



Distribution of building-associated wood-destroying fungi in the federal state of Styria, Austria

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Abstract

Wood is an important construction material, but when used incorrectly it can be subjected to deterioration by wood-destroying fungi. The brown rot producing dry rot fungus (*Serpula lacrymans*) is by far the most dangerous wood-destroying fungus in Europe. In the present publication, 645 fungal samples from damaged wood in the federal state of Styria (Austria) were examined and recorded by isolation date, geographical location, species identification of the wood-destroying fungus, location of damage, construction method, and age and type of building. In Styria, *Serpula* spp. accounted for 61.5% of damages, followed by *Antrodia* spp. (10.7%) and the genera *Gloeophyllum* (8.2%), *Coniophora* (3.9%) and *Donkioporia* (1.1%). Properties in the area of the Styrian capital Graz and old buildings were more often infested by wood-destroying fungi than houses in the rural area and new constructions.

1 Introduction

Wood rot is the degradation of wood by the destruction of organic materials caused by fungi. This process is predominantly affected by temperature and moisture as well as the durability of wood material (Krzisnik et al. 2018). Wood decaying fungi can be divided into brown rot, white rot and soft rot. Up to now, 120 different wood-destroying fungi in buildings have been identified in central Europe (Huckfeldt and Schmidt 2015). The fungus that causes the most severe damages to European buildings in service is the brown rot producing dry rot fungus (*Serpula lacrymans*), which was recently ranked as one of the world's ten most feared fungi (Hyde et al. 2018).

Wood still ranks among the leading construction materials in Europe because of its high load capacity, good thermal insulation, stability as well as low carbon footprint. However, when wood is not protected properly, insects and wood degrading fungi such as the dry rot fungus (*S. lacrymans*),

the cellar fungus (*Coniophora puteana*), *Antrodia* spp. and other wood-destroying fungi can cause severe damage to buildings and potentially cause human injuries. Some wood-destroying fungi can penetrate even masonry and are able to translocate water and nutrition over long distances.

Infestations of buildings with wood-destroying fungi can have different causes: contaminated construction wood, ingress of fungal spores into the building, or usage of fungus-infested timber. Precondition for the development of every fungal infestation is humidity, aerobic conditions facilitate the growth of wood-destroying fungi. Under appropriate conditions, fungal spores germinate and develop hyphae that colonize large areas. Infestations with wood-destroying fungi are often not recognized at an early stage because of the hidden nature of growth (behind wall paneling, under floorboards etc.). The mycelium continues to grow as long as there is enough nutrition available, thereafter, fruiting bodies are produced which form numerous spores. Adequate humidity and temperature are mandatory for the growth of wood-destroying fungi. Therefore, climatic changes may be an important factor for an increased occurrence. When a wood-destroying fungus has spread in a building, an accurate diagnosis of the nature of the fungus is mandatory for reliable estimate of the damage and proper renovation/restoration. Wood-destroying fungi can be substrate-specific species, which rely on certain wood, or unspecific, which can grow on different kinds of wood (Bavendamm 1969;

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Plank 1979; Schwarze 2007). In Northern Europe, mainly conifers are used as construction material. Hence, fungal species adapted to conifers like the genera *Serpula*, *Antrodia* and *Coniophora* are found to cause the majority of damages in buildings in this region (Schmidt 2010).

According to Dämon et al. (2000), a variety of wood-destroying fungi occurs in the federal state of Styria, depicted in a mycological map of “Weststeiermark”. Maurer et al. (2009) conducted a mycological mapping of the montane and subalpine altitude zones of “Obersteiermark” and found 500 wood-destroying fungal species, *S. lacrymans* once from a disposed spruce board on a forest edge. In Styria, *S. lacrymans* is the most widespread wood-destroying fungus in buildings. Building-associated records (covering more than four decades) are present of almost all political districts of Styria (Mayrhofer 2006). The infestation of buildings with *S. lacrymans* is estimated in a scale of 1000–2500 incidents annually according to IBO (Österreichisches Institut für Baubiologie und Bauökologie, Austrian Institute for Construction Biology and Ecology). These numbers are subject to considerable fluctuations because of, for example, changing weather events or flooding. In the past, it was mandatory to report the presence of *S. lacrymans* to the authorities in Austria, but not at the present time (Kalcher 2004), whereas, for example, in Germany, a reporting obligation still exists in some states (Thuringia, Hesse, Saarland, Hamburg and Saxony). However, in the case of an infestation of a building with wood-destroying fungi there are regulations and norms in Austria dealing with compulsory measures for damage management and control strategies.

The abatement and damage-abolition have to be performed by a specialized company based on an expert opinion (Behling 2004). In the case of wood-destroying fungi, there is the demand to differentiate between infestations by *S. lacrymans* and those by other wood-destroying fungi, because in the first case much more elaborate renovation measures are necessary.

So far, there have been no reports existing on the prevalence and incidence of wood-destroying fungi in buildings in different regions of the federal state of Styria/Austria. The goal of this study was to provide an overview on the frequency of wood-destroying fungi in different buildings and construction categories for this region.

