flexible when dry, sometimes across and inside masonry over a long distance, brown strands often present next to fruit body,

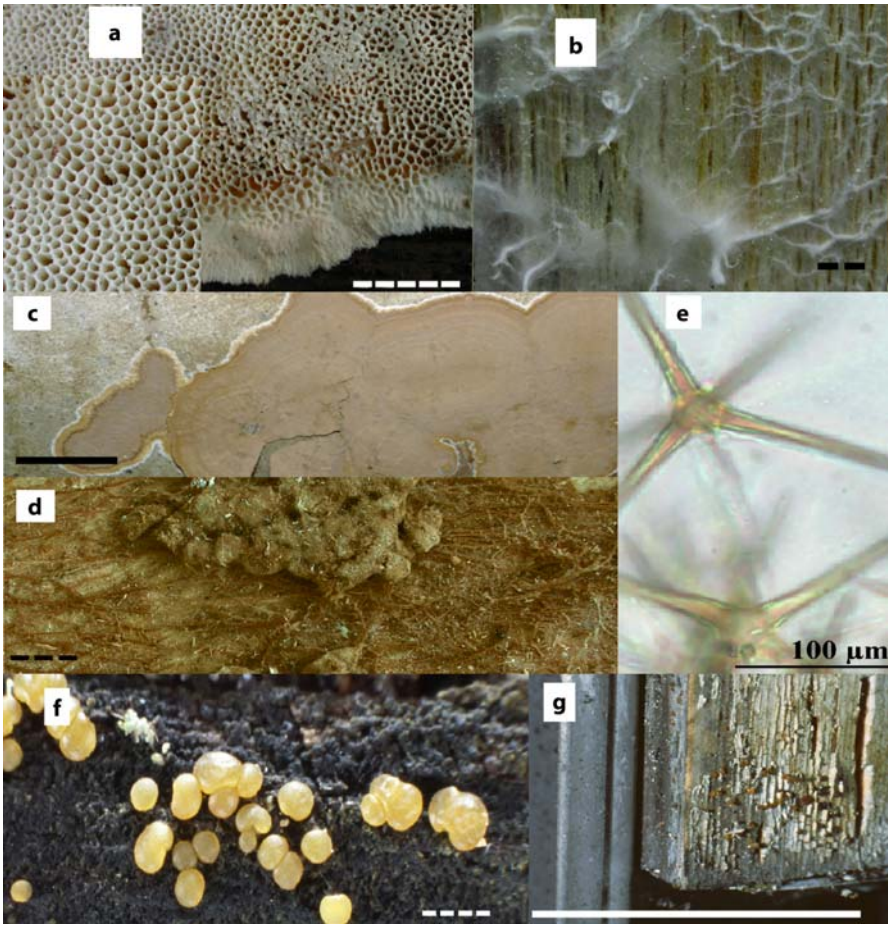

Fig. 8.18. *Diplomitoporus lindbladii* **a** Fruit body and detail. **b** Mycelium and strands on white-rotten wood; *Asterostroma cervicolor* **c** Fruit body on a ground ceiling. **d** Knotty mycelium and strands on a floorboard. **e** Stellar setae; *Dacrymyces stillatus* **f** Young fruit bodies. **g** Old fruit bodies on window joinery (photos T. Huckfeldt) — 5 cm, - - - 5 mm

embedded in white mycelium or in fruit bodies (*A. laxum*); surface mycelium of *A. cervicolor* first white, then brown, partly only small mycelial plugs;

Stellar setae (Fig. 8.18e): within basidiome, mycelium and strand (German: "Sternsetenpilz"); setae dichotomically branched, to 90 µm in diameter and partly rare in *A. laxum*, setae rarely branched and to 190 µm in diameter in *A. cervicolor*;

Significance: white-rot, softwoods, often on joinery, e.g., skirting boards, floor and ceiling boards, windows, fiber and gypsum boards, decay often limited in extent.

8.5.2.3
Dacrymyces stillatus, Orange Jelly

Fruit body (Fig. 8.18f, g): yellow-orange-red, also whitish, dark orange when dry, button-shaped, lenticular to mug- or plate-like, 1 – 15 mm wide, gelatinous-elastic, slimy melting when old, solitary and in groups, often two different forms on the same place, a brighter form with basidiospores and a darker form with arthrospores, often appearing through paint;

Significance: white rot, softwoods and hardwoods, wood darkens, decay commonly patchy with small pockets of rot, often restricted to interior of timber, on window and doorframes, common outdoors on windows, claddings and along the gable board of the roof (Alfredsen et al. 2005).

8.5.3
Common House-Rot Fungi

There is a bulk of knowledge on the common indoor wood decay fungi due to their economic importance. Thus, these species and species groups are described in more detail in the following (also Findlay 1967; Bavendamm 1969; Coggins 1980; Cockcroft 1981; Grosser 1985; Jennings and Bravery 1991; Ryvarden and Gilbertson 1993, 1994; Krieglsteiner 2000; Weiß et al. 2000; Kempe 2003; Sutter 2003; Huckfeldt and Schmidt 2005).

8.5.3.1
Donkioporia expansa, Oak Polypore

This fungus is only recognized since the 1920s as relevant for practice and since about 1985 as important decay fungus in buildings (Kleist and Seehann 1999; Erler 2005). Assumably, the species was often overlooked despite the less common decay type of a white rot in buildings and the large size of its fruit bodies. A reason it was overlooked may be that damage is often restricted to wood interior and not noticed until fruit bodies appear and furthermore that the fruit bodies are inconspicuously embedded in plentiful surface mycelium.

Occurrence: fairly rare, Central Europe, North America, in Germany preferentially in the south, at least in Europe almost exclusively restricted to structural timber, preferably *Quercus*, but also *Castanea*, *Fraxinus*, *Populus* and *Prunus*, frequently also on indoor timber of *Picea* and *Pinus*;

Fruit body (Fig. 8.19a, b): perennial, resupinate, first white, then ochre to reddish-tobacco-brown to grey with ageing, to 10 cm thick, becoming widely effused to a few square meters, firmly attached, an walls wavy to stairs-like, often multi-layered, tough-elastic with silvery surface when fresh, hard and brittle when dry, easily separable when old, mainly made up of long tubes, 4 – 5

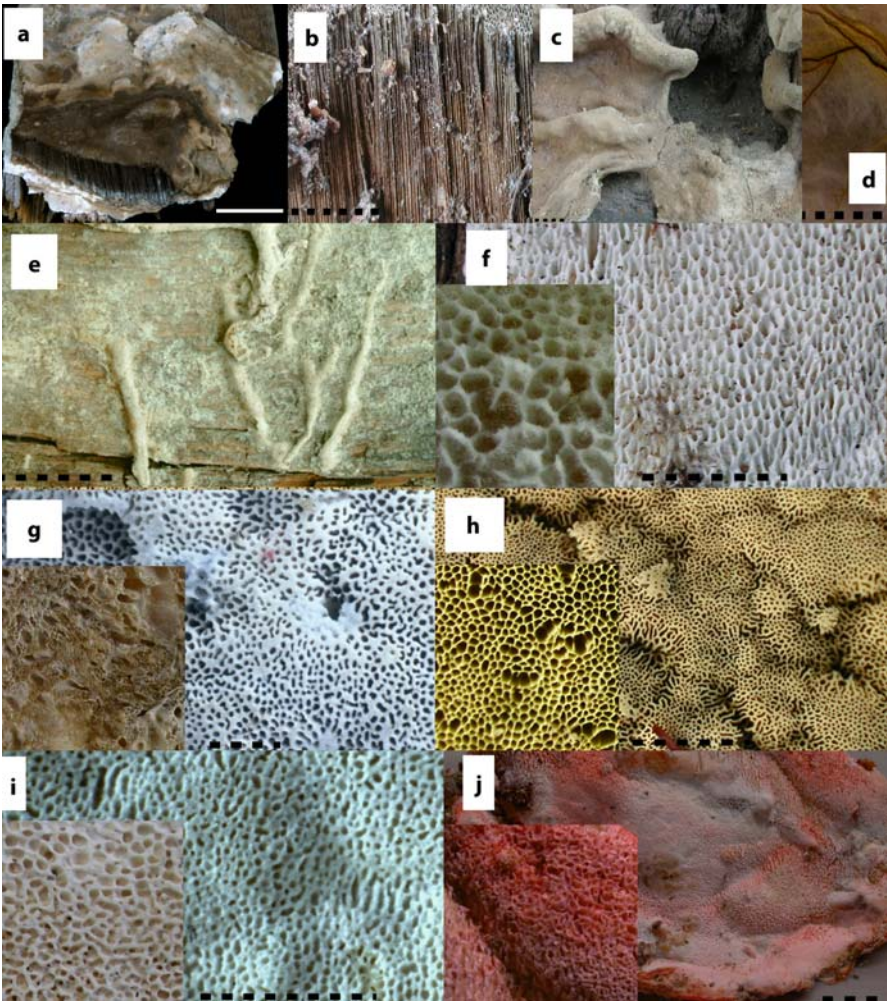

Fig. 8.19. *Donkioporia expansa* **a** Fruit body and mycelium. **b** Detail showing the long pores. **c** Old mycelium. **d** Strand-like structures grown on wood in laboratory culture; *Antrodia vaillantii* **e** Mycelium and strands. **f** Fruit body and detail. **g** *Antrodia sinuosa* fruit body and detail. **h** *Antrodia xantha* fruit body and detail. **i** *Antrodia serialis* fruit body and detail. **j** *Oligoporus placenta* fruit body and detail (photos **b–j**: T. Huckfeldt) — 5 cm, - - - 5 mm

circular to angular pores/mm, often amber guttation drops, which leave behind small black pits when dry; trimitic; ellipsoid spores 4.5–7 × 3.2–3.7 µm;

