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Cryptostroma corticale and its relationship to other pathogens and pests on *Acer pseudoplatanus*

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Abstract: In the present study, 20 sycamore maples (*Acer pseudoplatanus* L.) were evaluated on eight plots (160 trees) affected by sooty bark disease (SBD), caused by *Cryptostroma corticale* (Ellis & Everh.) P.H. Greg. & S. Waller in Northern Bohemia, Czech Republic. Mortality and presence of common pest taxa were assessed for each tree. Data were statistically evaluated using frequency and principal component analyses. The presence of *C. corticale* and *Prosthecium pyriforme* Jaklitsch & Voglmayr were positively related, with a significantly higher occurrence on dead trees. *Rhytisma acerinum* (Pers.) Fr. and *Aceria macrorhyncha* Nalepa were also positively related. However, the presence of *Drepanosiphum platanoidis* Schrank was not clearly related to the other evaluated taxa. Furthermore, *C corticale* was not present on Norway maple trees (*Acer platanoides* L.) growing on the plots. The results suggest that (*i*) the mortality of the sycamore was caused by *C. corticale*, while *P. pyriforme* was only an accompanying weak pathogen; (*ii*) *R. acerinum*, *A. macrorhyncha*, and *D. platanoidis* did not cause the mortality of the sycamore and their presence was not related to *C. corticale* infection; and (*iii*) planting more resistant maple species on sites susceptible to attack by SBD, particularly when stressed by drought, is recommended.

Keywords: Central Europe; forest protection; *Prosthecium pyriforme*; sooty bark disease; sycamore maple

The sycamore maple (*Acer pseudoplatanus* L.) is a tree with a scattered distribution in European forests (Hemery et al. 2010). While the tree naturally grows in Central and Eastern Europe, the mountains of Southern Europe, the Caucasus, and northern Asia Minor (Pasta et al. 2016), it has become naturalised far beyond its original range (EUFORGEN 2023). It is thus assumed that the tree will eventually spread to Northern Europe and the British Isles (Konatowska et al. 2023). *A. pseudoplatanus* thrives in calcareous soils, requires a permanent and good water supply, and avoids wet soils (EUFORGEN 2023).

Cryptostroma corticale (Ellis & Everh.) P.H. Greg. & S. Waller is an ascomycetous fungus and causative agent of sooty bark disease (SBD) on maples (*Acer* spp.). *C. corticale* was first recorded in Canada as a saprotroph on the bark of *A. pseudoplatanus*

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and *A. saccharum* Marsh. (Ellis, Everhart 1889). Symptoms of SBD were first recorded in Great Britain in 1945 on *A. pseudoplatanus* (Gregory et al. 1949). Subsequently, *C. corticale* was identified as a causative agent of SBD (Gregory, Waller 1951). *C. corticale* is currently present in the United Kingdom (Gregory, Waller 1951; Bevercombe, Rayner 2007), Austria (Cech 2004), Germany (Metzler 2006; Schlößer et al. 2023), the Czech Republic (Koukol et al. 2014; Kelnarová et al. 2017), Slovakia (Kunca et al. 2018, 2019), Bulgaria (Bencheva 2014), Slovenia (Ogris et al. 2021), Italy (Longa et al. 2016), Switzerland (Cochard et al. 2015), France, the Netherlands, Belgium, Norway, Canada, the United States (CABI 2021), and Russia (Gninenko et al. 2024). *C. corticale* mainly infects *A. pseudoplatanus*, but it can also occur on *A. platanoides* L. (Bencheva 2014), other maples (CABI 2021), *Fraxinus excelsior* L. (Langer et al. 2023), *Aesculus hippocastanum* L. (Brenken et al. 2024), *Quercus pubescens* Wildd, and *Ostrya carpinifolia* Scop. (Longa et al. 2016).

SBD was first recorded in the Czech Republic in 2005 on a maple in urban greenery in Prague (Koukol et al. 2014). *C. corticale* was subsequently confirmed in the city parks of Prague and the floodplain of the Vltava River (Koukol et al. 2014). The more frequent occurrence of *C. corticale* was recorded in localities on steep slopes, with a higher altitude, more substantial nitrogen oxide pollution, and a denser network of roads and paths (Kelnarová et al. 2017). The first occurrence of *C. corticale* in Czech forests was documented in 2014 (Černý et al. 2015). However, *C. corticale* probably occurred in Czech forests earlier but escaped attention due to its presence in the host tissues without any visible manifestation of the disease (Kelnarová et al. 2016). In recent years, infection by *C. corticale* has been confirmed on *A. pseudoplatanus* in several stands of the Czech forest in North Bohemia (Lorenc, Samek 2021).