2 Materials and methods

2.1 Data acquisition of fungi

From all 645 cases collected in Styria, fungal species, type of rot (brown or white rot), location of the damage, construction method, age (new: after 1945) and type of building (cultural monument or residential building, detached or

apartment building), isolation date, place and geographical region were recorded. Fungi identified at the Institute of Hygiene, Microbiology and Environmental Medicine, Medical University Graz (IHMU), were collected and preserved as illustrative material and for documentation of the local biodiversity of wood-destroying fungi in Styria.

Styria with its capital Graz is the second largest (16,401 km²) federal state in Austria, located in the south-east of the country, and around 61% of the area is forested. The north of Styria is alpine, the south mainly hilly and covered with meadows, pastures, crops as well as fruit orchards and vineyards. Styria is subdivided into seven regions and has more than 1.2 million inhabitants (01.01.2018, Statistik Austria 2018).

2.2 Identification of fungi

The identification of samples was primarily done by macroscopic characteristics. In wood-decaying fungi, these are specific surface mycelia, strands and fruiting bodies. Particularly important features are size, color and consistency of the fungus, texture and decay pattern of the wood (cubical cracking), depth of hyphal penetration, and also type (brown rot, white rot and soft rot) and intensity of wood rot (Weiss et al. 2000). When macroscopic diagnosis was inconclusive, microscopic identification took place. Therefore, identification keys were used together with microscopy (Gistl 1946; Huckfeldt and Schmidt 2015). If morphological examination did not lead to an unambiguous result as was the case in 177 samples, molecular methods (PCR, sequencing of the ITS region of ribosomal DNA) were used (Gardes and Bruns 1993; Schmidt 2000; Högberg and Land 2004). Identification based on the sequence data was carried out using BLAST (<http://blast.ncbi.nlm.nih.gov>) and GenBank (<http://www.ncbi.nlm.nih.gov/genbank>).

3 Results

Altogether 645 damage surveys were collected. Thereof 296 samples were examined at the IHMU, and data of 349 damage cases were provided by other institutions throughout Styria. Among all diagnosed wood-destroying fungi, 74 genera and 40 species were differentiated (Table 1).

3.1 Wood-destroying fungi by years

The occurrence of wood-destroying fungi in the years before 1980–2016 is listed in 10-year intervals (Table 2). From 645 collected fungi, 397 (61.5%) were *Serpula* spp., followed by *Antrodia* spp. (69/10.7%) and the genera *Gloeophyllum* (53/8.2%), *Coniophora* (25/3.9%) and *Donkioporia* (7/1.1%) (Table 2).

Table 1 Spectrum of wood-destroying fungal species

Genera and species	n	%
<i>Antrodia serialis</i>	3	0.5
<i>A. sinuosa</i>	1	0.2
<i>A. vaillantii</i>	5	0.8
<i>A. xantha</i>	7	1.1
<i>Antrodia</i> sp.	53	8.2
<i>Bjerkandera adusta</i>	1	0.2
<i>Coniophora marmorata</i>	1	0.2
<i>C. puteana</i>	16	2.5
<i>Coniophora</i> sp.	8	1.2
<i>Coprinopsis</i> sp.	1	0.2
<i>Coprinus patouillardii</i>	1	0.2
<i>Crustoderma dryinum</i>	1	0.2
<i>Cylindrobasidium evolens</i>	1	0.2
<i>Donkioporia expansa</i>	7	1.1
<i>Fomes fomentarius</i>	1	0.2
<i>Fomitopsis pinicola</i>	1	0.2
<i>Ganoderma</i> sp.	1	0.2
<i>Gloeophyllum abietinum</i>	8	1.2
<i>G. sepiarium</i>	18	2.8
<i>G. trabeum</i>	6	0.9
<i>Gloeophyllum</i> sp.	21	3.3
<i>Hyphodontia sambuci</i>	1	0.2
<i>Leucogyrophana mollusca</i>	1	0.2
<i>L. pinastri</i>	4	0.6
<i>Neolentinus lepideus</i>	2	0.3
<i>Penidiella kurandae</i>	1	0.2
<i>Pestalotiopsis protearum</i>	1	0.2
<i>Peziza varia</i>	2	0.3
<i>Pylotopsis nidulans</i>	1	0.2
<i>Pluteus cervinus</i>	1	0.2
<i>Polyporus</i> sp.	7	1.1
<i>Resinicium bicolor</i>	2	0.3
<i>Rhodonía placenta</i>	3	0.5
<i>Rigidoporus vitreus</i>	1	0.2
<i>Schizopora radula</i>	1	0.2
<i>Scytalidium lignicola</i>	2	0.3
<i>Serpula himantioides</i>	2	0.3
<i>Serpula lacrymans</i>	395	61.2
<i>Stereum hirsutum</i>	1	0.2
<i>Talaromyces radicus</i>	1	0.2
<i>Tapinella panuoides</i>	2	0.3
<i>Trametes abietina</i>	1	0.2
<i>T. hirsuta</i>	1	0.2
<i>T. trogii</i>	2	0.3
<i>Trametes</i> sp.	3	0.5
<i>Trechispora farinacea</i>	2	0.3
<i>Trechispora</i> sp.	1	0.2
<i>Tyronectria viriens</i>	1	0.2
Other genera	41	6.4
Sum	645	100.0

3.2 Wood-destroying fungi by region

Based on the addresses of damage events, it is possible to show the distribution of wood-destroying fungi in the seven regions of Styria (Fig. 1). The highest number (342/53.0%) was found in “Steirischer Zentralraum” which also includes the Styrian capital Graz (273/42.3%), the lowest number in Liezen (22/3.4%). The frequency of wood-destroying fungi by region is listed in Table 3.