Mycelium (Fig. 8.19a,c): inside wood shakes and cavities, at high air humidity also on free wood surfaces with thin, skin-like mycelial flaps with bizarre seeds, later thick, brownish surface mycelium, guttation as on fruit bodies, black demarcation lines between mycelium and woody substrate;

Strands (Fig. 8.19d): not yet observed in buildings, strand-like structures on wood samples in laboratory culture, rare, cream, yellowish to grey-brown, root-like, hidden under mycelium;

Significance: The Oak polypore inhabits damp areas in kitchens, bathrooms, WC, cellars, cow-sheds, occurs on beams, under floors, in mines, on bridge timber, and cooling tower wood [Azobé, Bangkirai; v. Acker et al. (1995); v. Acker and Stevens (1996)]. It produces a white-rot. Continuous high wood moisture promotes growth (defective sanitary facilities, cooling tower wood). The fungus is often found at beam-ends that are enclosed in damp walls. At initial attack of softwoods, the timber surface remains often nearly intact ("interior rot"). In laboratory culture, minimum wood moisture for wood colonization was 21% u and for wood decay 26%. Greatest wood mass losses occurred between 34 and 126% (Table 8.7). Moisture maximum was 256%. Temperature optimum was 28 °C, and maximum was 34 °C (Table 3.8). The fungus survived for 4 h in dry wood of 95 °C (Huckfeldt 2003). Wood mass losses according to EN 113 were: oak sapwood 45%, oak heartwood 23%, beech 50%, birch 60%, pine sapwood 40% (Kleist and Seehann 1999). Assumably, there is no spread by strands from moist to dry wood and no growth through the masonry because strands were only found in vitro to date. Thus, refurbishment only needs drying and exchange of destroyed timber. In oaks, the fungus is often associated with the death-watch beetle, *Xestobium rufovillosum*.

8.5.3.2 Indoor Polypores: *Antrodia* Species and *Oligoporus placenta*

Four *Antrodia* species and *O. placenta* may be assigned to the indoor polypore fungi.

Occurrence: circumglobal in the coniferous forest zone, mostly on softwoods (Findlay 1967; Domański 1972; Coggins 1980; Lombard and Chamuris 1990; Grosser 1985; Lombard 1990; Ryvarden and Gilbertson 1993, 1994; Krieglsteiner 2000; Sutter 2003);

Antrodia vaillantii occurs circumglobal in the coniferous forest zone and in Europe widely distributed, but rather rare in Fennoscandia. It is the most frequent fungus in British mines (Coggins 1980). *Antrodia sinuosa* is circumpolar in the boreal conifer zone, widespread in Europe, North America, East Asia, North Africa, and Australia (Domański 1972). The species was in Sweden with 1,045 damages between 1978 and 1988 with 13% portion the most common indoor polypore (Viitanen and Ritschkoff 1991a). *Antrodia serialis* attacks logs and piles, causes heart rot in standing trees and occurs widespread, also in Himalaya and Africa (Seehann 1984; Breitenbach and Kränzlin 1986), rarely (1.4%) in buildings (Viitanen and Ritschkoff 1991a; Coggins 1980), within the roof area, in cellars and under corridors (Domański 1972). *Antrodia xan-*

tha (Domański 1972) occurs in Europe and North America on fallen stems, branches, stumps, in greenhouses (Findlay 1967), at windows (Thörnqvist et al. 1987), on timber in swimming pools and in flat roofs (Coggins 1980). *Oligoporus placenta* is rare, but widespread in Europe except for the Mediterranean. In North America, the fungus is the most common wood decayer in ships (Findlay 1967) and was exported to Great Britain (Coggins 1980). In North America, *O. placenta* and *A. serialis* are common on mine timber and poles (Gilbertson and Ryvarden 1986).

Antrodia vaillantii, Mine polypore, Broad-spored white polypore

Fruit body (Fig. 8.19f): annual, resupinate, first white, then light yellow to grey, drying, as corky layer (to 1 cm thick) on the wood underside or above as pad; 2–4 circular-angular pores/mm hymenium, to 12 mm long; dimitic; hyaline spores 5–7 × 3–4 µm;

Strands (Fig. 8.19e): pure white, felty, 0.5–7 mm in diameter, ice flower-like, flexible also if dry; fibers numerous, white, flexible, 2–4 µm thick, unsoluble in 5% KOH; vessels not rare, to 25 µm in diameter, partly with thick walls and reduced lumen, no wall thickenings; vegetative hyphae with clamps, 2–6 µm in diameter, often also thick-walled.

Antrodia sinuosa, White polypore, Small-spored white polypore

Fruit body (Fig. 8.19g): similar to *A. vaillantii*, annual, resupinate, to 5 mm thick; 1–3 circular-sinuous pores/mm, to 3 mm long; dimitic; hyaline spores 4–6 × 1–2 µm;

Strands: similar to *A. vaillantii.*

Antrodia xantha, Yellow polypore

Fruit body (Fig. 8.19h): annual, resupinate, first yellowish, then pale, white-cream, crusty to bracket-shaped, to 10 mm thick, 1 m wide; 3–7 circular-angular pores/mm, to 5 mm long; margin without pores; on vertical substrates small knots, to 8 mm large, partly grown together; dimitic; hyaline spores 4–5 × 1–1.5 µm;

Strands: similar to *A. vaillantii*, but partly yellow discolored, later often pale and then undistinguishable from *A. vaillantii.*

Antrodia serialis, Effused tramete, Row polypore

Fruit body (Fig. 8.19i): annual to biennial, resupinate to pileate, first white to cream-ochre, then pink-spotted, to 6 mm thick, to a few decimeters wide; 2–4 circular, partly slitted pores/mm, to 5 mm long; distinct, wavy margin; also in rows; dimitic; hyaline spores 4–7 × 3–5 µm;

Strands: not yet found.

***Oligoporus placenta*, (Reddish) Sap polypore**

Fruit body (Fig. 8.19j): annual, resupinate, either white to grey-brown (form *monticola*) or later pink to salmon-violet (reddish form *placenta*) (Domański 1972), easily passing, to 1 cm thick; 2–4 circular-angular-slitted pores/mm, to 15 mm long; monomitic; hyaline spores 4–6 × 2–2.5 µm;

Strands: on wood samples in laboratory culture, white, partly yellowing, easily refractable, to 1 mm in diameter; fibers and vessels rare or absent.

Significance: The five "indoor polypores" form a group of brown-rot fungi that are associated with the decay of softwoods in buildings. In Central Europe, these fungi belong after the Dry rot fungus, *Serpula lacrymans*, and together with the *Coniophora* cellar fungi to the most common indoor decay fungi. They accounted for 14% of indoor decay fungi in Denmark (Koch 1985) and Finland (Viitanen and Ritschkoff 1991a). A survey in California ranked *A. vaillantii*, *A. sinuosa, A. xantha* and *O. placenta* with 29% occurrence as the main group (Wilcox and Dietz 1997).

The polypores have similar biology and distribution (Lombard and Gilbertson 1965; Donk 1974; Breitenbach and Kränzlin 1986; Lombard and Chamuris 1990; Bech-Andersen 1995; Schmidt and Moreth 1996, 2003). They differ in their fruit body, spore morphology (Jülich 1984; Ryvarden and Gilbertson 1993, 1994) and sexuality. Some species also fruit in laboratory culture, which supports identification of mycelia and tests for sexuality. *Antrodia vaillantii* is tetrapolar heterothallic (Lombard 1990), *A. serialis*, *A. sinuosa* and *O. placenta* are bipolar (Domański 1972; Stalpers 1978). Three *Antrodia* species develop strands (Falck 1912; Stalpers 1978; Jülich 1984), *O. placenta* only in vitro. However, the vegetative mycelium that has been isolated from decayed wood is hardly distinguishable (Nobles 1965). Due to the limited differentiating features, misinterpretations occur.

