Epiphytic bryophytes and lichens in Graz and Podgorica (Austria and Montenegro)

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In Graz (Austria) and Podgorica (Montenegro), epiphytic lichens and bryophytes were studied in 2017 based on a standardized approach. On 165 trees in Graz, 27 bryophyte and 38 lichen species were determined. In Podgorica, on 161 trees, 29 bryophyte and 52 lichen species were found. The mean epiphytic cover in Graz was significantly higher. Mean bryophyte cover was higher in Podgorica, mean lichen cover was significantly higher in Graz. Many species occurred in both cities. The mean species number per plot was nearly the same in both cities. Five urban habitat types were distinguished: parks, garden city, residential area, industrial area, and areas along rivers. Mean species numbers of lichens and bryophytes differed significantly between phorophyte species. The tree trunk circumference had no significant impact on the species number. Bryophytes preferred a northern and western exposition on the tree trunk. For lichens, this pattern could not be confirmed. *Agonimia opuntiella*, *Caloplaca cerinelloides*, *Candelariella viae-lacteae*, *Catapyrenium psoromoides*, and *Mycobilimbia epixanthoides* were reported for the first time in Montenegro.

Zusammenfassung: Sündhofer, R., Mayrhofer, H., Werth, S., Dragićević, S. & Berg, C. 2021. Epiphytsche Moose und Flechten in Graz und Podgorica (Österreich and Montenegro). – Herzogia **34**: 299–326.

In Graz (Österreich) und Podgorica (Montenegro) sind im Jahr 2017 epiphytische Flechten und Moose nach einer standardisierten Methode untersucht worden. Auf 165 Bäumen in Graz sind 27 Moos- und 38 Flechtenarten bestimmt worden. Der durchschnittliche Deckungsgrad der Epiphyten war in Graz deutlich höher, wobei die Moose einen höheren Deckungsgrad in Podgorica, die Flechten einen höheren in Graz aufwiesen. In Podgorica sind auf 161 Bäumen 29 Moos- und 52 Flechtenarten gefunden worden. Etliche Arten kamen in beiden Städten vor. Die mittlere Artenzahl pro Aufnahmefläche war in beiden Städten beinahe gleich. Die Städte sind in fünf verschiedene urban geprägte Stadttypen eingeteilt worden: Parks, Gartenstädte, Wohngebiete, Industriegebiete und Gebiete entlang von Flüssen. Die mittlere Artenzahl von Flechten und Moosen war signifikant unterschiedlich je nach Baumart. Der Umfang von Baumstämmen hatte keinen signifikanten Einfluss auf die Artenzahl. Moose bevorzugten nördliche und westliche Exposition am Baumstamm. Für Flechten konnte dies nicht bestätigt werden. *Agonimia opuntiella*, *Caloplaca cerinelloides*, *Candelariella viae-lacteae*, *Catapyrenium psoromoides* und *Mycobilimbia epixanthoides* sind Neufunde für Montenegro.

Key words: Epiphytes, tree bark, urban ecology, cities.

Introduction

Different prognoses show that by 2050, about 70 % of the global human population will live in cities. The development of urban biocoenoses, habitats and ecosystems could be a key feature of nature conservation strategies in the future, and constitute an important research field in urban ecology. The city structure varies depending on the degree of soil sealing and the human use of an area. The ecological influences change significantly from the edge to the center of a city. Different small-scale niches and ecological gradients, and the absence of typical threat factors of our agricultural landscape (fertilization, use of agrochemicals, hunting) allow different plant and animal groups to live in the cities, partly in high species numbers and abundances (Reichholf 2007).

In all cities of the world where the climate allows tree growth (in arid areas facilitated by irrigation), trees are important elements of urban design. They are valued as shade providers, temperature controllers, humidifiers and air filters (Tzoulas et al. 2007), often enhanced by epiphytic plants (Frahm et al. 2007). In temperate and Mediterranean climate zones, lichens, mosses and liverworts represent the most important epiphytes (Zotz & Bader 2009).

Epiphytic cryptogam communities are influenced by several environmental factors. Important climatic factors are radiation, temperature and precipitation and their seasonality, as well as air humidity and wind (Frahm 1998, Dietrich & Scheidegger 1996). In urban environments, the macroclimate of the particular region as well as light and shade are strongly altered by the location of the tree and the surrounding buildings (meso- and microclimate). A tree provides several environmental particularities like shade, and especially diversification in structure, nutrient content, reaction (pH-value) and water content of the bark itself as a substrate for epiphytic communities (Engel et al. 2003). Some environmental factors are special for urban environments, like higher minimum temperatures, reduced air humidity, increased air pollution and aerosol concentration, salt spray during winter and irrigation during summer (Schubert 1984).