Serpula spp. were by far the most prevalent wood-destroying fungi in Styria. There exist 397 (61.5%) records (395 *S. lacrymans* and two *S. himantioides*). In “Liezen”, *S. lacrymans* was found 14 times, in “Steirischer Zentralraum” 204 times, alone in the city of Graz 165 times. The “wild relative” of *S. lacrymans*, *S. himantioides*, was documented twice in the present study in “Südweststeiermark” and “Steirischer Zentralraum”.

Strand mycelia or fruiting bodies of *Antrodia* spp. were found in 69 cases (10.7%) in Styrian buildings. From “Steirischer Zentralraum”, 36 cases were reported, among them 29 from Graz, whereby three different species (*A. sinuosa*, *A. vaillantii*, *A. xantha*) were identified. *Antrodia* spp. were also found in the hilly districts of “Oststeiermark” (5) and in the mountainous regions of “Obersteiermark” (13), whereby *A. serialis* was found as well besides the above mentioned species.

Gloeophyllum spp. are widespread in Styria, 53 isolates (8.2%) were documented. They were found in the first place in “Steirischer Zentralraum” (36), whereby *G. sepiarium* was predominant in “Steirischer Zentralraum” and *G. trabeum* in “Obersteiermark”.

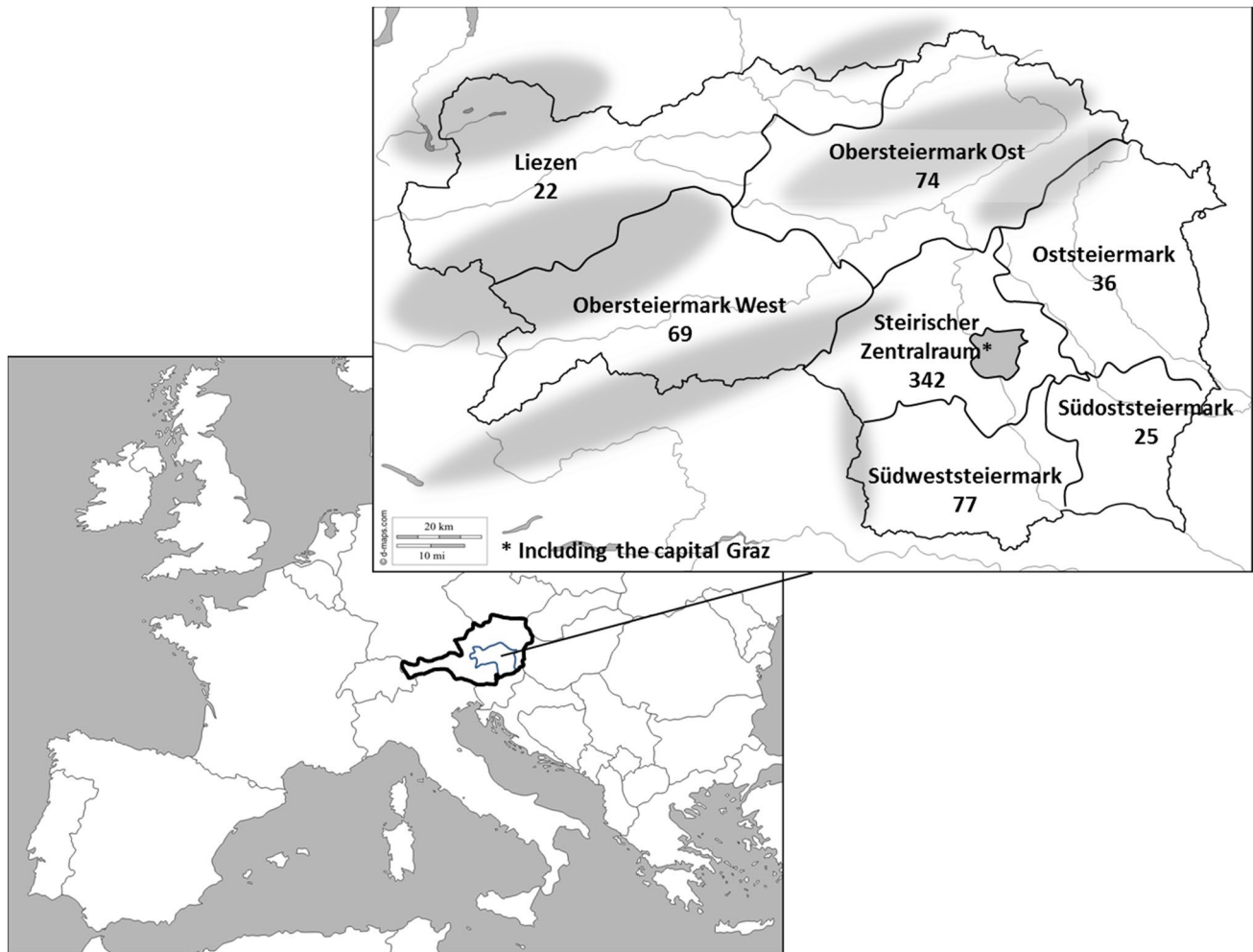
Coniophora spp., mainly *C. puteana*, were documented 25 times (3.9%) in Styria, and one single specimen of *C. marmorata* was reported from an apartment building in Graz (“Steirischer Zentralraum”).