The spores (conidia) of *C. corticale* are typically ovoid and 4–6.5 μm × 3.5–4 μm, although their shape may be distorted by pressure from adjacent conidia (Gregory, Waller 1951). The conidia can be dispersed by air as far as 310 km from the site of the closest disease outbreak (Muller et al. 2023). Conidia have also been found on grey squirrels (*Sciurus caroliniensis* Gmelin) (Abbott et al. 1977) and woodpeckers (Hennes 2022), which are important vectors of many microorganisms, including fungi (Johansson et al. 2021). Therefore, the role of these animals in the dispersion of *C. corticale* cannot be excluded (Hennes 2022).

C. corticale can live on host trees as an endophyte, without initially presenting visible symptoms of infection (Schlößer et al. 2023; Bußkamp et al. 2024). However, the likelihood of presentation increases with the severity of hot and dry conditions (Ogris et al. 2021; Burgdorf et al. 2022). The first symptoms of SBD include wilting and branch dieback. Later, a greenish-brown stain can be observed in the cross-sections of the trunk. Subcortical stromata are produced in places where the pathogen reaches the bark. Ultimately, dark spore masses are visible under peeled, necrotised bark, and the dead host remains covered with dark stroma (Gregory, Waller 1951). Infection by *C. corticale* makes wood unusable for further processing, which leads to considerable economic losses in the timber industry (Kespohl et al. 2022).

The optimal growth temperature of *C. corticale* is 25 °C (Dickenson 1980; Dickenson, Wheeler 1981; Ogris et al. 2021). Accordingly, the release of *C. corticale* conidia in the conditions of Central Europe is most substantial during the summer months (with the highest air temperatures) (Burgdorf et al. 2022). An accumulated water deficit in spring and summer lower than –132 mm has been correlated with SBD outbreaks (Muller et al. 2023). In recent years, *C. corticale,* as well as SBD, have spread in response to higher temperatures and repeated periods of drought (Longa et al. 2016; Schlößer et al. 2023). In the event of the widespread planting of maples and an increase in summer droughts and temperatures, a significant spread of this pathogen in Europe can be expected (Lorenc, Samek 2021; Schlößer et al. 2023).

Inhalation of large amounts of *C. corticale* conidia can cause a hypersensitivity pneumonitis called 'maple bark stripper lung' in humans. Persons who have intensive contact with infested trees or wood (e.g. woodmen, foresters, sawyers, or paper mill workers) are particularly at risk of developing this condition (Braun et al. 2021; Kespohl et al. 2022).

To prevent the release of *C. corticale* conidia, it is necessary to remove necrotised branches and infested individuals from the stand and ensure higher air humidity when processing or storing necrotised wood (Kelnarová 2015). To avoid contact with *C. corticale* conidia, work on infested trees should be done during rainy periods and colder

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seasons, with fewer conidia in the air, and workers should wear personal protective equipment (Braun et al. 2021; Kespohl et al. 2022). The removed trees should also be replaced with other species. When planting sycamore maples in new localities, it is essential to focus on the habitat requirements of the tree species (Kelnarová 2015). No effective fungicides or biopreparates against *C. corticale* are available.

The aims of the present study were (*i*) to assess tree mortality, the presence of harmful biotic agents, and their relationship on *A. pseudoplatanus* trees in sycamore maple forest stands with symptoms of SBD, and (*ii*) to recommend precautions against SBD in light of this assessment.

MATERIAL AND METHODS

The assessment was carried out at eight research sites (stands) of sycamores with symptoms of SBD in Northern Bohemia, Czech Republic (Table 1) in May 2022. Twenty sycamore trees were evaluated at each site (a total of 160 trees). The first tree evaluated on each plot was the one growing in the centre of the largest focus of SBD. After the first tree was evaluated, 19 trees growing closest to the first tree were examined (whether healthy or infected). The trees were selected in this way due to the focal occurrence of trees with SBD symptoms (with a different method of tree selection, trees with SBD symptoms would not be included at some sites). Tree mortality (0 live, 1 dead) and the presence of individual taxa, either in terms of individuals or symptoms (0 absent, 1 present), were assessed for each tree. Taxa were assessed as present if one or more of the following objects were found: stromata for *C. corticale*, fruit bodies or stromata for other fungal pathogens, or individuals (any stages) or galls for animal pests. In unclear cases, samples were taken from the trees, and taxon identification was subsequently carried out in the laboratory using the necessary techniques (e.g. cultivation in wet chambers and identification of fungal stromata, fruit bodies, spores, or animal pest individuals using a microscope).

