Cryptogamic epiphytes and microhabitat diversity on non-native green ash (*Fraxinus pennsylvanica* Marsh., Oleaceae) in urban habitats

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With the increased planting of non-native trees within urban environments there is a need for investigating the impacts they may have on the indigenous biodiversity. In this study, we explored the diversity of epiphytic lichens and bryophytes as well as the tree-related microhabitats on planted, non-native green ash *Fraxinus pennsylvanica* and compared it to that of indigenous *Fraxinuss excelsior* and *Quercus robur*. We conducted sampling on trees of similar growing conditions and size within two cities of eastern Germany (Dresden and Dessau-Roßlau). In our analysis we did not find any significant differences in epiphyte diversity and abundance. By contrast, microhabitat diversity was significantly higher on *F. pennsylvanica* than on the indigenous tree species, which we attribute to the pioneer character of *F. pennsylvanica* with faster ageing. Our results underline a low impact of *F. pennsylvanica* on epiphytic lichen and bryophyte diversity, while indigenous animals might even benefit from the higher diversity and frequency of microhabitats on trees of this species. Therefore, its use as an ornamental tree should not be generally rejected in urban environments.

Keywords: Alien Trees, Bryophytes, Invasiveness, Lichens

Introduction

In urban environments, the propagation of non-native (i.e., alien) tree species is indispensable, as many indigenous species do no longer tolerate the extreme conditions of urban habitats (Roloff et al. 2018, Doroski et al. 2020). As such, non-native tree species might safeguard important tree-related ecosystem services (Dickie et al. 2014). However, some of these species may have serious impacts on indigenous communities, but evidence is rare (Sladonja et al. 2015). Likewise, the potentially beneficial effects are often unknown (Schlaepfer et al. 2011, Litt et al. 2014). This specifically holds true for the impact of non-native trees on epiphytic lichens and bryophytes, a species group that often makes a significant contribution to urban biodiversity (Prather et al. 2018). It has been found that some non-native tree species can support rare epiphyte and bryophyte species and harbour highly diverse epiphyte communities (John & Stapper 2015, Fudali & Szymanowski 2019). Though, systematic comparisons to indigenous host tree species in the same habitat are scarce and specifically lacking for urban habitats. Even fewer data are available for further tree-inhabiting taxa such as fungi and insects (Gossner 2016, Mitchell et al. 2017, Böl 2018). Investigation of these taxa can be difficult, time-consuming and expensive. This is also due to their high species diversity, demand for specialized and rare taxonomic expertise and often inconspicuous, seasonal appearances. Therefore, the trade-off between investigation effort and indicator value of such taxa can be disadvantageous (Larrieu et al. 2018). In the absence of direct data on many species groups, tree-related habitat structures have been suggested to serve as a proxy for biodiversity assessments (Paillet et al. 2018). In urban environments microhabitats such as trunk cavities or crown deadwood are critical for many species (Zapponi et al. 2014, Fröhlich & Ciach 2020). These microhabitats are also supposed to occur on mature and over-aged non-native trees, but evidence is scarce (Zapponi et al. 2014, Bovyn et al. 2019). Among the trees that are increasingly planted in German cities, North American green ash (*Fraxinus pennsylvanica* Marsh., Oleaceae), including natural and cultivated varieties, has been proven to be tolerant to harsh environmental conditions ( Böl 2018). In addition, *F. pennsylvanica* is attractive for its appearance. Furthermore, *F. pennsylvanica* is discussed as an alternative to the indigenous common ash (*F. excelsior L.*), which is hardly affected by ash dieback (Mitchell et al. 2017). *F. pennsylvanica* was introduced to some central European countries in the 18th century as an ornamental tree and it was planted in alluvial hardwood forests (Schmiedel et al. 2013). In near-natural habitats of Germany and other European countries this tree species is being considered as invasive (Prots et al. 2011, Nehring et al. 2013, Danielewicz & Wiatrowska 2014). By contrast, the impact on indigenous epiphytic communities has not yet been assessed in urban habitats of central Europe (but see studies conducted in North America and Eastern Europe – Galé 1966, 1970, Fojcik & Stebel 2001, Hyerczyk 2005, Matwiejuk & Choinowska 2016), and data for tree-related microhabitats are lacking.