The white-rot fungus *Donkioporia expansa* was found for the first time in Styria in 2007 in “Liezen”, since then *D. expansa* was discovered as well in other regions, in total 7 times (1.1%).

Altogether 94 sites (14.6%) with other wood-destroying fungi were documented in Styria, mainly in “Steirischer Zentralraum” (47, Graz 34), “Obersteiermark West” (13) and “Obersteiermark Ost” (11). *Fomitopsis pinicola*, *Coprinus parouillardii* and *Peziza varia* were detected in urban areas in apartment buildings. *Rhodonía placenta* (formerly *Postia* or *Oligoporus placenta*) grew in the city of Graz (“Steirischer Zentralraum”), in “Obersteiermark Ost” in an historical building and in “Obersteiermark West” in a mountain hut. *Resinicium bicolor* was isolated in “Oststeiermark” and “Obersteiermark Ost”. From the wood-destroying genus *Trametes*, the species *T. abietina* was identified in urban areas, and *T. trogii* in

Table 2 Chronological occurrence of the 5 most common wood-destroying fungal genera in Styria

Genera	< 1980	1980–1989	1990–1999	2000–2009	2010–2016	Sum	%
<i>Serpula</i>	12	14	155	106	110	397	61.5
<i>Antrodia</i>	1	0	11	21	36	69	10.7
<i>Gloeophyllum</i>	2	1	7	13	30	53	8.2
<i>Coniophora</i>	0	0	5	9	11	25	3.9
<i>Donkioporia</i>	0	0	0	3	4	7	1.1
Other fungi	2	3	15	23	51	94	14.6
Sum	17	18	193	175	242	645	100.0

**Fig. 1** Number of wood-destroying fungi in the seven regions and their localization in Styria, Austria

“Obersteiermark Ost”. *Leucogyrophana pinastri* and *L. mollusca* were found once each in wooden huts.

3.3 Wood-destroying fungi by construction categories

The prevalence of wood-destroying fungi in different buildings was grouped in these categories: old buildings

(before 1945) and new buildings, cultural buildings and residential buildings, single-family houses and apartment buildings (listed in Table 4).

Wood-destroying fungi were found more frequently in old buildings (530/82.1%) than in new buildings (115/17.9%). *S. lacrymans* occurred in old buildings 351 times (88.4%), in new buildings 46 times (11.6%).

Table 3 Frequency of wood-destroying fungi (n=645) in the 7 Styrian regions

Region	Frequency						Sum
	<i>Serpula</i> 61.5%	<i>Antrodia</i> 10.7%	<i>Gloeophyllum</i> 8.2%	<i>Coniophora</i> 3.9%	<i>Donkioporia</i> 1.1%	Other 14.6%	
Liezen	14	2	0	2	1	3	22
Obersteiermark Ost	44	7	7	2	3	11	74
Obersteiermark West	49	6	0	1	0	13	69
Oststeiermark	18	5	5	2	0	6	36
Steirischer Zentralraum	205	36	36	15	3	47	342
Südoststeiermark	15	4	3	1	0	2	25
Südweststeiermark	52	9	2	2	0	12	77
Sum	397	69	53	25	7	94	645

Table 4 Distribution of wood-destroying fungi in different types of houses in Styria and the capital Graz (in parentheses)

Genera	Old buildings ^a	New buildings	Cultural buildings	Residential buildings	Single-family houses	Apartment buildings
<i>Serpula</i>	351 (153)	46 (12)	62 (3)	335 (162)	234 (49)	163 (116)
<i>Antrodia</i>	55 (22)	14 (6)	9 (0)	60 (28)	39 (9)	30 (19)
<i>Gloeophyllum</i>	31 (13)	22 (14)	4 (0)	49 (27)	31 (15)	22 (12)
<i>Coniophora</i>	21 (12)	4 (2)	0 (0)	25 (14)	10 (2)	15 (12)
<i>Donkioporia</i>	4 (2)	3 (1)	0 (0)	7 (3)	2 (0)	5 (3)
Others	68 (24)	26 (12)	18 (3)	76 (33)	59 (11)	35 (25)

^aOld buildings: constructed before 1945

3.4 Wood-destroying fungi by sampling location

The substrate of the investigated wood-destroying fungi was mostly processed wood within infested buildings. Most of the fungi were isolated from wood in cellars and the roof, or from support beams and floors. The type of wood was above all spruce (*Picea abies*), oak (*Quercus* spp.) and pine (*Pinus sylvestris*). Figure 2 illustrates the location of the wood decaying fungi.

Serpula spp., in particular *S. lacrymans* was found most frequently on or in floors and in cellar rooms (Fig. 2). Its close relative *S. himantioides* was isolated twice, once on a rotten floor of spruce wood in a farmhouse and once on spruce flooring in a multistory building in the city.

Antrodia spp. grow on coniferous wood and destroy mainly wood in roof frames and ceiling constructions, as was the case by *A. xantha* and *A. sinuosa*. *A. serialis* appeared in the floor in cellars, and *A. vaillantii* in wet rooms. In some churches in Styria, this fungus infested the wood of pedestals from pews.