Furthermore, the nomenclature has a confusing history and is still not always uniform (Cockcroft 1981). Fungi have been variously classified as *Polyporus, Poria*, *Amyloporia, Fibroporia* (Domański 1972). Misleading synonyms in the older literature such as *Polyporus vaporarius* and *Poria vaporaria* have been used for different species, viz. *A. vaillantii* (Bavendamm 1952c), *A. sinuosa*, and *O. placenta*. According to Ryvarden and Gilbertson (1994), the Reddish sap polypore, formerly *Tyromyces placenta* (Fr.) Ryv., was placed in *Oligoporus*, since the genus *Tyromyces* is restricted to fungi causing a white rot. Older synonyms are *Postia placenta* (Fr.) M.J. Larsen & Lomb., *Poria placenta* (Fr.) Cooke sensu J. Eriksson, *Poria monticola* Murr., and the haploid standard strain *Poria vaporaria* (Pers.) Fr. sensu J. Liese (Domański 1972). *Postia* is a nomen provisorium/nudum in the sense of Fries and illegitimate in the sense of Karsten. Isolate MAD 698 of *Postia placenta* was thoroughly investigated in view of brown-rot decay mechanisms (e.g., Clausen et al. 1993; Highley and Dashek 1998). Difficulties may increase because *O. placenta* separates into the

forms *placenta* with salmon-pink fruit bodies ("Reddish sap polypore") and *monticola,* never with reddish stain (Domański 1972). Monokaryotic isolates of *O. placenta* were used for testing wood preservatives in Germany (*Poria vaporaria* "standard strain II") and are obligatory in the recent European standard EN 113 (see Table 3.9, 3.10, named "*Poria placenta*" FPRL 280). Even literature from 2005 uses the names *Postia placenta* and *Poria placenta*.

For species identification in the case that only vegetative mycelium is present, rDNA-ITS sequencing separates the five species (Schmidt and Moreth 2003; Chap. 2.4.2.2).

For an easier understanding during a practical valuation of a fungal damage, the different fungi are often summarized as "indoor polypores" or as "Vaillantii group", particularly because they differ from the Cellar fungus and Dry rot fungus by their mycelia, strands, and fruit bodies. The polypores, particularly *A. vaillantii*, form a well-developed white and cottony surface mycelium without "inhibition colors", which, thus, can be confused with the young mycelium of the Dry rot fungus. Polypore mycelium spreads ice flower-like over the substrate, that of the Dry rot fungus is converted with ageing into silvery-grey skins, and that of the cellar fungi is dominated by fine black strands. White (*A. vaillantii*), to string-thick, smooth and flexible strands develop within the mycelium and grow over non-woody substrates and also through porous masonry (Grosser 1985), the latter, however, less intensive than by the Dry rot fungus. The white to yellow (*A. xantha*) or red (*O. placenta* f. *placenta*) fruit bodies show pores that are visible with the naked eye (Fig. 8.19). The dry wood shows the typical brown-cubical rot. It is often said that the cubes caused by the polypores and the cellar fungi are smaller than those by the Dry rot fungus. The cube size varies however also as a function of the wood moisture content (Grosser et al. 2003). After advanced decay, the dried substrate of most brown-rot fungi can be ground with the fingers to a brown powder ("lignin").

The polypores attack predominantly coniferous woods in damp new and old buildings, particularly in the upper floor, furthermore mine timber, stored timber as well as timber in outside use, particularly in the soil/air zone, such as poles and sleepers. They also attack trees as wound parasites and live on stumps and fallen trees (Krieglsteiner 2000). *Antrodia serialis* was found in over-mature Sitka spruce trees (Seehann 1984). "Dry" wood should not become infected. In the laboratory, however, wood of 22% moisture content was colonized (Table 8.7). As so-called "wet-rot fungi" (Coggins 1980; Bravery et al. 2003), they need wet wood with moisture contents from 30 to 90% u for a long time. According to literature, the optimum is around 45% (Table 3.6). Laboratory experiments revealed that minimum moisture for wood decay by *A. vaillantii* was 29% and the optimum 52 to 150% (Table 8.7). With timber drying, *Antrodia* species were supposed to die (Bavendamm 1952c; Coggins 1980). However, more convincing seems that they only stop growth (Grosser

1985). In the laboratory, over 11 years were survived by "dryness resistance" (Theden 1972), so that fungi may come to life again. There is also resistance to high temperature: *Antrodia vaillantii, A. sinuosa* and *O. placenta* survived on agar 3 h at 65 °C. *Antrodia vaillantii* and *O. placenta* withstood heat of 80 °C for 4 h in slowly dried wood samples (Huckfeldt 2003), which has to be considered in view of a possible treatment of infected homes with hot air.

Some species destroy timber in soil contact, like poles and palisades, even if it is properly impregnated with chrome-copper salts (Stephan et al. 1996). Especially *A. vaillantii* but also *A. xantha* and *O. placenta* are known for copper tolerance (Da Costa and Kerruish 1964) due to the production of oxalic acid (Rabanus 1939; Da Costa 1959; Sutter et al. 1983, 1984; Jordan et al. 1996). Strain variation occurred (Da Costa and Kerruish 1964; Collett 1992a, 1992b), and monokaryons were more tolerant than their parental strains (Da Costa and Kerruish 1965). In vitro, *A. vaillantii* was the most copper-tolerant fungus among the five species (Table 3.10) and produced most oxalic acid (Table 3.9; Schmidt and Moreth 2003). *Antrodia vaillantii* is also tolerant to arsenic (Göttsche and Borck 1990; Stephan and Peek 1992).

8.5.3.3 Cellar fungi: *Coniophora* species

Occurrence: The genus *Coniophora* comprises about 20 species occurring worldwide with a broad host range primarily on conifers (Ginns 1982). Seven species occur in Europe (Jülich 1984) and five in Western Germany (Krieglsteiner 1991). *Coniophora puteana* is frequently associated with brown-rot decay in European buildings. The fungus was estimated to be twice as common as the Dry rot fungus in the UK (Eaton and Hale 1993). It comprised over 50% of the inquiries at the Danish Technological Institute (Koch 1985), 16.3% in Norway (Alfredsen et al. 2005), and 13% at the Finnish Forest Products Laboratory (Viitanen and Ritschkoff 1991a). The fungus has been used for nearly 70 years as a test fungus for wood preservatives in Europe. It also occurs in the USA, Canada, South America, Africa, India, Japan, Australia, and New Zealand. Further "cellar fungi" that attack indoor timber in Europe are especially *C. marmorata*, and also *C. arida* and *C olivacea* (Fig. 8.20). In Europe, the cellar fungi cause with about 10% frequency the two to third most common fungal indoor wood decay after *S. lacrymans*. In Australia and New Zealand, *C. arida* and *C. olivacea* are common. Some further *Coniophora* species also occur in buildings, mines and glass houses, but predominantly in warm climatic zones (Ginns 1982). The species can be differentiated by their fruit bodies (Jülich and Stalpers 1980; Breitenbach and Kränzlin 1986; Krieglsteiner 2000). However, the species concept within *Coniophora* is difficult because there are only a few, and unstable characteristics, which complicates species identification in infected buildings. With regard to isolates in culture, *Coniophora* cannot

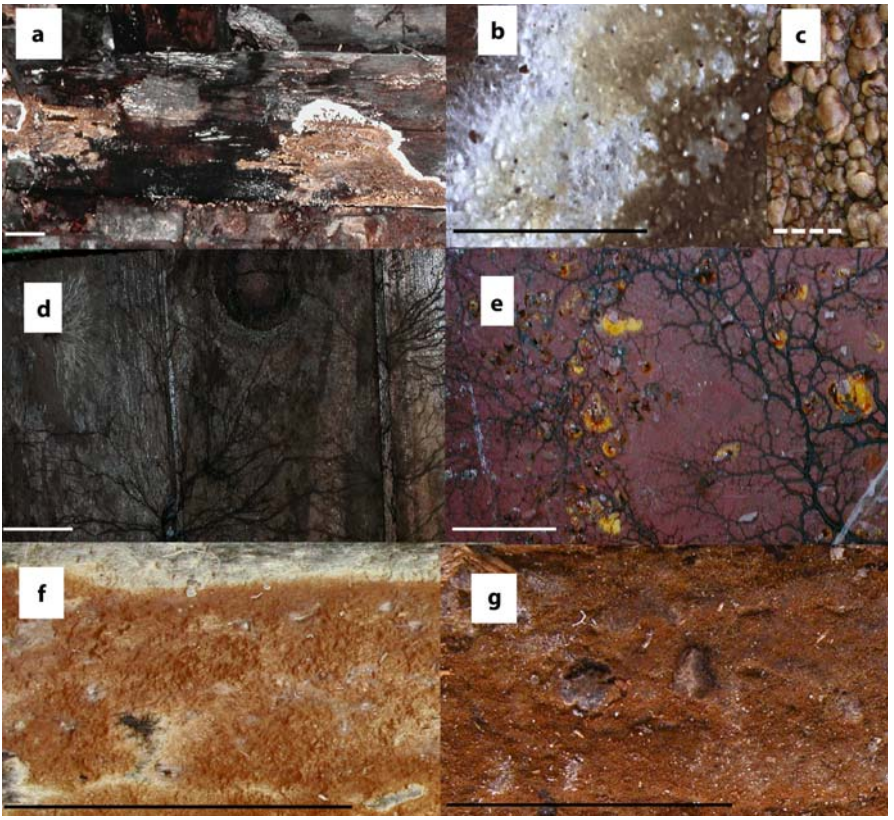

Fig. 8.20. Cellar fungi. *Coniophora puteana* **a** Fruit body. **b** Fruit body margin. **c** Fruit body detail with warts. **d** Strands in a false ceiling. **e** Strands on a steel girder. **f** *Coniophora arida* fruit body. **g** *Coniophora olivacea* fruit body (photos T. Huckfeldt) — 5 cm, - - - 5 mm