The presence of *C. corticale* (as the presence of stromata) was also inspected on all Norway maple trees at the research sites.

The data were statistically tested using Microsoft Excel (Version 365) and Statistica software (Version 10, 2010, StatSoft). Frequency analyses of the observed values and their comparisons with expected values (χ^2) were used to assess the relationship between tree mortality and the presence of individual taxa. Principal component analysis (PCA) was used to assess the relationship among individual taxa present only on live sycamore trees (a total of 124). The presence of the following taxa was included in the PCA analysis: *Cryptostroma corticale*, *Prosthecium pyriforme* Jaklitsch & Voglmayr (anamorph *Stegonsporium pyriforme* [Hoffm.] Corda), *Rhytisma acerinum* (Pers.) Fr., *Aceria macrorhyncha* Nalepa, and *Drepanosiphum platanoidis* Schrank. Other taxa were not included in the statistical analysis due to their low density.

RESULTS

Out of the 160 assessed individual sycamore trees, 36 were dead (23% tree mortality). *C. corticale* was present in all dead and 24% of live trees. *P. pyriforme* was present in 19% of dead and 3% of live trees. *D. platanoidis* occurred predominantly on live trees, and *R. acerinum* and *Aceria macrorhyncha* were found exclusively on live trees (Table 2). Differences in the rates of presence be-

Table 1. Summary information about research sites

Site	GPS	Altitude (m a.s.l.)	Soil type (CENIA 2023)
Hostovice	50°37'49"N, 14°1'50"E	455	Eutric Cambisols
Lom	50°36'42"N, 13°38'30"E	380	Dystric Cambisols
Nová Ves	50°37'27"N, 13°49'18"E	325	Eutric Cambisols
Podlešín	50°37'10"N, 14°2'57"E	465	Eutric Cambisols
Velvěty	50°36'14"N, 13°53'1"E	215	Eutric Cambisols
Braňany	50°32'29"N, 13°41'12"E	295	Heap Anthrosols
Petrohrad	50°7'31"N, 13°26'22"E	385	Acidic Cambisols
Podbořany	50°12'37"N, 13°26'19"E	330	Modal Cambisols

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Table 2. Numbers and percentages of *Acer pseudoplatanus* trees with the presence of assessed pest taxa (total 160 trees) and the results of analyses of frequencies

Variable	Live trees (124)		Dead trees (36)		Total (160)		χ^2	*df*	*P*
	N	%	*N*	%	*N*	%			
Mortality	–	–	–	–	36	23	–	–	–
Cryptostroma corticale	30	24	36	100	66	41	66.16	1	***
Prosthecium pyriforme	4	3	7	19	11	7	11.46	1	***
Rhytisma acerinum	11	9	0	0	11	7	3.43	1	0.06
Drepanosiphum platanoidis	114	92	2	6	116	73	104.41	1	***
Aceria macrorhyncha	33	27	0	0	33	21	12.07	1	***

***Significance level $P < 0.001$; *N* – number of trees; % – percentage of trees; χ^2 – values of the analyses of frequencies; *df* – degrees of freedom

tween dead and live trees were statistically significant for *C. corticale*, *P. pyriforme*, *D. platanoidis*, and *A. macrorhyncha* (Table 2).

On dead sycamore trees (total 36), only co-occurrences of *C. corticale* with *P. pyriforme* (7) and *C. corticale* with *D. platanoidis* (2) were found (Figure 1).

On live sycamore trees (a total of 124), the highest numbers of co-occurrences were found between *D. platanoidis* with *A. macorhyncha* (29) and *C. corticale* with *D. platanoidis* (28). Relatively high numbers of co-occurrences were found between *R. acerinum* with *A. macrorhyncha* (10), considering the high number of trees with an absence of both taxa (90). No co-occurrences were found between *P. pyriforme* with *R. acerinum* and *P. pyriforme* with *A. macrorhyncha* (Figure 2).

The PCA analysis of the live sycamore trees showed that (*i*) the presence of *C. corticale* and *P. pyriforme* were positively related, (*ii*) the presence of *R. acerinum* and *A. macrorhyncha* were also positively related, and (*iii*) the presence of *D. platanoidis* were not clearly related to the other evaluated taxa (Figure 3).