Gloeophyllum spp. occurred in roofs, windows and door constructions, as well as on wood on terraces and balconies. While *G. sepiarium* and *G. trabeum* were more frequently found in attics, *G. abietinum* preferred window and door frames.

True to its name, locations of the cellar fungus *Coniophora puteana* were mainly cellar walls and floors, above all those with contact to the earth. This fungus was rarely found in attics or on ceiling beams. The only finding site of *C. marmorata* was a brick floor in a cellar in Graz.

Donkioporia expansa infested heavily soaked parts of floors and beams in old buildings, producing white rot.

Besides the five most common genera of wood-destroying fungi in Styria, many other fungi were identified, as shown in Table 1. They occur mainly in ceiling beams or on floors of single-family houses and apartment buildings. In such a manner, specific genera of wood-destroying fungi may correlate to certain parts of a building: *Corioloopsis*, *Peziza*, *Resinicium*, *Tapinella* and *Trametes* occur in floors, *Rhodonia*, *Trechispora* and *Trametes* in wooden walls and beams, *Pluteus* in cellars. In wooden attics or on ceiling beams, the following wood-decaying fungi were found: *Penidiella*, *Phylotopsis*, *Resinicium*, *Pestalotiopsis*, *Rigidoporus*, *Schizopora*, *Scytalidium* and *Talaromyces*. *Leucogyrophana pinastri* has grown in two buildings on the spruce floor in a castle and on the basement ceiling of a farmhouse. *Leucogyrophana mollusca* was discovered in an alpine wooden house on floors and walls.

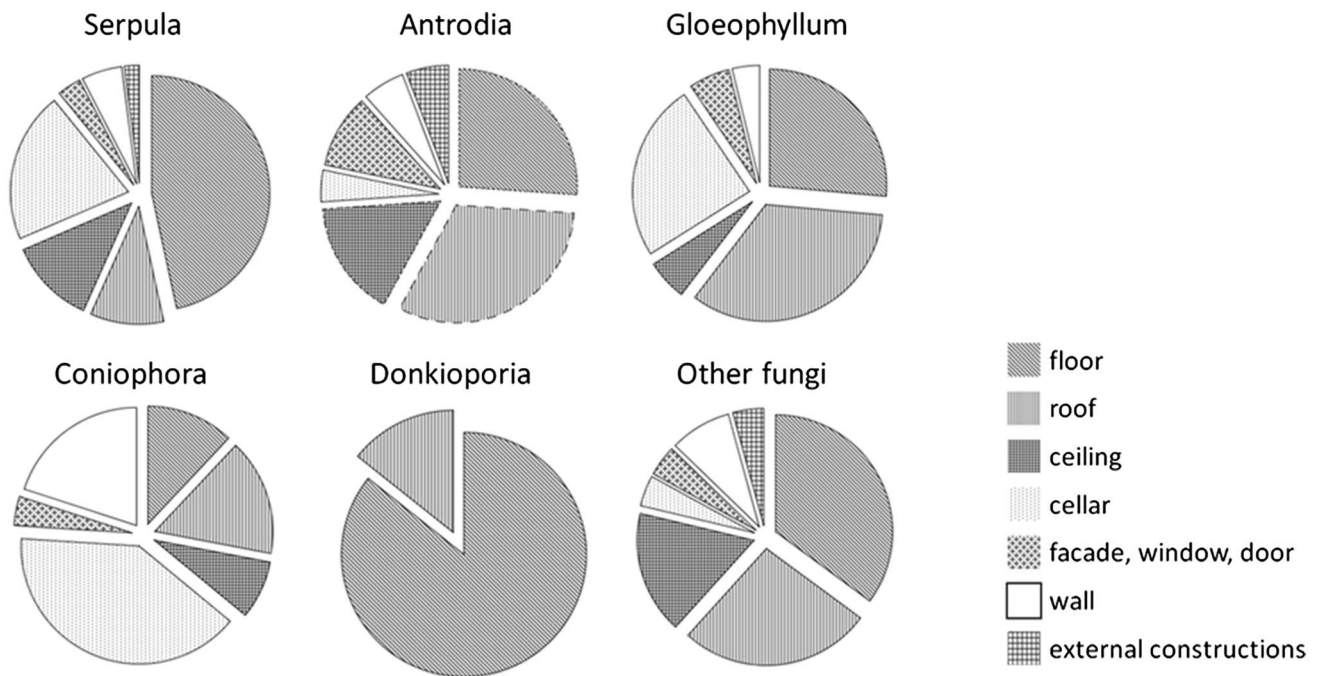


Fig. 2 Wood-destrating fungi by sampling location

4 Discussion

The data of this study offer a first overview on the distribution and spectrum of wood-destrating fungi in Styria, but it is by no means comprehensive.