Based on observations in two German
cities (namely Dresden and Dessau-Roßlau), this study deals with two questions: (i) Does planted F. pennsylvanica have a negative impact on the diversity of indigenous epiphytic lichens and bryophytes? (ii) Which microhabitats do evolve on planted F. pennsylvanica, compared to indigenous broadleaved tree species?

Material and methods

Trees were investigated in the cities of Dresden (51° 03′ N, 13° 44′ E – Saxony Federal State) and Dessau-Roßlau (51° 52′ N, 12° 15′ E – Saxony-Anhalt Federal State) in 2018 and 2019. Climate is characterized as warm-temperate, with mean annual precipitation and mean annual temperature of 650 mm and 9.0 °C for Dessau-Roßlau for the past decades and 9.0 °C for Dresden and 542 mm and 9.2 °C for Dessau-Roßlau, this study deals with two questions: (i) Does planted F. pennsylvanica have a negative impact on the diversity of indigenous epiphytic lichens and bryophytes? (ii) Which microhabitats do evolve on planted F. pennsylvanica, compared to indigenous broadleaved tree species?

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For each individual of F. pennsylvanica we selected nearby individuals of F. excelsior and Q. robur at similar growing conditions and, preferably, similar size (i.e., diameter at breast height, DBH). Therefore, sample trees were not selected randomly and sample tree number was determined by the number of possible species triplets. As a consequence, six replicate groups in Dresden and five replicate groups in Dessau-Roßlau were established. The Dresden set mainly includes mature and old trees of DBH > 60 cm, while the sample trees in Dessau-Roßlau are much younger with a DBH < 40 cm.

Epiphytic lichens and bryophytes were recorded in the lower trunk section of the trees (0-2 m). Species abundance was quantified by modified percentage estimation referred to the trunk section area covered (Dittrich et al. 2013). For additionally exploring epiphytes in the (often overlooked) tree canopy (Prather et al. 2018) we made use of a peri-urban, over-aged, F. pennsylvanica specimen in Dessau-Roßlau, of which large parts of the unstable crown had been cut off and deposited nearby in July 2018. Of a sample tree of F. pennsylvanica in Dresden, we could also access downed canopy branches for a survey of canopy-inhabiting epiphyte species. Nomenclature of species is based on Wirth et al. (2013) for lichens, Caspari et al. (2018) for bryophytes and Buttler & Hand (2008) for vascular plants.

For each tree, we determined the three features DBH, site hemeroby and bark pH (Tab. 1). DBH was measured with a measuring tape, and we classified hemeroby (i.e., the degree of human impact) of the growing site according to a scale of three classes: class 1 included sites of lowest hemeroby (e.g., abandoned parks and urban succession forests), class 2 represented sites of medium hemeroby (e.g., managed parks and sides of secondary roads), while class 3 included sites of highest hemeroby, i.e., main street roadsides. In the bark pH analyses, 1 g of sample tree bark was dried and pulverized. Re-hydrated with 20 ml of de-ionised water, these suspensions were horizontally shaken for 24 hours. The pH values were measured with the electronic analyser Toledo MP-220® (Mettler-Toledo, Greifensee, Switzerland) in the suspension (method after Lüth 2010). Tree-related microhabitats were determined after Kraus et al. (2016), and their presence was noted for each sample tree.