The gas, water and nutrient transport of epiphytic cryptogam species functions through the organism´s surface exposed directly to the air (Frahm 1998, Wirth 2002). Therefore, epiphytic cryptogams are particularly appropriate indicators of abiotic parameters and highly useful in long-term monitoring approaches (Frahm et al. 2007).

This study has been carried out to improve the knowledge of epiphytes of two cities in two different climatic regions. As the University of Graz has a long-term cooperation with the University of Montenegro and the Museum of Natural History in Podgorica, preliminary studies in former years showed significant differences in the epiphyte flora of the two cities. From this, the idea was born to investigate these differences in more detail. As the number of bryophyte species decreases from Central Europe to the Mediterranean region (Frahm 2010), we started with the hypothesis that the epiphyte flora in Podgorica is impoverished compared to that of Graz. In Graz, the epiphytic lichen flora was an issue of repeated studies starting with Ehrendorfer et al. (1971) and Grill et al. (1988). Wilfling et al. (2003) provided a comprehensive analysis of the epiphytic lichen flora of Graz in relation air pollution. The bryophyte flora was only sporadically investigated. Teutsch (2010) collected bryophytes on the Grazer Schlossberg and in the Botanical Garden of Graz. However, her aim was to investigate the diversity of bryophytes on all substrates. In the city area of Podgorica only some special parts were previously studied (Anđić et al. 2013), but comparable data on epiphytes does not exist.

The aim of this study was to get a deeper insight in the ecological conditions of epiphytic species of the two cities under different climate conditions by applying a standardized sampling design. We classified different structured parts of the cities according to Lososová et al. (2012) in habitat types (described in Material and Methods). These urban habitat types are influenced by different level of sealing, traffic and other external factors. These could have on influence on epiphytes cover and diversity. With this study we wanted to answer the following questions: How high is the epiphyte species diversity in the two cities? What are the differences in species composition and abundance between both cities? Do the different habitat types and tree species influence the epiphytic species composition? Does the exposition of an epiphyte sampling plot have an impact on species richness and cover? Are there differences in the ecological requirements between bryophytes and lichens?

Study areas

Graz

Graz is a city with approximately 289,000 inhabitants in southeastern Austria, about 150 km in the Southwest of Vienna, and covers an area of 127.5 km². This equals a population density of 22.6 inhabitats/ha. It lies on the foothills of the Alps; in the West, North and East mountains of the Grazer Bergland surround Graz. In the South, the area opens into an alluvial basin and the Styrian lowlands. Graz ranges from 330 m to 754 m above sea level. The river Mur separates the city into an eastern and a western part.

Graz is affected by the Illyrian climate, which is a transition of the Mediterranean, Alpine and Pannonian climates (Figure 1).

The potential natural vegetation of Graz (WAGNER 1985) is the Querco-Carpinetum with *Carpinus betulus*, *Quercus petraea*, and *Tilia cordata*, and a submontane Querco-Fagetum with *Fagus sylvatica*, *Quercus robur*, *Tilia* ssp., *Acer* ssp., *Fraxinus excelsior*, *Ulmus glabra* and *Carpinus betulus*. We found all these tree species as city trees during our investigation, most of them planted or in over-used forest remains. Floodplain forests such as Salicetum albae, Fraxino-Populetum and Fraxino-Ulmetum would potentially grow along the Mur (WILLNER & GRABHERR 2007).