be differentiated at the species level by morphological and cultural characteristics (Stalpers 1978). Thus, isolations from buildings were summarized as *C. puteana*/ *C. marmorata* (Guillitte 1992). Sequencing of the rDNA-ITS separated the species (Schmidt et al. 2002b). Based on fruit-body identification, *C. marmorata* is rather common in southern Germany. The following description is based mainly on Huckfeldt (2003), Huckfeldt and Schmidt (2005) and Schmidt and Huckfeldt (2005).

Coniophora puteana, (Brown) Cellar fungus

Fruit body (Fig. 8.20a–c): annual, resupinate, light to dark brown, first white-yellow, then brownish; indistinct, fibrous margin; to 4 mm thick, to a few decimeters wide, firmly attached, fragile when dry; warty knots up to 5 mm thick; monomitic; yellow-brown spores 9 – 16 × 6 – 9 µm;

Strands (Fig. 8.20d, e): first white, soon brown-black, to 2 mm thick, root-like, fragile, black wood beneath the strands; fibers brown, 2–5 µm thick, lumina visible; vessels 10–30 µm thick, often deformed, no bars; vegetative hyphae mostly clampless, rarely with multiple clamps, with brown drops (1–5 µm) holding the hyphal net together.

Coniophora marmorata, Marmoreus cellar fungus

Fruit body: annual, resupinate, pale to olive-brown, grey margin, to 0.4 mm thick, to 15 cm wide, separable, felty; dimitic; no picture available because not yet found in buildings in northern Germany;

Strands: brownish, to 1 mm thick, easily separable, no drops.

Coniophora arida, Arid cellar fungus

Fruit body (Fig. 8.20f): annual, resupinate, white-ochre to yellow-brown, light margin, to 0.3 mm thick, to 10 cm wide, firmly attached, smooth to felty, fine-frayed margin; monomitic;

Strands: rare, white to brown, 0.1 mm thick.

Coniophora olivacea, Olive cellar fungus

Fruit body (Fig. 8.20g): annual, resupinate, olive-brown, margin lighter, fraying with strands, to 0.6 mm thick, to 6 cm wide, firmly attached, smooth to warty, fibrous-cottony, septate cystidia, monomitic, partly merging fruit bodies;

Strands: brown, thin.

Significance: The older European literature on occurrence, biology and significance of the cellar fungi summarizes the several fungi to *C. puteana*. This fungus was said to be the most common species in new buildings. It however occurs also in damp old buildings, on stored wood, timber in soil contact like poles, piles, sleepers and on bridge timber as well as rarely on stumps and as wound or a weakness parasite on living trees (Bavendamm 1951a; Grosser 1985; Breitenbach and Kränzlin 1986; Sutter 2003). Of 177 Basidiomycetes on American mine timbers, 83 isolates were *C. puteana* (Eslyn and Lombard 1983). In buildings it does not occur, like the name misleadingly suggests, only in cellars, but it can ascend everywhere on damp timber up to the roof (Schultze-Dewitz 1985, 1990). Beside softwoods, it attacks also several hardwoods (Wälchli 1976). As a so-called wet rot fungus (Bravery et al. 2003) with relatively high requirement for moisture from 30 to about 70% u and the optimum around 50% (Table 3.6), all timber in the area of damp walls (beam ends and wall slats), damp floors and ceilings in kitchens, bathrooms and toilets as well as all timber in areas with water vapor development (swimming pools, launderettes) is endangered. In vitro, minimum moisture of *C. puteana* for wood colonization was 18% u and for decay 22%. The optimum moisture was broad, from 36 to 210% (Table 8.7). Damage by the cellar fungi is quite

comparable with that one of the Dry rot fungus and can even exceed it. A fresh floorboard can be completely destroyed in 1 year, so the danger exists that furniture or persons can fall through. These types of damages occurred in Germany frequently during the building boom in the postwar years, if insufficiently dried wood were used, or the homes had not sufficiently dried before they were moved into and drying was prevented by humidity-impermeable painting, linoleum, or carpet.

The cellar fungi belong to the fast-growing house-rot fungi and reached on agar at 23 °C up to 11 mm radial increase per day (Table 3.11). The optimum temperature (Table 3.8) was between 20 and 27.5 °C, whereby *C. marmorata* preferred the warmer range, and the maximum was between 25 and about 37.5 °C. Isolate Ebw. 1 of *C. puteana* survived 15 min. at 60 °C (Mirič and Willeitner 1984) and 3 h at 55 °C (Table 3.8). In slowly dried wood samples, even 4 h at about 70 °C were withstood (Huckfeldt 2003). The data concerning a possible dryness resistance of the fungus vary: after observations from practice, it dies when drying; up to 7 years were however survived in dry wood in the laboratory (Theden 1972). There was isolate variation with regard to the sensitivity to wood preservatives (Gersonde 1958).

Recognition characteristics (Fig. 8.20): The diagnosis is not always easy, since fruit bodies are rare and colonized wood shows frequently no or only meager surface mycelium (Käärik 1981). The few centimeters to several decimeters wide, resupinate, brownish fruit bodies resemble those of the Dry rot fungus, are however thinner. The species *C. puteana* is easy to recognize of the warty knots on the hymenophore (name: "carrying cones"). Characteristic on agar are double and multiple clamps. The initial stages of the rot are frequently ignored, since hardly infection signs become visible on exposed wood exterior surfaces, e.g., on baseboards, while the wood at the backside is already completely rotten and overgrown by thread-thin, radiate to root-like, brown to black strands (Fig. 8.20d,e). Early signs of rot are often dark discolorations under the paints.

8.5.3.4
Dry-rot fungi: *Serpula* species, *Leucogyrophana* species, *Meruliporia incrassata*

This chapter deals with the brown-rot causing dry-rot fungi, namely *Serpula lacrymans* and *S. himantioides*, and the *Leucogyrophana* species, *L. mollusca*, *L. pinastri* and *L. pulverulenta* (Fig. 8.21). Due to its economic relevance in Europe, emphasis is laid on *S. lacrymans*, however, the American pendant, the American dry rot fungus, *Meruliporia incrassata*, is considered.

The way of spelling of the epithet "lacrimans", which can be attributed to Fries (1821), is linguistically correct, however illegal, since the original spelling by Wulfen in 1781 was with "y" (Pegler 1991).

Occurrence and significance: The True dry rot fungus, *S. lacrymans*, is the most dangerous house-rot fungus in central, eastern, and northern Europe, northwards to the Hebrides. It grows however also in cooler areas of Japan (Doi 1991), Korea, India, Pakistan and Siberia (Krieglsteiner 2000), in New Zealand and southern Australia (Thornton 1991), in Mexico, Canada and in the northern USA (Rayner and Boddy 1988). The data concerning its involvement in fungal indoor damage reach from 16% in Norway (Alfredsen et al. 2005) over 22% in Denmark (Koch 1991), 54% in Poland (Ważny and Czajnik 1963) and North Germany (Schmidt and Huckfeldt 2005) to 59% in Sweden (Viitanen and Ritschkoff 1991a). For example, the annual repair costs of dry rot damage amount to at least 150 million £ in Great Britain (Jennings and Bravery 1991).

Since the fundamental work by Hartig (1885), Mez (1908), Falck (1912: cf. Hüttermann 1991) and Wehmer (1915) *S. lacrymans* belongs to the best-investigated fungi. The older observations and results are described by Liese (1950), Bavendamm (1951b), Cartwright and Findlay (1958), Harmsen (1960), Savory (1964), Wagenführ and Steiger (1966), Findlay (1967), Bavendamm (1969), Coggins (1980) and Segmüller and Wälchli (1981). A literature search from 1988 lists 1200 publications (Seehann and Hegarty 1988). Informative photographs for diagnosis on the basis fruit bodies (Fig. 8.21a, b) are by Grosser (1985) and on the Internet (www.hausschwamminfo.de). Younger reviews and laboratory findings to the biology and physiology are by Jennings and Bravery (1991), Viitanen and Ritschkoff (1991a), Schmidt and Moreth-Kebernik (1991a), Eaton and Hale (1993), Huckfeldt (2003), Schmidt (2003), Huckfeldt and Schmidt (2005), Huckfeldt et al. (2005), Schmidt and Huckfeldt 2005). There is a German instruction leaflet with experiences from the practice on life conditions and refurbishment (Grosser et al. 2003).