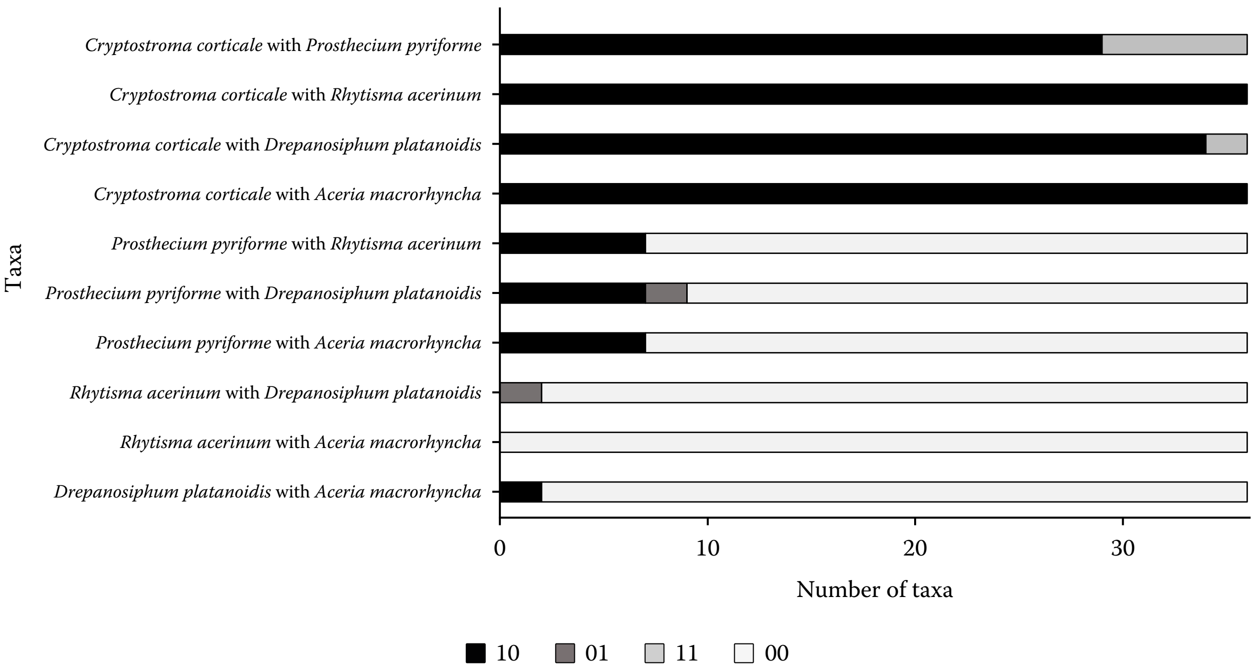

Figure 1. Numbers of taxa on dead *Acer pseudoplatanus* trees (total 36)

10 – first taxon present and second absent; 01 – first taxon absent and second present; 11 – both taxa present; 00 – both taxa absent

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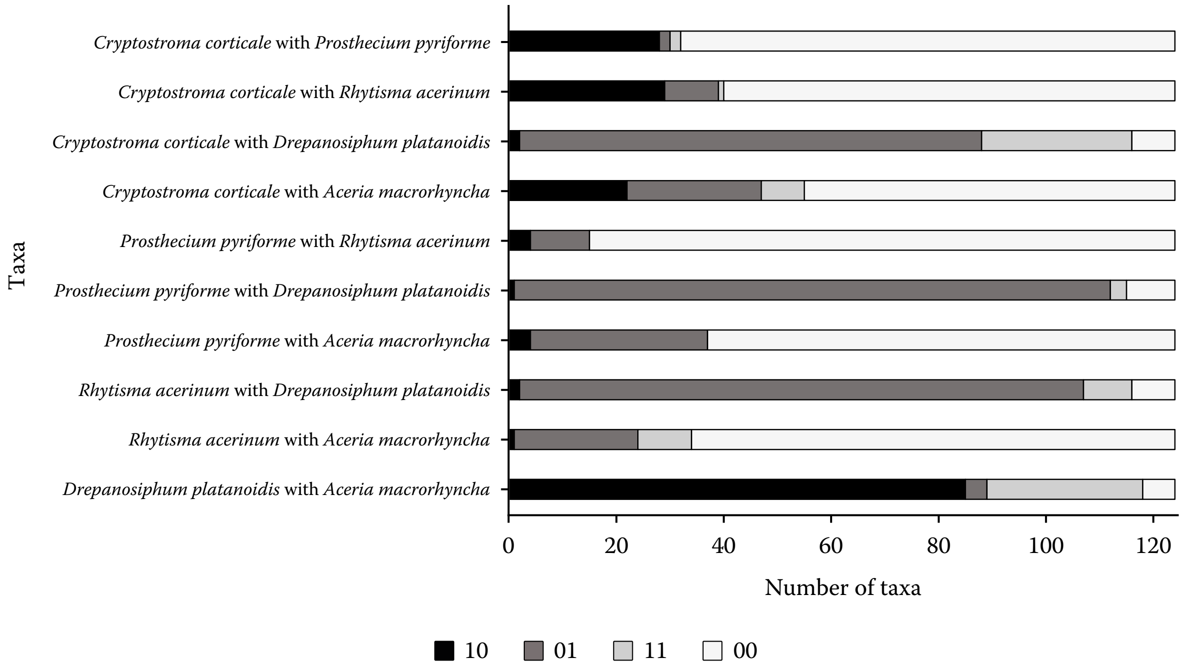