“Dry rot” was first mentioned in 1765, when devastation of construction wood became a serious problem (Singh 1999). Some of the wood-destrating fungi were transported from one country to another through timber imports (Weir 1919). Because *S. lacrymans* has the highest destructive potential and occurs quite frequently, this fungus is in the focus of most of the studies concerning wood-destrating fungi. According to the Austrian national heritage agency (Bundesdenkmalamt), up to 200 renovation cases are reported every year in Styria. *S. lacrymans* is widely distributed in Styria and up to now, 397 reports from different regions exist. *S. lacrymans* occurs more frequently in mountainous regions and in the city of Graz than in the hilly southern regions. The hot spots of *S. lacrymans* in Germany are North Rhine-Westphalia and the cities Hamburg and Munich (Buchwald 1989). In Finland, 110 wood-destrating fungi (59% *S. lacrymans*) were diagnosed between 1978 and 1984, and 116 cases between 1985 and 1988 (43% *S. lacrymans*) (Paajanen and Viitanen 1989). During the period of 1996–2002, *S. lacrymans* was the most frequent wood-destrating fungus in Latvian buildings with 46.7% (Irbe and Andersone 2009). In a study by Pilt et al. (2009), 633 damage cases were reported in Estonian buildings between 2002 and 2008. In these cases, *S. lacrymans* was also

most frequently isolated (502 cases, 79.3%). Second was *C. puteana* (7.0%), followed by *Antrodia* spp. (5.3%) (Pilt et al. 2009). In Norway the most commonly found brown rot producing fungi were *C. puteana* (16.3%) and *S. lacrymans* (16.0%), whereas in Finland *Antrodia* spp. were more prevalent (Alfredsen et al. 2005). In the present study, 40 different species from 74 genera of wood-destrating fungi were identified in Styrian buildings. This is, compared to Estonia with 16 species, quite a high number. The sum of 35 species of wood-destrating fungi was reported from 1428 building investigations in Norway (Pilt et al. 2009; Alfredsen et al. 2005). Schmidt (2007) described 80 wood-destrating basidiomycetes that commonly occur in German buildings.

The dry rot fungus *S. lacrymans*, on the one hand, is able to adjust to the environment, therefore it is present worldwide, but on the other hand, it needs specific parameters to survive and grow in buildings (Maurice et al. 2011). It can be found in Europe as well as in cold regions in Asian countries. Engh et al. (2010) have found significant genetical differences between European and Japanese isolates. Genetical data led to the conclusion that the evolutionary origin of *S. lacrymans* is in the Himalayas (Kausarud et al. 2007; Skrede et al. 2011). Kausarud (2004) demonstrated the occurrence of geographically widespread vegetative compatibility groups in *S. lacrymans* in Europe. In a recently published review by Gabriel and Svec (2017), the authors report *S. lacrymans* to be the most abundant wood decaying fungus in the following European countries: Poland, Germany (both former FRG and GDR), Belgium, Latvia, Finland and

Estonia, and the second most common in Denmark, Norway and Romania. *S. lacrymans* has also spread over New Zealand and southern Australia (Thornton 1991), as well as over central and northern America (Watkinson and Eastwood 2012). According to Palfreyman (2001), *S. lacrymans* has not been reported from tropical countries. The distribution of *S. himantioides* is unclear in many places. It was recorded from central and northern Europe, northern Asia, northern America, southern Australia and New Zealand (Kausrud et al. 2004, GBIF 2017). In France, *S. himantioides* is often in close association with *D. expansa* (Pottier et al. 2014). In contrast to *S. lacrymans*, *S. himantioides* grows in nature and only rarely in buildings (Maurer et al. 2014; Palfreyman et al. 2003). In the present study, *S. himantioides* was found in a farmhouse and in a multistory building in the city. Maurer et al. (2013) have reported on the occurrence of this fungus once on a disposed spruce board and once on a board in a stream bed. Two species of *Serpula*, namely *S. lacrymans* and *S. himantioides* from Himalayan forests, were first successfully cultured and identified in 1997 (White et al. 1997, 2001).

Investigations of more than 5000 damage reports in Germany have shown that all wooden structures in buildings can be a substrate for wood-destroying fungi when the wood is not protected properly (Schmidt 2007). Areas of particular interest are the implications of wood-destroying fungi on buildings with different construction methods, softwood and hardwood timbers, and location of the damage site.

On average 0.4 damage cases per 1000 inhabitants were reported in the present study in rural areas and small towns (Styria without Graz) but 1.0/1000 inhabitants in the capital Graz (Table 5). This above-average accumulation of wood-destroying fungi, above all *S. lacrymans*, in the city of Graz, may be explained by the fact that Graz suffered from massive

damages by aircraft bombs during the “Second World War (WW2)”. In 57 bombing raids between 1939 and 1945, a total of 7743 buildings were destroyed or damaged in Graz, 8999 apartments were made unusable and 11,065 apartments were damaged. In total, 3707 tons of bombs were thrown on Graz, almost 2000 people (1% of the population) died, and an estimate number of 1500 people was injured (Brunner 1989). Consequently many damaged buildings remained exposed unprotected to all types of weather for years, before reconstruction began, mostly without antifungal preservation. Furthermore, fungus-infested construction wood was most likely brought as firewood into undamaged buildings. For many buildings in Graz, where *S. lacrymans* has been found up to the present, bombing damages during WW2 are documented.

According to Huckfeldt et al. (2011), *S. lacrymans* mostly occurs under floor boards, in the ceiling or under poorly sealed bathrooms or leaking pipes, but infrequently in attics. The authors reported *S. lacrymans* both in new and old buildings. In the present study, this fungus was found mostly in old buildings (88.4%). In new buildings, the incorporation of moist or infested wood or inadequate drying out of buildings can lead to the development of damages caused by wood-destroying fungi. In this study, *S. lacrymans* was found in floors in 46.6% of cases. In a Norwegian survey, *S. lacrymans* was responsible for damages in the floor in 17.0% and in walls in 17.1% (Alfredsen et al. 2005).