As cause of the special danger of the fungus the following features were specified: Its "omnipresent" spores germinate on damp wood or other cellulosic materials (paper, cardboard), and the mycelium can reach wood by growing over and through substrates that do not serve as a nutrient. For initial colonization, it only needs low wood moisture content. The conventional wisdom is that it is the only fungus that can infect so-called "dry" timber (min. 21% u) and masonry (min. 0.6% water content) and widely spread by mycelium (Fig. 8.21c) and its highly developed strands (Fig. 8.21d; name: "small serpent"), thereby growing over and through wood and several other materials, like porous or ruptured masonry or its wall joints, supplying channels for electricity, and water pipes (Coggins 1991; Jennings 1991). However, recent laboratory experiments showed that *S. lacrymans* is not unequalled as is also other indoor fungi colonized dry wood (Table 8.7). Coggins (1980, 1991) stressed that the initial colonization of a substrate, as for example the growth through wall joints, occurs by the youngest hyphae of the vegetative mycelium, in contrast to the infection way of *Armillaria* species that do this by means of rhizomorphs. In contrast, the strands develop as a secondary mycelium behind

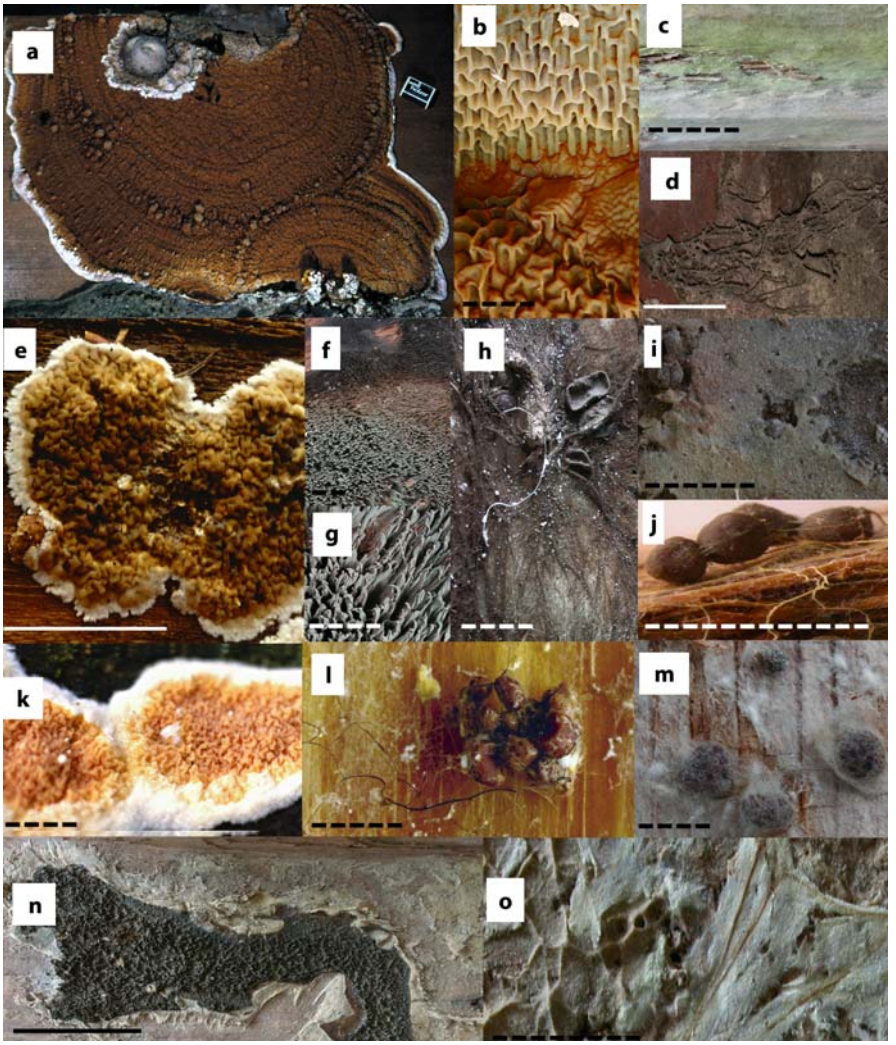

Fig. 8.21. Dry-rot fungi. *Serpula lacrymans* **a** Fruit body. **b** Detail. **c** Mycelium. **d** Strands. **e** *Serpula himantioides* fruit body; *Leucogyrophana pinastri* **f** Old fruit body. **g** Detail. **h** Old strands and sclerotia, **i** Mycelium and sclerotia. **j** Young sclerotia. **k** *Leucogyrophana mollusca* fruit body. **l** Hair-like strands and sclerotia. **m** Mycelium and sclerotia; *Leucogyrophana pulverulenta* **n** Old fruit body, **o** Mycelium and strands (photos **b–o**: T. Huckfeldt) — 5 cm, - - - 5 mm

the growth front and serve rather to transport nutrients to the hyphal margin. Alkaline materials to pH 10 can be overgrown, and alkalinity is decreased by excretion of liquid (pH 3–4) at the hyphal tip. An acute infection is often for a longer time not recognized due to the "hidden way of life". Spores and still

alive mycelia can lead to re-infections in the case of careless or inappropriate remedial treatments (Bravery et al. 2003). Thick mats of surface mycelium may cover the attacked timber assumably preventing the wood from drying.

Serpula lacrymans occurs predominantly in older buildings and in the cellar and ground floor area (Schultze-Dewitz 1985, 1990; Koch 1990). Uninhabited and poorly ventilated houses and all buildings with high relative air humidity in connection with damages to the structural fabric are particularly endangered. Important causes of dry rot infections are building defects that affect increased wood moisture content (e.g., Paajanen and Viitanen 1989). The mycelium reacts sensitively to draught and humidity removal, generally to climatic changes, so that it often develops in false ceilings and false soil areas under floors and behind wall coverings, from where it spreads. Because of this hidden way of life, often only fruit bodies on masonry, baseboards, doorframes or stairway steps show that the higher floors are already infected. In extreme cases, e.g., during the refurbishment of listed buildings, all timbers as well as large parts of the masonry have to be removed. A survey of houses in northern Germany indicated that old buildings are particularly at risk, which had insulating windows as the only measure of heat insulation. Now, the moisture in the building condenses on other weak spots like empty spaces of the brickwork at the back of heaters (Huckfeldt et al. 2005).

Except in homes, the fungus occurs on mine timber and rarely in the open (poles, sleepers), but in the boreal climate not in the forest. However, according to Pegler (1991), the species occurs outdoors in Central Europe and North America, and according to Bech-Andersen (1995), in the Himalayas in conifers forests. Phylogenetic trees based on the rDNA-ITS sequence showed that the outdoor isolates from the Himalaya and from California belong to the species *S. lacrymans* (Chap. 2.4.2.2). Phylogenetic analyses indicate that the indoor isolates of *S. lacrymans* may have originated from an ancient lineage closely related to the Californian outdoor isolates (Kauserud et al. 2004b).

In the open, the Wild merulius *S. himantioides* (Fig. 8.21e) is common, in Europe frequently on spruce wood, stumps, structural timber in outdoor use, and rarely on living trees. Occasionally, it is also found in buildings (Falck 1927; Harmsen 1978; Grosser 1985; Seehann 1986; Pegler 1991).

As further dry-rot fungi occur three *Leucogyrophana* species (Fig. 8.21f–o) in the forest on fallen stems and branches, and on wood in indoor use: *L. mollusca*, *L. pinastri* (Schulze and Theden 1948; Siepmann 1970) and *L. pulverulenta* (Harmsen 1953). They differ from *Serpula* by smaller spores (Ginns 1978; Pegler 1991; Breitenbach and Kränzlin 1986). *Leucogyrophana pulverulenta* is rather common in Denmark. The three fungi need a higher wood moisture content than *S. lacrymans* (cf. Table 8.7).