Statistical analyses

We compared the frequency and mean cover of the epiphyte species as well as the frequency of microhabitats between the three tree species in the two cities. To detect a significant turnover in species composition between the trees, the epiphyte relevés were subjected to one-way ANOSIM (Clarke 1993) using species abundance ranks for group-wise comparisons. Significant differences in tree features and the single species cover were tested by Kruskal-Wallis test, as the data were not normally distributed (Shapiro-Wilk test, p > 0.05). Differences in microhabitat and species diversity were additionally tested for significance between the sample tree species with the Wilcoxon test. Most statistical analyses were done using the software R v. 3.6.3, especially the package “R commander” (R Core Team 2020, Fox 2017), whereas ANOSIM was performed with the software PAST v. 4.01 (Hammer et al. 2001). As climate and growing conditions of the sample tree species in the two regions did not strongly differ, we summarized all sample trees in analyses on the general trends (i.e., N = 11 replicates). Detailed epiphyte species composition and microhabitat spectra were analysed separately for the two cities and size classes, respectively.

Results

In the entire tree set, epiphyte diversity was not significantly different between F. pennsylvanica, F. excelsior and Q. robur (Wilcoxon test, p > 0.05 – Fig. 1). However, diversity of epiphytic bryophytes was lowest in Q. robur individuals. Trends were similarly expressed in both study areas (Kruskal-Wallis test, p > 0.05; Wilcoxon test, p > 0.05 – Tab. 2). Furthermore, no significant differences were found in the epiphyte

### Tab. 1 - Sample tree features in Dresden and Dessau-Roßlau (mean ± standard error).

| Feature          | Dresden     | Dessau-Roßlau |
|------------------|-------------|---------------|
|                  | Fp          | Fe            | Qr            | Fp          | Fe            | Qr            |
| Replicates       | 6           | 6             | 6             | 5           | 5             | 5             |
| Bark pH          | 5.3 ± 0.2   | 5.6 ± 0.2     | 5.1 ± 0.3     | 5.8 ± 0.1   | 5.6 ± 0.3     | 5.5 ± 0.1     |
| Tree DBH (cm)    | 66.2 ± 6.6  | 71.4 ± 9.5    | 69.3 ± 9.7    | 24.9 ± 2.1  | 26.9 ± 3.8    | 26.2 ± 4.9    |
| Site hemeroby    | 2.0 ± 0.2   | 2.0 ± 0.2     | 1.8 ± 0.2     | 2.8 ± 0.2   | 2.8 ± 0.2     | 2.4 ± 0.2     |

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Tab. 2 - Epiphyte species (frequency, mean cover ± standard error) on sample trees in Dresden and Dessau-Roßlau. (Fp): Fraxinus pennsylvanica; (Fe): Fraxinus excelsior; (Qr): Quercus robur; (+): mean cover <0.1%. Statistical testing of the data did not yield significant differences within the relevant study area and between the sample tree species (p > 0.05, Kruskal-Wallis-Test; Wilcoxon test).

Rare species: Dresden - Fp: crustose lichen indet., Phlyctis argena, Brachythecium salebrosum, Cladonia cladosporioides, Physcomitrium perlatum, F. pennsylvanica, Ulota bruchii; Fe: Candelariella aurella, Flavoparmelia sorediata, Physcomitrium capillare; Qr: Physcia spec. Dessau-Roßlau - Fp: Candelariella xanthostigma; Fe: Arthonia radiata, Candelariella reflexa; Qr: Candelariella spec., Parmotrema perlatum.

In contrast to the epiphytic species, differences in microhabitats were more pronounced between the three tree species. Microhabitat diversity was significantly higher in F. pennsylvanica than in the two indigenous tree species in all sample trees (Fig. 2) and in Dessau-Roßlau. The same pattern was found in Dresden, though not significant (Tab. 4). Additionally, the fre-
frequency of trees with microhabitats was considerably higher in F. pennsylvanica than in F. excelsior and Q. robur in both cities (Tab. 4). Thereby, mistletoes (Viscum album L.) and different types of crown deadwood were the most frequent microhabitats found in Dresden. In Dessau-Roßlau, microhabitats were even exclusively found on F. pennsylvanica. Here, mistletoes and high lichen cover were the only microhabitats present (Tab. 4).