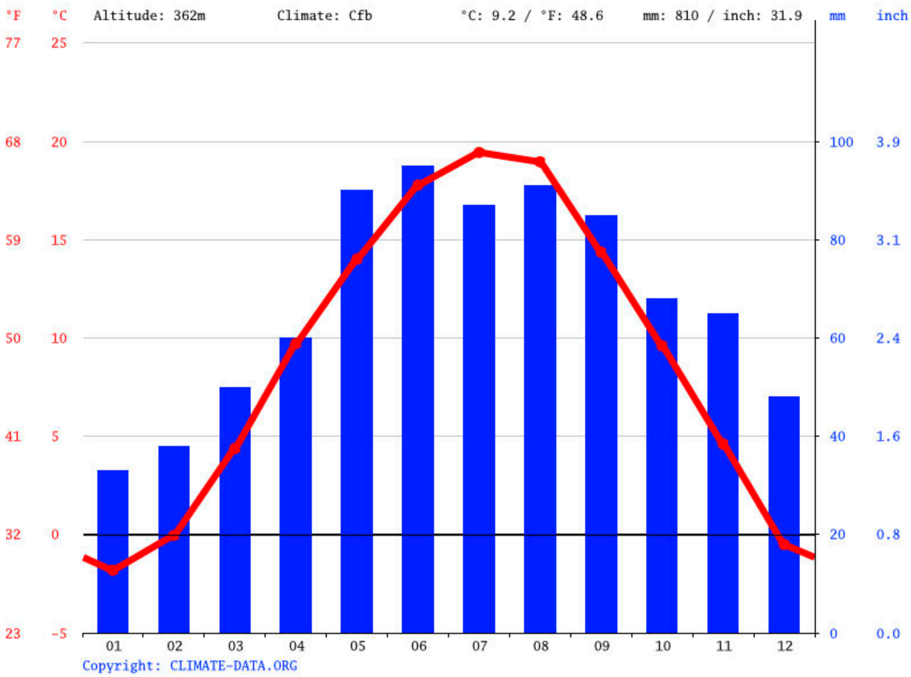

Fig. 1. The climate diagram shows the warm and wet summers and cold and drier winters with frost and snow. Precipitation occurs mainly in the summer months (https://de.climate-data.org/).

Podgorica

Podgorica is the capital of Montenegro. The city lies about 15 km in the North of the Lake Skadar and has about 190,000 inhabitants and an area of 54.3 km², with a population density of 35 inhabitats/ha. The largest part of Podgorica – Skodra valley as well as the northwestern, northern and eastern parts of the surrounding mountain slopes (Kučke and Piperske mountains), belong to Podgorica, as well as the hills of the Lješanska nahija (Radojičić 1996, 2002). Its altitude ranges from 40 m up to about 280 m above sea level. The area of Tuzi – which was part of the city of Podgorica – became an independent municipality in 2018. At the time of our study there was no precise official map of the city of Podgorica available, so we had to make our own decisions about certain border courses.

The hydrological network consists of the river Morača and its tributaries: Zeta, Cijevna, Ribnica, Matica, and Sitnica as well as the Mareza spring (Ičević 2003). The climate of Podgorica is moderate Mediterranean, with a distinct winter precipitation regime. Parts of the Dinaric Mountains separate Lake Skadar and Podgorica from the Adriatic Sea.

Figure 2 shows that Podgorica has a moderate Mediterranean climate, with a strong winter precipitation regime. The annual precipitation is higher than in most of Mediterranean regions.

Podgorica is located in the Rusco-Carpinetum orientalis zone (alliance Carpinion orientalis, order Quercetalia pubescentis), but due to constant degradation (cutting, fires and grazing), only fragments of natural vegetation are still present at some microlocalities on the city's hills. The flora and vegetation of Podgorica was previously recorded as scrub and forest communi-

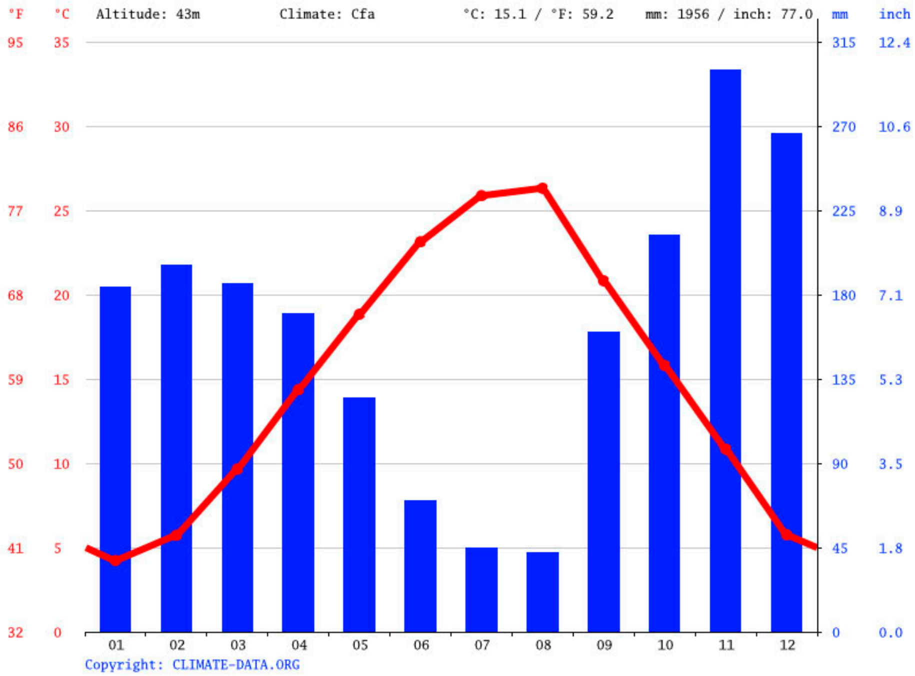

Fig. 2. The climate diagram shows hot and dry summers and mild and wet winters; frost is rare and snow is usually lacking. Precipitation occurs mainly in the winter months, and is extraordinarily high for a Mediterranean location (https://de.climate-data.org/).

ties: Paliuretum adriaticum, Rusco-Carpinetum orientalis, and Quercetum trojanae montenegrinum. A major part of the city area (city parks) has been forested with Aleppo pine (*Pinus halepensis*), black pine (*Pinus nigra*) and cypress (*Cupressus sempervirens*, Čurović et al. 2003, Stešević & Jovanović 2008, Stešević et al. 2014).