Whereas *S. lacrymans* is restricted in North America to the northern parts of the USA and Canada, the American dry rot fungus *Meruliporia incrassata* (first reported in the USA in 1913) occurs particularly in the southern states

and the Pacific northwest of the USA (Verrall 1968; Palmer and Eslyn 1980; Gilbertson and Ryvarden 1987; Burdsall 1991; Zabel and Morrell 1992; Eaton and Hale 1993; Jellison et al. 2004). Being a warm-temperature fungus, two isolates from the USA and Canada grew best between 22.5 and 25 °C and died after 3 weeks of culturing at about 35 °C (Schmidt 2003). Burdsall (1991) named 24–30 °C as the optimal temperature range for growth and above 36 °C as the lethal temperature. Jellison et al. (2004) quoted 28–30 °C as the optimal range for growth, and 3–30 h at 40 °C for lethal. Sapwood and heartwood of many gymnosperms and angiosperms are attacked. It was rarely found on standing trees, infrequently on felled logs and stumps, on structural timber outdoors such as in mills, lumber yards, on shingles, on bridge timber, posts, but is common on moist wood or wood located near a permanent or intermittent water supply if the wood is untreated (Palmer and Eslyn 1980). Some characteristics of wood decay by this fungus are similar to those of *S. lacrymans*, notably its sensitivity to dryness by mostly dying in pure culture tests with southern pine blocks of 30% wood moisture at 90% RH at 27 °C (Palmer and Eslyn 1980), and its ability to transport nutrients and water from a feeding source to the advancing mycelial front spreading over non-wooden mortar and bricks. Pictures of mycelium and strands are by Zabel and Morrell (1992).

The *Serpula* and *Leucogyrophana* species as well as *M. incrassata* can be differentiated by their fruit bodies and strands (Appendix 1). Molecular techniques separate the vegetative mycelia (Chap. 2.4.2). The following description is based on observations and measurements in buildings and on results from wood samples in laboratory tests (Huckfeldt and Schmidt 2005; Schmidt and Huckfeldt 2005) and is supplemented especially for *M. incrassata* from Palmer and Eslyn (1980), Gilbertson and Ryvarden (1987), and Burdsall (1991).

Serpula lacrymans, (True) Dry rot fungus

Fruit body (Fig. 8.21a, b): annual to perenniell, resupinate to effused-reflexed and imbricate, sometimes stalactite-like, rust-brown, old: black; bulging, white-yellowish, sharp margin; fleshy-thick (to 12 mm), to 2 m wide, hymenophore merulioid; first monomitic, later dimitic containing fibers; yellow-brown, thick-walled spores 9–12 × 4.5–6 µm; tetrapolar;

Strands (Fig. 8.21d): young: white; old: grey-brown; to 3 cm in diameter, audibly breaking when dry, embedded in flabby mycelium; fibers 3–5 µm thick, hardly septate, without buckles, straight, rigidly, refractive; vessels to 60 µm thick, with bar-likes or warty wall thickenings, not or rarely branched.

Serpula himantioides, Wild merulius

Fruit body (Fig. 8.21e): annual, resupinate, sometimes membrane-like, rust-brown; white, sharp, not bulging margin, < 2 mm thick, hymenophore smooth to merulioid; yellow-brown, thick-walled spores 9–12 × 5–6 µm; tetrapolar;

Strands: white to grey-brown, about 1 mm in diameter, microscopic characteristics similar to *S. lacrymans.*

***Leucogyrophana mollusca*, Soft dry rot fungus**

Fruit body (Fig. 8.21k): resupinate, orange to yellow-brown; old: grey-blackish; white, cottony-frayed margin; 1–2 mm thick, to a few decimeters wide, easily separable; hymenophore merulioid, tooth-like elevations; uneven, brown-violet to grey-black sclerotia (Fig. 8.21m), 1–6 mm, often in groups; yellowish-brown spores 6–7.5 × 4–6 µm;

Strands (Fig. 8.21l): hair-like, first cream-yellow, soon brown-black, below 1 mm thick, separated from mycelium ("barked"), flexible when dry, fragile when old; no fibers; vessels up to 25 µm thick, numerous, in groups, with bar-thickenings.

***Leucogyrophana pinastri*, Mine dry rot fungus, Yellow-margin dry rot fungus**

Fruit body (Fig. 8.21f, g): resupinate, first yellow-orange, then olive-yellow to brown, grey-black when old, to 1 m wide, hymenophore merulioid to irpicoid to hydnoid; round-oval, brown-black sclerotia to 2–3 mm thick; hyaline to yellow spores 5–6 × 3.5–4.5 µm;

Strands: first yellowish, then grey-brown (Fig. 8.21h), hair-thin, separated from mycelium; no fibers; vessels to 15 µm thick, numerous, in groups, with bar-thickenings.

***Leucogyrophana pulverulenta*, Small dry rot fungus**

Fruit body: resupinate, first sulphur-canary yellow, then (Fig. 8.21n) olive-yellow to cinnamon-brown, also grey-black when old, white, indistinct margin, to 20 cm wide; hymenophore smooth to merulioid, no sclerotia; hyaline to yellow, thick-walled spores 5–6 × 3.5–4.5 µm;

Strands (Fig. 8.21o): white, to 2 mm thick, not clearly separated; no fibers; vessels to 20 µm thick, numerous, in groups, bar-thickenings indistinct or absent.

***Meruliporia incrassata*, American dry rot fungus**

Fruit body: similar to *S. lacrymans,* annual, resupinate to effused, 20 cm or more in length, thin, easily separable, whitish to buff margin, grey center, becoming darker as it matures; 1 to 12 mm thick, fleshy, brittle when dried; first appearing as a felted pad of mycelium with formation of pores beginning at the center, subsequent fertile to the margin; hymenophore poroid, occasionally merulioid; whitish to buff or ochre-grey when fresh, grey-brown to black when drying, unequally circular to angular pores, 1–3/mm; monomitic; thick-walled oblong to ellipsoid spores, variable in size, 8–16 × 4–8 µm;

Strands: first as vein-like structures in the mycelium, often extending into soil or masonry, appearing whitish when young, browny-black with age (Eaton and Hale 1993), 0.3–5.1 cm in diameter, length up to 9 m (Palmer and Eslyn 1980).

Recognition characteristics of *S. lacrymans* (Fig. 8.21)

Wood: The relatively large cubes of the brown-cubical rot (Fig. 7.1a) are no reliable characteristic. Painted doorframes or baseboards first show blisters and fine tears in the lacquer and after longer infestation, wavy surfaces.

Fruit body: The brownish, to 12 mm thick and 2 m size, mostly resupinate fruit body growing on wood or masonry (Fig. 8.21a) is conspicuous. From shakes and vertical planes grow pad and bracket-like fruit bodies. The gyroso-reticulate hymenophore is traditionally named "merulioid" (Fig. 8.21b), which derives from the former generic name *Merulius*. The margin is whitish, often bulging and always with a sharply limited front. Particularly at the margin, as also with the mycelium, arise liquid drops of neutral pH value due to guttation, which led to the naming *lacrymans* (watering). Fresh fruit bodies have a pleasant smell like fungi, but putrefy after sporulation and then easily stink (from the ammonia). The old, dry, then black-brown fruit bodies hardly show the merulioid structure. Fruit bodies develop over the whole year, with an amassment in the late summer until winter (Nuß et al. 1991).

Affected areas are often widely covered with brown, elliptical, yellow-brown spores with small, pointed extension at an end and partly with up to five intracellular oil droplets (Hegarty and Schmitt 1988; Pegler 1991; Nuß et al. 1991). Falck (1912) calculated the spore release by a 1-m^2 fruit body to 3×10^9 spores per hour.

First, however, inconstant fructification in the laboratory culture was obtained by Falck (1912), Cymorek and Hegarty (1986b) stimulated fructification by 12 °C incubation and by natural temperature change in the open (cool) (Hegarty and Seehann 1987; Hegarty 1991). Fruit bodies relatively often developed in pure cultures, if the mycelium was first incubated for about 4 weeks at 25 °C on malt agar and then at about 20 °C and natural daylight (Schmidt and Moreth-Kebernik 1991b; Fig. 3.1).

Mycelium (Fig. 8.21c) **and biology:** During initial growth, with sufficient humidity and standing air, often a white, woolly thick aerial mycelium develops, which is rapidly interspersed by the typical strands. Yellow to wine-red (also violet) discolorations ("inhibition colors") by restraining influences [light, accumulation of toxic metabolites, increased temperature: Zoberst (1952), Cartwright and Findlay (1958)] are characteristic and led to the former generic name *Merulius*, going back to the yellow beak of the male blackbird *Turdus merula* (Coggins 1980). Older mycelium collapses to removable, dirty grey to silvery skins, in which the branched strand system is embedded. The match-

to pencil-thick, up to 2 to 4-m-long, grey-brown and on their surface fibrously roughened strands (Fig. 8.21d, Table 2.4; Falck 1912) break when being dry with audible cracking. Strands are formed only in aerial mycelium, and there as well by dikaryotic as by monokaryotic mycelium, and not in substrate mycelium and reach (at 20 °C) 5 mm length increase per day (Nuß et al. 1991).