**Discussion**

In both cities and the entire dataset of all sample trees, the impact of F. pennsylvanica on urban epiphyte diversity was not significant. In contrast to Mitchell et al. (2017) we found that most epiphytes growing on F. excelsior also occurred on F. pennsylvanica and Q. robur. At a low level of acidifying pollution, differences between tree species and even between live and dead trees are generally less pronounced (Bates & Brown 1981, Hauck 2005). While the abundance of some lichens can strongly shift due to slight variations in bark pH (Hauck et al. 2011), the ecological amplitude of many other epiphyte species enables their colonization even of trees with strongly different bark chemistry and structure (Bates & Brown 1981, Mitchell et al. 2021). Therefore, the small bark pH variations in both cities across the three tree species did not affect epiphyte community composition either, as well as their naturalization status (Mitchell et al. 2021).

Few epiphyte species preferably occurred on one tree species. Based on the total number of epiphytic lichen species, however, a cross-regional comparison between different cities and host-trees points to larger differences between the tree species but also to a high variation across the different study areas (Tab. 5). Such results, including our own study, support the findings of Richter et al. (2009) that the importance of different host tree species for epiphyte diversity also depends on the surrounding local habitat or urban landscape type. Besides, none of the available previous studies provided detailed information on the age and number of the tree specimens studied, which might contribute to the different local diversity patterns (Tab. 5).

Some additional species found in the canopy of two F. pennsylvanica trees also point on an incomplete epiphyte assessment by our trunk-based investigation, at least in Dresden. But this methodological limitation applies to all sampled trees included in the comparison. Furthermore, species confined to the tree canopy in closed forests can be expected to occur at lower trunk sections of tree individuals outside forests (Wirth et al. 2009). This is also substantiated by the different vertical epiphyte stratification on the two completely surveyed trees at different growing conditions (Tab. 3). Therefore, the share of neglected epiphyte species in urban areas may be lower than in closed forest stands (Boch et al. 2015). Consequently, surveys of the lower tree trunk sections can be sufficient for analyses of the diversity and indicator value of cryptogamic epiphytes in urban areas (Prather et al. 2018).

Most of the lichen and bryophyte species found can be classified as pollution-tolerant, i.e., toxitolerant, acidophytic or nitrophytic (Dierßen 2001, Wirth et al. 2013). They are common in settlement areas and have partly been found in previous studies on urban F. pennsylvanica in Eastern Europe (Gallé 1966, 1970, Fejčik & Stebel 2001, Matwiejuk & Chojnowska 2016). Locally noteworthy are Climacium dendroides and Zawackia viridis, which rarely occur in urban areas and are confined to the larger trees in Dresden (Tab. 2). Rarely found Flavoparmelia soredians and Parmotrema perforatum indicate climate warming (VDI 2017). Much more than host tree identity, the epiphytes found depict the imprint of...
The long-lived species, the higher frequency and diversity thus, higher age (den than in Dessau-Roßlau can mainly be bound biota. The (overall) higher micro biont, 2011: based on the description of the investigated sites; (2): F. pennsylvanica only in one location; (3): F. pennsylvanica included F. p. var. subintegerrima; F. excelsior: F. excelsior “Hessel”; no specimens of Q. robur.

Conclusions
Our study provides evidence on a low impact of the non-native tree species F. pennsylvanica on the diversity of epiphytic lichens and bryophytes in urban habitats, when compared to the two common indigenous tree species F. excelsior and Q. robur. The higher frequency of tree-related microhabitats, with significantly higher microhabitat diversity found for F. pennsylvanica compared to the two indigenous tree species, could even be potentially beneficial to the urban fauna. Therefore, in contrast to near-natural habitats of high conservation value such as alluvial hardwood forests, the use of F. pennsylvanica as ornamental tree in urban environments of central Europe should not be generally recommended. However, cross-regional conclusions are limited and further research should focus on its interaction with other taxonomic groups. The spontaneous establishment and potential spread of F. pennsylvanica in urban environments and beyond should, nonetheless, be monitored and managed.