The second most frequently isolated wood-destroying fungal genus was *Antrodia*. *A. serialis* infested cellars and wooden floors (garden hut), *A. sinuosa* preferred roof beams in old buildings, and *A. vaillantii* chipboards in new buildings. In Styrian monasteries and churches, *A. xantha* was found in roof frames and beams. The wooden ceiling of an indoor swimming pool was also subject of damage by an *Antrodia* species. In Europe, the most common species of *Antrodia* is *A. vaillantii*, which occurs preferably in spruce wood (Schmidt 1994). *A. sinuosa* is found in Europe, northern America and Australia on coniferous wood (Schmidt 2010). *Antrodia* was the most frequent genus of fungi in Norwegian roof beams (17.3%), in roof and wall constructions (28.6%) and in exterior constructions (Alfredsen et al. 2005; Gabriel and Svec 2017). *A. serialis* was only found sporadically in buildings from other countries (Schmidt 1994). Maurer et al. (2009) discovered *A. serialis* in the montane, subalpine region of Styria. The yellow pore fungus *A. xantha* was found on windows, swimming pools and flat roofs (Schmidt 1994).

Gloeophyllum comprises three important wood-destroying species, which are found widespread in Europe, in North America, northern Africa and Asia. *G. abietinum* is the most common species and prefers the wood of spruce and fir. In the present study, it was mostly found in urban areas on outdoor wooden constructions. This is consistent with findings

Table 5 Cases of damages by wood-destroying fungi per region and population numbers from 2017 (modified after Statistik Austria)

Region	Population 2017	Wood-destroying fungi	Cases per 1000 residents
Liezen	80,011	22	0.3
Obersteiermark Ost	160,777	74	0.5
Obersteiermark West	101,006	69	0.7
Oststeiermark	180,299	36	0.2
Südoststeiermark	86,044	25	0.3
Südweststeiermark	142,556	77	0.5
Steirischer Zentralraum (without Graz)	202,736	69	0.4
Graz	283,869	273	1.0
Styria without Graz	953,429	372	0.4
Styria complete	1,237,298	645	0.5

from other studies where this fungus is described as common destroyer of weathered hardwood constructions, when sufficient moisture and warming sunlight is present (Pfabigan 2011; Schmidt et al. 2002). *G. abietinum* occurs in northern regions, and frequently destroys wooden windows, whereas the quite rare *G. trabeum* is commonly found in the south and prefers deciduous wood (Schmidt 1994). According to Plank (1979), *G. odoratum* is connected to spruce wood, *G. sepiarium* also grows on fir and pine wood, which is commonly used as construction material. Molecular and biological investigations proved the occurrence of *G. trabeum*, *G. abietinum* and *G. sepiarium* (rusty gilled polypore) in buildings in Germany (Schmidt et al. 2002). These three species are important destroyers of wooden windows and are often found in the attics of buildings. In the present study, these three *Gloeophyllum* spp. were found as well. *G. abietinum* was isolated in a higher number from windows and doorframes, as well as from balconies and terraces, *G. sepiarium* was present on wood in the exterior area of mountain huts, on terraces, fences and roofs in urban buildings, and *G. trabeum* on wooden constructions in the roof, on floors and in wet areas. *G. sepiarium* was found in Norwegian buildings in floors (1.5%), in walls (1.9%), in roofs (6.0%), on window- and doorframes (1.9%), and mostly in external areas of buildings (13.2%). *G. trabeum* was not reported from Norwegian buildings, but in Finland, this species was found together with *G. sepiarium*, the former mainly in saunas and from roof beams (Alfredsen et al. 2005). The increase in *Gloeophyllum* spp. in Denmark was traced back by Koch (1991) to the fact that window and roof constructions are often deficient (Schmidt 2010), others claim that the rise of *G. sepiarium* on window frames is a consequence of the introduction of thermo-windows (Alfredsen et al. 2005).

Coniophora is present in Europe with 12 species, of which five are regularly found in the environment (Huckfeldt and Schmidt 2015). The wet or cellar rot *C. puteana* is by far the most frequent species within this genus. *C. puteana* occurs mainly in new buildings, but also in old buildings, it can spread over the whole object, from cellar to roof (Grosser 1985; Schmidt and Huckfeldt 2011). This fungus proliferates in moist walls with cracks, occurs under boards in kitchens and bathrooms but can also develop outdoors on masts, poles and windows. In Denmark and Romania, *C. puteana* was the most commonly isolated wood-destroying fungus in buildings (Gabriel and Svec 2017). This fungus was also present in walls (14.4%), on roofs (11.3%), on window and door frames (15.5%) and in external constructions (19.8%) (Alfredsen et al. 2005). *C. puteana* was also found in historical buildings on “Deception Island” in Antarctica (Held and Blanchette 2017). In the present study, *Coniophora* spp. did not occur in historical buildings. Sterflinger (2010) described *C. puteana* together with *S. lacrymans* in churches, when wooden altars or roofs are defect.