The fungus is tetrapolar heterothallic. Only dikaryons show clamps (Harmsen et al. 1958), while only monokaryons form plentifully arthrospores (Schmidt and Moreth-Kebernik 1991c). Contrary to *Antrodia sinuosa* and *Coniophora puteana*, the clamps are as large as the hyphal diameter (Nuß et al. 1991). Matings between different isolates of *S. lacrymans* revealed physiological differences between the different mycelial types, but also constancy of the characteristics over several generations (Schmidt and Moreth-Kebernik 1989b, 1990, 1991a): The dikaryons (parents and F_1 and F_2 generation) grew significantly faster than the mycelia of the two appropriate monokaryons and the two heterokaryon types (A# B=, A= B#). Regarding wood decay, dikaryons and monokaryons showed greater activity than the heterokaryons (also Elliott et al. 1979). Monokaryons and heterokaryons however tolerated higher temperature than the dikaryons, by growing still at 28 °C. Monokaryons also endured higher protective agent concentrations and this was also proven for *Antrodia vaillantii* and *Gloeophyllum trabeum* (Da Costa and Kerruish 1965). Related to practice, such physiological differences between the different mycelial types could become relevant, since dikaryons can revert under adverse conditions to the monokaryotic stage, as for example *G. trabeum* by arsenic (Kerruish and DaCosta 1963) and *S. lacrymans* by relatively high temperature (Schmidt and Moreth-Kebernik 1990). The more tolerant monokaryons would survive and can mate under again favorable conditions to dikaryons and thus have overcome the adverse environment.

The vegetative hyphae in the aerial mycelium are thicker (about 6 µm) than the hyphae within woody tissue, with about 2 µm. Within wood, medallion clamps also occur. The distance between the two clamps is shorter than in aerial mycelium, and often almost right-angled hyphal branching occurs. Morphologic characteristics of mycelium, fruit body, and spores were described by Nuß et al. (1991).

Conifers are preferred. Hardwoods with dark heart like oak and chestnut are more resistant than light species (Wälchli 1973). Beside wood and masonry, composite woods (chipboards, fiberboards), carpets, and textiles are attacked and insulating materials (Grinda and Kerner-Gang 1982) like mineral wool are through-grown and damaged (Bech-Andersen 1987b).

Because of the relatively low optimal temperature range of 17 to 23 °C, the mycelium grows preferentially in the cooler cellar and ground floor areas. The total span reaches from 0 to 26–27 °C, and growth stops at 27–28 °C, which differentiates the species from the similar *S. himantioides*. The mycelium died on agar at 55 °C for 3 h (Table 3.8, also Mirič and Willeitner 1984). In dried

wood samples, however, only 70 °C for 4 h were lethal (Huckfeldt et al. 2005). The spores were killed after 1 h at 100 °C (Hegarty et al. 1986). Thus, hot-air treatment procedures of attacked buildings (see below), as they are used in Denmark and also proposed for Germany, kill neither the spores nor the hyphae growing within large-dimensioned timbers and masonry.

The minimum wood moisture for initial colonization is 21% u (Huckfeldt 2003). The opinion has it that this infection of wood below the fiber saturation range of about 30% is possible, because the Dry rot fungus is particularly effective to transport nutrients and water by means of mycelium and strands, and here particularly by the vessel hyphae, from a moist nutrient source [wood over fiber saturation or wet masonry: Dickinson (1982)] to the infestation of "dry wood" (Wälchli 1980; Jennings 1987, 1991; Coggins 1991; Savory 1964). Not to stamp out, even in recent publications, is the erroneous opinion that *S. lacrymans* is extraordinary to colonize dry timber by the exclusive water production via its own enzymatic wood decay (Chap. 3.3). Also incorrect is that it takes up the necessary water from the air humidity.

Compared to Cellar fungus and the indoor polypores, the Dry rot fungus was considered to be sensitive to high wood moisture content (Cartwright and Findlay 1958). There is an older reference that it even reduced high wood moistures by guttation in favor of higher air humidity (Miller 1932). The optimal wood moisture for initial decay is about 30–40% u and shifts with longer decomposition rather to 40–60% (Wälchli 1980). The maximum of about 90% (Wälchli 1980) was higher than the 55% moisture content often cited in the older literature. In piled wood samples (Table 8.7), the optimum wood moisture was between 45 and 140%, and even samples with initial values of 240% wood moisture were decayed with wood mass loss over 2% (Huckfeldt and Schmidt 2005), so that the total span reached from 21 to 240%. The common term in English "Dry rot fungus" (Savory 1964; Coggins 1980; Bravery et al. 2003) and in German "Trockenfäule-Erreger" is paradoxical, since the Dry rot fungus also (like all other decay fungi) needs free water in the cell lumina for the enzymatic wood decay and is susceptible to desiccation. By means of mycelium (and strands), the fungus transports beside nutrients and water also minerals, e.g., the wood-decay limiting nitrogen (Watkinson et al. 1981) from the soil under a house to wood decay in the interior (Doi 1989; Doi and Togashi 1989; also Weigl and Ziegler 1960; Jennings 1991). After Savory (1964), the main significance of the strands lies in the nutrient translocation and not in the water transport (also Bravery and Grant 1985). Literature data to the requirements for temperature and humidity are also by Viitanen and Ritschkoff (1991a).

The mycelium of *S. lacrymans* is said to show dryness resistance of many years. However, the few experiments available revealed that it can reach at least under laboratory the dryness resistance only by a slow moisture removal. Assumably, the mycelium needs time to revert first into the monokaryotic stage

with its resistant arthrospores. Furthermore, the resistance at 20 °C amounted only about 1 year. Only at low temperature (7.5 °C), the fungus survived several years (Theden 1972; also Savory 1964). Nevertheless, the remaining infected areas form a danger potential for new growth. Infected timber parts can exhibit just so much moisture to enable a slight growth and thus a longer survival than by means of dryness resistance (Grosser 1985). Furthermore, the danger of re-infection may derive from the dryness-resistant spores, whose duration of germ ability was said to amount to 20 years. In infected buildings, *S. lacrymans* frequently produces basidiospores, and basidiospores seem to be the main agent of dispersal (Falck 1912; Langendorf 1961; Schultze-Dewitz 1985). Vegetative spread by mycelium and strands seems to be restricted to within buildings or the soil in subfloor space (Doi 1991). However, according to Wälchli (1980) the infection occurs instead by mycelium that is brought in with timber from other remedial treatments and via wooden boxes or shoes.

Beside the requirement for low temperature, the preferential indoor occurrence of *S. lacrymans* was attributed to the intensive synthesis and secretion of oxalic acid (Jennings 1991; cf. Table 3.9), whose excessive production was said to be neutralized as calcium oxalate by calcium from masonry or by chelating with iron from girders (Bech-Andersen 1985, 1987a, 1987b; cf. Palfreyman et al. 1996). Oxalic acid is also implicated in copper tolerance of fungi. Although a single isolate of *S. lacrymans* was only able to grow on agar at a low concentration of copper sulphate (Table 3.10), Haustrup et al. (2005) showed 11 out of 12 isolates to be tolerant against copper citrate. The implication of calcium in oxalate precipitation was also shown for *M. incrassata* (Jellison et al. 2004). Thus, dry rot attack in buildings is often found in the ends of beams, which are not separated from the masonry.

During controversies, e.g., in the context of house buying, frequently the question of the infection date plays a role, for whose determination the daily average mycelial growth is often used. According to Jennings (1991), the linear mycelial extension on wood, masonry and insulants ranges from 0.65 to 9 mm/d. Assuming a 5-mm radial increase per day on malt agar at optimal temperature (Table 2.2), 15 cm follow per month. Due to the changing and not always optimal conditions in buildings and because different isolates of the fungus exhibited considerable differences in growth rate [1.5–7 mm/d: Cymorek and Hegarty (1986a); Seehann and v. Riebesell (1988)], an exact age determination on the basis of the mycelial extension is impossible. Similarly, the decay of pine sapwood samples varied among 25 isolates from 12 to 56% in 6 weeks of cultivation (Cymorek and Hegarty 1986a; Thornton 1991), and different isolates differed likewise in their sensitivity to wood preservatives (Abou Heilah and Hutchinson 1977; Cymorek and Hegarty 1986a; Ważny and Thornton 1989a, 1989b, 1992; Ważny et al. 1992). Important is also the decision if the mycelium in a building is alive or dead. Subculturing on malt agar is possible, but isolations from mycelium are often contaminated by molds. Vital

staining with fluorescein diacetate is suitable (Huckfeldt et al. 2000; also Koch et al. 1989; Bjurman 1994).