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**Table 4 - Frequency (%) of microhabitats found on the sample trees in the two cities (classification and coding after Kraus et al. 2016).**

| Feature                                      | Dresden | Dessau-Roßlau | Code |
|----------------------------------------------|---------|---------------|------|
| % sample trees with microhabitats            | Fp: 83  | Fe: 50        | Qr: 33 |
| Diversity of microhabitats                   | 1.5 ± 0.4 a | 0.5 ± 0.2 a | 0.3 ± 0.2 a |
| Mistletoe (Viscum album)                     | 50      | -             | -    |
| Trunk cavity with ground contact             | 33      | 17            | -    |
| Dead branches / crown deadwood               | 33      | -             | 17   |
| Small trunk cavities                         | 17      | 17            | -    |
| Annual polyopes (cf. Laetiporus spec.)      | 17      | -             | -    |
| Small vertebrate nest (songbird)            | 17      | -             | -    |
| Branch hole / rot hole                       | -       | 17            | -    |
| Gallery of bore holes (cf. Hylesinus fraxini)| -       | 17            | -    |
| Liana cover >25% (Hedera helix)             | -       | -             | 17   |
| Epiphytic foliose lichen cover >25%         | -       | -             | 60   |

**Table 5 - Number of lichen species on the investigated host tree species in different cities of Europe and North America.**

| City          | Total | Fp | Fe | Qr | Site hemeroby | Reference          |
|---------------|-------|----|----|----|---------------|--------------------|
| Szeged (HUN)  | 24    | 3  | 24 | 11 | 2-3           | Matwiejuk & Chojnowska (2016)[51] |
| Dresden (D)   | 20    | 6  | 11 | 11 | 2             | Gallé (1970)       |
| Dessau-Roßlau (D) | 19 | 9  | 15 | 11 | 1-3           | This study         |
| Chicago (USA) | 18    | 13 | 11 | 8  | 2-3           | Hyerczyk (2005)[52] |
| Szeged (HUN)  | 16    | 15 | 7  | -  | 2             | Gallé (1966)       |

(past) pollution, together with recent eutrophication and over-warming of urban areas. These factors lead to both impoverishment and homogenization of epiphyte communities (Stapper & John 2015, Liška & Herben 2008).

While epiphytic lichens and bryophytes were documented by direct surveys in this study, the possible occurrences of other taxa can be estimated from structural tree attributes (Paillet et al. 2018). So far, the higher frequency and significantly higher diversity of microhabitats found on urban F. pennsylvanica compared to the two indigenous tree species (Fig. 2) points to a certain ecological significance for tree-bound biota. The (overall) higher microhabitat diversity on sample trees in Dresden than in Dessau-Roßlau can mainly be attributed to their larger dimensions and, thus, higher age (Paillet et al. 2019).

In comparison to the two indigenous tree species, the higher frequency and diversity of microhabitats may be due to the pioneer character and shorter life span of F. pennsylvanica (125-150 yrs – Schmiedel 2011). This could lead to faster ageing and more timely creation of microhabitats compared to the intermediate F. excelsior and the long-lived Q. robur. This is also substantiated by the results for Dessau-Roßlau. Here, among the younger-aged sample trees, only F. pennsylvanica had evolved any microhabitats at all. Within the Dresden dataset, microhabitat frequency and diversity was higher in F. pennsylvanica (though not statistically significant in the case of microhabitat diversity) than on the two indigenous tree species. However, data on indigenous animal species which actually use such microhabitats on F. pennsylvanica in general, are widely lacking (Mitchell et al. 2017). In Dresden, we at least encountered an active wasp hive in a trunk cavity of F. pennsylvanica and a bird nest on twigs. The aforementioned over-aged F. pennsylvanica specimen in Dessau-Roßlau (Tab. 3) had a hollow trunk and accompanied a Hornet hive (Vespa cabro L.) in 2017. On declining specimens in Dresden, not included in the sampling, we observed woodpecker holes (Dendrocopos major L.). In central German alluvial hardwood forests, F. pennsylvanica is also used by several cave-nesting bird species (Krause et al. 2008). However, in alluvial hardwood forests, indigenous taxa might yet use indigenous trees to a disproportionately higher degree than non-native tree species (Smith & Finch 2014).

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