Figure 2. Numbers of taxa on live *Acer pseudoplatanus* trees (total 124)

10 – first taxon present and second absent; 01 – first taxon absent and second present; 11 – both taxa present; 00 – both taxa absent

Norway maple trees (*Acer platanoides* L.) of different ages were abundant at three sites (Nová Ves, Braňany, Petrohrad). *C. corticale* was not recorded on any of the Norway maples (no fruit bodies or symptoms of SBD), and these trees exhibited good health at all sites.

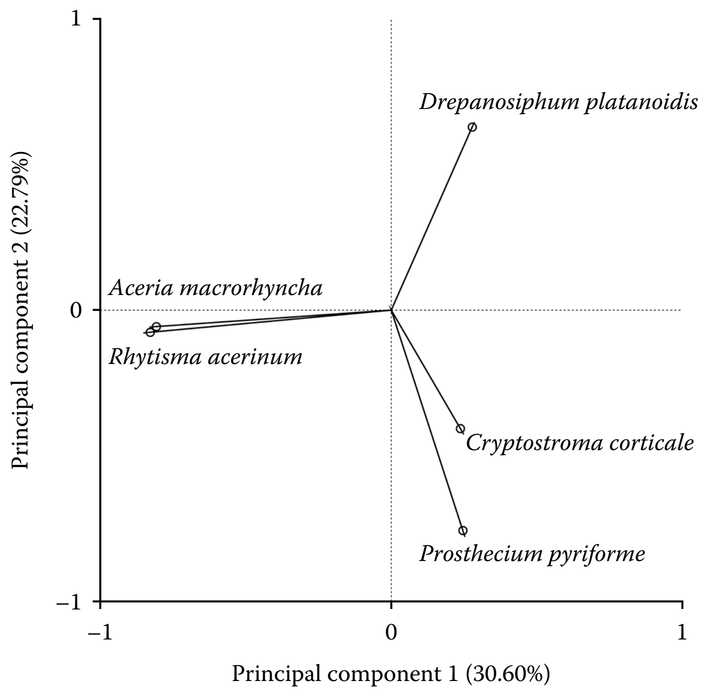

Figure 3. Principal component analysis (PCA) for live *Acer pseudoplatanus* trees

Line ended by a small empty circle – variable; number of samples (live trees) = 124; number of variables = 5

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DISCUSSION

The findings revealed that the presence of *Cryptostroma corticale* and *Prosthecium pyriforme* were positively related (Figure 3), and both taxa occurred significantly more often on dead trees (Table 2). The presence of *C. corticale* together with *P. pyriforme* on declining, dying, and dead sycamore trees was previously recorded in the Czech Republic (Lorenc, Samek 2021), Slovakia (Kunca et al. 2018, 2019, 2020), and Germany (Hülsewig 2019). *C. corticale* is an important pathogen of maples, including the sycamore, and can lead to the mortality of infected trees (Gregory, Waller 1951; Hemery et al. 2010; Černý et al. 2015). This finding corresponds with the presence of *C. corticale* on all dead trees in the present study (Table 2; Figure 1).