The possibilities to identify *S. lacrymans* cover the classical methods of fruit body investigation (Grosser 1985; Pegler 1991), strand diagnosis (Falck 1912; Table 2.4, Appendix 1), and mycelium analysis by identification key (Stalpers 1978). As modern techniques, protein polyacrylamide gel electrophoresis (Schmidt and Kebernik 1989; Vigrow et al. 1989; Palfreyman et al. 1991; Fig. 2.19) and immunological tests (Palfreyman et al. 1988; Vigrow et al. 1991c; Toft 1992, 1993; Glancy and Palfreyman 1993) were tested for suitability. DNA techniques have been established (Schmidt 2000) and are already used commercially. MALDI-TOF mass spectrometry was capable of differentiating the mycelium of the True dry rot fungus and its closest relative the Wild merulius (Schmidt and Kallow 2005; Fig. 2.24). Measurement of microbial volatile organic compounds (MVOCs) may identify wood-decay fungi (Bjurman 1992b). Pinenes, acrolein, and ketones were found in *Serpula lacrymans*, *Coniophora puteana,* and *Oligoporus placenta* (Korpi et al. 1999). Mono- and sesquiterpenes, aliphatic alcohols, aldehydes and ketones, and some aromatic compounds were emitted by *Fomitopsis pinicola*, *Piptoporus betulinus,* and further species (Rosecke et al. 2000). Blei et al. (2005) showed that MVOC analysis was able to distinguish pure cultures of *Antrodia sinuosa*, *C. puteana*, *Donkioporia expansa*, *Gloeophyllum sepiarium*, *S. lacrymans,* and *S. himantioides*. Field experiments, however, were influenced by the distance of sampling from the infested and/or destroyed wood and also by the rates of air changes. To improve the technique of MVOC analysis, Keller et al. (2005) measured volatile compounds in non-infested living and bedrooms as a background reference for infestation. Trained sniffer dogs can also detect *S. lacrymans* (Koch 1991).

If *S. lacrymans* is proven, the fungus is (beside longhorn beetle and termites) the only biological damage causer for which there is the obligation in some German states (Hamburg, Hessen, Sachsen, Thüringen, and Saarland) to become registered. Since costs of refurbishment can be considerable (to € 3,000 per m^2 living space), the determination of the extent of the damage and the remedial treatments should be done by a renowned company. In Germany, refurbishment has to follow the standard DIN 68800 part 4. In the case of a lawsuit, §459 of the German Civil Code regarding "regress for material defects" takes effect.

8.5.4 Prevention of Indoor Decay Fungi and Refurbishment of Buildings

All decaying fungi need water for wood decay. Elimination of the source of moisture and drying of wood and masonry after prolonged wetting are the

most important remedial treatments. Since *S. lacrymans* can transport water, it cannot be excluded that sources of dampness are overlooked during repair, and thus more-extensive measures are necessary for its control.

The first remedial treatment of dry rot infestation is described in the Bible in Leviticus 14:33–48. Preventive measures against all house-rot fungi are avoidance of general building defects and of those during refurbishment of old buildings: moisture ascending in the masonry, seeping rain water, insufficient ventilation, installation of wet or infested timber and wet fillers, allside walled beam ends, lack of building drainage, condensation water by wrong thermal insulation and inappropriate vapor barriers, unsatisfactory underside blockage of buildings without cellars, wrong structure of floors, reuse of attacked building debris, leakages in bathrooms and insufficient wood protection.

To the common causes belong also unrepaired building damage: leaky roofs, shattered windowpanes, leaky or sweating water and heater lines, clogged or defective rainwater and drainage facilities as well as water damage caused by burst piping, defective washing machines and dishwasher water pipelines, cellar floodings and fire-fighting water (Thornton 1989a; Paajanen and Viitanen 1989; Bricknell 1991; Doi 1991; Wälchli 1991).

Particularly regarding cellar fungi, flooring in new buildings should not done too early. Damp bulk goods in ceilings shall be avoided.

The danger of infestation exists via spores and by infected timber and wooden boxes, which are stored as firewood in damp cellars, and by mycelium via the shoes of workers.

If a fungus is found, it should be first determined whether it concerns *S. lacrymans* or another fungus, as this decision may require the obligation to register the fungus and influences the extent of remedial treatments. In cases of doubt, laboratory identification should be performed by appropriate institutes, national testing institutions, offices for plant protection or in the laboratories of wood preservative manufacturers. The German standard DIN 68800 demands that if an exact species identification is not possible, then refurbishment is to be proceeded in such a way, as if the True dry rot fungus were present.

Then the extent of the damage has to be established. German guidelines for control measures are listed in Table 8.8 (Grosser et al. 2003).

Table 8.8. German guidelines for control measures during refurbishment

DIN 68800 Part 4: Wood preservation; control measures against wood-destroying fungi and insects, issue 1992
Part 3: Wood preservation; protective chemical wood preservation, issue 1990
Part 2: Wood preservation in building construction; protective structural measures, issue 1984
DIN 52175: Wood preservation; term, fundamentals, issue 1975
Concretization rule for building work (VOB part B)

Refurbishment methods are described by Grosser (1985), Blow (1987), Wälchli (1991), Bech-Andersen (1995), Gründlinger (1997), Sutter (2003), Bravery et al. (2003) and Grosser et al. (2003), briefly: Elimination of the source of moisture, removal of all infected timber 1 m beyond the last evidence of fungus or decay, disposal of the attacked timber and the other infected building materials, physical (heat) and chemical treatment (boron, quaternary ammonium compounds) of infested masonry with certified preservatives for those species that colonize brickwork, use of preservative-treated timbers for replacement following DIN 68800, and providing adequate ventilation.

Eradication in the roof space with hot air as it is used against insects (Paul 1990) is already done or is being considered to fight fungi in some European countries (Koch 1991; Sallmann 2005). However, first these treatments are technically wrong in view of a safe killing of mycelium and spores of house-rot fungi in wood and in masonry, since the necessary heat (Schmidt and Huckfeldt 2005; Huckfeldt et al. 2005; Table 3.8) is not obtained, particularly not in the inside of thick timber. Second, heat treatment is economically doubtful due to the endangerment of the structural fabric and third, from an ecological viewpoint, enormous energy is needed.

Microwaves are also used or being considered as an alternative method. Irradiation tests with microwaves from 1990 to 1992 in Denmark in about 100 cases of fungal infestation killed the mycelium of *S. lacrymans* that previously had been inserted into the brickwork within 10 min (Bech-Andersen and Andersen 1992; Kjerulf-Jensen and Koch 1992). However, microwave treatment is a fire risk if metal fastenings are present in the timber (Bravery et al. 2003) and there are general doubts on the suitability of the technique for buildings (Sallmann 2005).

For registered historical buildings and wood artifacts, the suitability of fumigants was tested mainly for the control of insects, but also to control decay fungi. Against fungi, bromomethane and ethylene oxide have been used (Unger et al. 2001). Fumigants, however, do not provide protection against new infestations. In the laboratory, aminoisobutyric acid, which is analogous to the amino acid alanine, reduced the decay of wood samples by *S. lacrymans* from 22 to 1% (Elliott and Watkinson 1989). An intervention in the trehalose metabolism of *S. lacrymans* was suggested to influence the internal translocation processes (Jennings 1991). The binding of iron by chelating agents inhibited mycelial growth, EDTA prevented decay of pine samples by *Coniophora puteana*, *Gloeophyllum trabeum* and *Oligoporus placenta* (Viikari and Ritschkoff 1992), and tellurium acid wood decay by *C. puteana* (Lloyd and Dickinson 1992). Polyoxin acted as inhibitor of the chitin synthase of several fungi (Johnson and Chen 1983). Particularly the *Trichoderma* species display a wide arsenal of antagonistic mechanisms that make these fungi attractive as biological control agents (Highley and Ricard 1988; Giron and Morrell 1989; Doi and Yamada

1991; Rattray et al. 1996; Bruce 2000). Bacteria decreased wood decay by *O. placenta* (Murmanis et al. 1988; Benko and Highley 1990).

From a biological point of view, there is no reason that all indoor wood decay fungi should be a problem. The biological requirements of the common species are known. Control measures are straightforward. Even once a fungus is established, it is mainly only necessary to change the conditions in the building to a long-term removal of moisture. There was only slight wood decay by some house-rot fungi below the fiber saturation range of about 30% u. The lower limit for decay of pinewood samples (mass loss slightly over 2% within 5 months) was 22% (Table 8.7). This also applies to the feared *S. lacrymans*. This fungus turned out in many laboratory tests on temperature and drying effects to behave rather sensitively when compared to the cellar fungi and the indoor polypores. The only biological specific features of *S. lacrymans* are its more highly developed strand system to transport nutrients from a moist feeding source over considerable distances and to colonize new substrate, its formation of thick surface mycelium that prevents the colonized wood from drying, and its ability to grow through masonry.

The most important measure against all fungi in buildings is to detect and eliminate the cause of the increased moisture content of wood and masonry that is in contact with wood as well to exclude any re-moistening, including through condensation and faults by the home user. If the destroyed timber has been replaced and lasting dryness of the wood can be guaranteed, there is no need for further provision, from the biological view, as there is no fungus known which destroys dry wood (below 22% u), not even *S. lacrymans*. Since practice, however, shows that in many cases a lasting dryness cannot be ensured in buildings, there are specific recommendations (and in Germany regulations) for the case of *S. lacrymans* infestation.