Of the other species, only *C. marmorata* was recorded once in a cellar floor of an apartment building in this study. In Denmark, *C. marmorata* is found quite frequently in buildings after water leakage. Krieglsteiner (1991) documented *C. marmorata* for former Western German States. *C. prasinoides*, which was reported in Germany on a floor of spruce wood by Huckfeldt and Schmidt (2013), was not found in the present study.

Donkioporia expansa is not as well-known as other wood-destroying fungi, but its occurrence in Germany and Austria is gaining in importance. In Europe, there are reports from England, Czech Republic, Slovakia, Belgium, France and Germany. It was declared „important wood-destroying fungus in buildings” between 1990 and 1999 (Kleist and Seehann 1999; Bobekova et al. 2008). *D. expansa* prefers moist to wet wood, decays hard- and softwoods by white rot and is found consequently mainly in wet rooms as kitchens and bathrooms (Kleist and Seehann 1999). Pfabigan (2011) reported on a case of damage due to massive dampness in the ceiling below a kitchen and a desolate shower. This fungus occurs mainly in coniferous wood, but it can also infest the duramen of oakwood. (Schmidt 2010).

Investigations indoors show that other wood-destroying fungi are involved as well. Many species are also found in Styria, and the occurrence of some of them is documented in the database for fungi (Dämon and Krisai-Greilhuber 2012). The genus *Leucogyrophana* prefers wooden farmhouses and floors in historical buildings in this study. In Norway, *Leucogyrophana* holds 3% of the total number of wood-destroying fungi (Alfredsen et al. 2005). *L. pinastri*, found under boards during a survey, was even blamed to be the cause of an extrinsic allergic alveolitis (Stone et al. 1989). *L. pulverulenta* causes brown rot and occurs regularly in German buildings with earthy, wet substrates (Huckfeldt et al. 2011).

The distribution range of *Fomes fomentarius* corresponds widely to the appearance of deciduous trees. In the present study, it was found in an attic. *Fomitopsis* sp. may destroy wood when stored improperly (Rayner and Boddy 1988; Schwarze et al. 1999). In this study, *Fomitopsis pinicola* was isolated from a floor. *F. pinicola* grows on hard- and softwood in all regions in Styria (Maurer et al. 2014). *F. pinicola* was also isolated from buildings in Estonia (Plank 1979). In Italy, it was found only outdoors (Saitta et al. 2011).

Rhodonia placenta, which was introduced from North America, appeared in the present studies once in a wooden hut made of spruce timber (Findlay 1967). An infestation of the floor and the thermal insulation with wood chips in a new timber frame building by *R. placenta* was reported from Germany just a few years after residents moved in (http://www.holzfragen.de/seiten/rosafarbener_saftporling.html). *R. placenta* is very common in North America and serves

as a model organism for brown rot decay mechanism and comparative genome analysis (Gaskell et al. 2017).

Tapinella (Paxillus) panuoides is also present on coniferous wood. It grows on bridges, balconies, garden furniture or together with *S. lacrymans* in cellars, stables etc. (Schmidt 1994). In the present study, *T. panuoides* was found in the cellar of a farmhouse, and *T. hirsuta* in the attic of a single-family house and in the ceiling of a rectory. *Tapinella* spp. are not only present in Styria but also in the neighboring federal state of Carinthia (Sperdin 1976). Wilcox and Dietz (1997) described the prevalence of *Rhodonina placenta*, *T. panuoides* and other wood-destroying fungi on freshly cut wood. These fungi were possibly brought into the wood during processing or after flooding (Heidegger-Kastenhuber 2007).

In Europe, the genus *Trametes* is represented by nine species (Tomsovsky et al. 2006). *Trametes* spp., above all *T. trogii*, are residents of deciduous wood in moist riparian forests, also in Germany (Kreisel 1962). Whereas *T. trogii* was found in the present study in wall- and ceiling constructions, *T. abietina* was isolated from the roof of the wet zone of a sauna. *T. trogii* was also found in Graz in the floor of a new building.

The ochre crust fungus (*Crustoderma dryinum*) was discovered first in southwestern Germany after a water damage (Grimm et al. 2016). *C. dryinum* was also reported sporadically from Scandinavia, France and the Austrian federal state Tyrol (Dämon 2001). In the present study, it was identified only once on the wooden ceiling of a house with water damage.

Species like *Stereum hirsutum*, which may infest older and weakened trees, can also be introduced into buildings (Blinkova and Ivanenko 2016). Cease et al. (1989) discovered *Scytalidium* sp. in the wood of a birch and confirmed the interaction between *Scytalidium* sp. and brown and white rot fungi. In the present study, *Scytalidium lignicola* grew in an attic and a ceiling.

Polyporus spp. were found sporadically in a wooden ceiling, floor and roof terrace, *Tapinella panuoides* in the bathroom of a single-family house, *Resinicium bicolor* in the floor of a single-family house and the attic of an apartment building, and *Trechispora farinacea* in a wooden ceiling and on incorrectly stored timber.

5 Conclusion

Wood-destroying fungi in buildings are present in all regions of the federal state of Styria, with a prevalence for buildings in the urban area and properties constructed before 1945. The most common species is the dry rot fungus *Serpula lacrymans*, which is found in all types of buildings and in all Styrian regions. More work and above all active cooperation

and networking between scientific institutions and commercial companies focused on wood-destroying fungi in buildings must be done to increase the knowledge in this subject.

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