P. pyriforme is an ascomycetous fungus, forming pear-shaped conidia with a size of 30–50 μm × 14–20 μm and the rare occurrence of ascospores with longitudinal compartments (Voglmayr, Jaklitsch 2008). It is a common but weak pathogen of maples (Voglmayr, Jaklitsch 2008, 2014; Bußkamp et al. 2024) and tends to attack already weakened trees (Sinclair, Lyon 2005). Therefore, the relatively high presence of *P. pyriforme* on dead trees in the present study was probably due to the infection of *C. corticale*, which led to the weakening and death of the trees. Thus, the main cause of death among the sycamores in the present study can be attributed to *C. corticale*, whereas the relative impact of *P. pyriforme* on death was actually low.

Rhytisma acerinum is an ascomycetous fungus that causes tar spots on maples of all ages (Vakula et al. 2016). The occurrence of *R. acerinum* on leaves can be interpreted as the reason for its presence only on the live trees (with leaves) in the present study. Insignificant differences in the presence of *R. acerinum* between dead and live trees in the present study were probably due to the low number of live trees infected by this pathogen (11) (Table 2). Higher temperatures and lower precipitation have a negative effect on *R. acerinum* (Gosling et al. 2016). The different optimal temperature and precipitation conditions of *C. corticale* and *R. acerinum* could explain their unrelated occurrence on the live sycamore trees in the present study. In the Czech Republic, *R. acerinum* is a common species without phytopathological importance (Palovčíková 2023). Therefore, it can be concluded that *R. acerinum* did not cause the death of the sycamore maples in the present study.

Aceria macrorhyncha is a sucking mite from the family *Eriophyidae*, which forms pointed galls up to 6 mm in length on the upper side of maple leaves (Rychlý 2023). The occurrence of *A. macrorhyncha* galls on leaves is the reason for its presence on only the live trees (with leaves) in the present study. In fact, both *A. macrorhyncha* and *R. acerinum* occur on leaves, which could explain their positively related presence on live trees in the present study (Figure 3). While *A. macrorrhyncha* is a common species in the Czech Republic, it is not a threat to woody plants (Rychlý 2023). Therefore, *A. macrorhyncha* did not cause the death of the sycamore maples in the present study.

Drepanosiphum platanoidis is a monocyclic aphid that sucks on the leaves of maples, especially sycamore (Blackman, Eastop 2023). Therefore, it was almost absent on the dead trees (with 100% defoliation) in the present study. The aphid has fluctuating abundance throughout the year, with a peak in spring (Kindlman, Dixon 2010). This explains the high occurrence of the aphid on the sycamore in the present study during the evaluation period (May). Damage to trees caused by sucking of *D. platanoidis* is usually only local (Fryč 2023). However, the aphid can excrete large amounts of honeydew, thereby creating ideal conditions for the growth of fungi, including *C. corticale* (Curran et al. 2022). This could be the reason for the high rate of co-occurrence of *C. corticale* and *D. platanoidis* on live trees (28) in the present study (Figure 2). On the other hand, this high co-occurrence could be simply due to the otherwise unrelated high occurrence of both taxa. Accordingly, a positive relationship between the occurrence of *C. corticale* and *D. platanoidis* was not recorded in the present study (Figure 3).

No *C. corticale* fruit bodies or symptoms of SBD were recorded on the Norway maple in the present study. *C. corticale* can live on host trees as endophytes, with no symptoms of infection (Kelnarová et al. 2017; Schlößer et al. 2023; Bußkamp et al. 2024). However, the difference between the health status and tree mortality rates of the sycamore and Norway maple trees due to SBD in the present study was obvious. Both Norway and field maples (*Acer campestre* L.) are more resistant to *C. corticale* infection (Braun 2021) and drought stress (Lazic et al. 2002;

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Sjöman et al. 2015), which is a key factor in the development of SBD (Longa et al. 2016; Schlößer et al. 2023). Therefore, planting Norway and field maples instead of sycamore in stands susceptible to attack by SBD is recommended.

CONCLUSION

The tree mortality of sycamore in the present study was caused by *C. corticale*. This pathogen was often accompanied by *P. pyriforme*, which did not cause the death of the sycamore. *R. acerinum*, *A. macrorhyncha*, and *D. platanoidis* did not cause the mortality of the sycamore, and their presence was not related to *C. corticale* infection. An increased risk of SBD attack and subsequent mass death of the sycamore can be expected in stands with a significant share of trees stressed by drought. Therefore, planting more resistant maple species (e.g. Norway and field maples in Central Europe) is recommended.

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