Comparison of Graz and Podgorica

Graz and Podgorica share some features. Both cities lie in the zone of deciduous broadleaf forest, with Podgorica on its southern edge. Both are limestone areas parted by a river and they are surrounded by hills and mountains. But, lots of differences are striking: both average temperature as well a consisting mostly s precipitation in Podgorica is distinct higher as in Graz. The vegetation of Graz is under the influence of frost, in Podgorica frost is extremely rare. The potential natural vegetation of both cities also differs due to their distinct species pools.

Material and Methods

Urban habitat types

We classified both city areas according to urban habitat types. The most important criterion was the density of ground sealing by structural development. Among the different urban habitat types, ecological conditions can vary drastically. We adapted the urban habitat types of Lososová et al. (2012) and distinguished among five different categories in Graz and Podgorica with the help of aerial photographs:

Industrial area: This habitat type consists of > 90% sealed areas with scattered planted trees which are rather young. Factories, construction sites, traffic and railway zones, business sites, waste disposal sites and abandoned construction or building sites are the most common features in this urban habitat type.

Park: These are vegetated areas which mostly consist of planted, often not autochthonic trees and shrubs. Frequently mowed and maintained lawns usually cover the ground. We include cemeteries and small over-used forest remains in this urban habitat type. In Graz, most of the Parks with deciduous trees do not need extra watering. In the inner parts of Podgorica, the parks are often irrigated. Here, deciduous trees are dominant; while the large Parks outside the center are dominated by conifers like *Pinus halepensis*.

Residential area: This is the typical face of a city. It is composed of continuous rows of apartment buildings or multistory blocks surrounding large green backyards. There are wide streets and access roads and lots of citizens live here. The city centers of Podgorica and Graz are included in this category. The old towns of the cities are rather small and have a high degree of sealing. There are nearly no trees. Our category is a combination of “Historical city square” and “Residential area with compact building pattern” of Lososová et al. (2012).

Areas along rivers (Mur/Morača): Along the Mur is a green belt of narrow remnants of riparian forests with *Salix fragilis* (including *Salix* × *rubens*), *Salix alba*, *Populus nigra* and *Ulmus laevis*. Along the Morača it was not easy to find trees which fit the collecting requirements defined in the sampling design (e.g. 80 cm minimum trunk circumference). The most common tree species here, *Ficus carica*, grows more like a shrub and is nearly without epiphytes. Additionally, it is difficult and dangerous to reach the trees down in the canyon. Due to low numbers of sampled trees we excluded the Areas along rivers of Podgorica from most of the habitat type analyses.

Garden City: This area combines the “Residential area with open building pattern” and the “Boulevard with 19th-century houses” by Lososová et al. (2012). In both cities, these areas mostly consist of small family houses surrounded by private gardens. In Graz, it also includes “villa quarters” with large villa houses and private gardens. During the sampling process it becames clear that access was mostly denied or very time-consuming. In Graz two trees, and in Podgorica no trees, were sampled. We excluded Garden City from most of the habitat type analyses.

The distribution of the urban habitat types is shown in the city maps (Figure 3 and Figure 4). Areas not belonging to any of the urban habitat types (remains of the natural landscape, managed forests or agricultural areas) were excluded. Residential areas are mainly located in the central part of the cities, while Garden city areas are peripheral. In Graz, many small parks can be found, while in Podgorica, a few large park areas are distributed over the whole city area. Industrial areas are concentrated from the middle to the south of the cities.

Table 1 shows the area of the different urban habitat types in Graz and Podgorica. Podgorica is about 70 km² smaller than Graz. The areas of Garden city, Residential area, Industrial area and Areas along rivers in Podgorica are smaller than in Graz. Only the area of Parks is larger in Podgorica. The percentage data mostly reflect these ratios. In Graz, 84.2 % of the whole area falls within urban habitat types – in Podgorica 73.4 %.

Sampling design

We used an adapted sampling method based on Frahm et al. (2007), who recommended a standardized method for the collection of bryophytes as bioindicators. Some changes of this method were necessary to adapt it to our resources and the specific conditions of the two cities. We did not use a grid net, but applied a stratified systematic sampling design by trying to sample at least 30 trees in every urban habitat type. Also, for two reasons, we did not limit

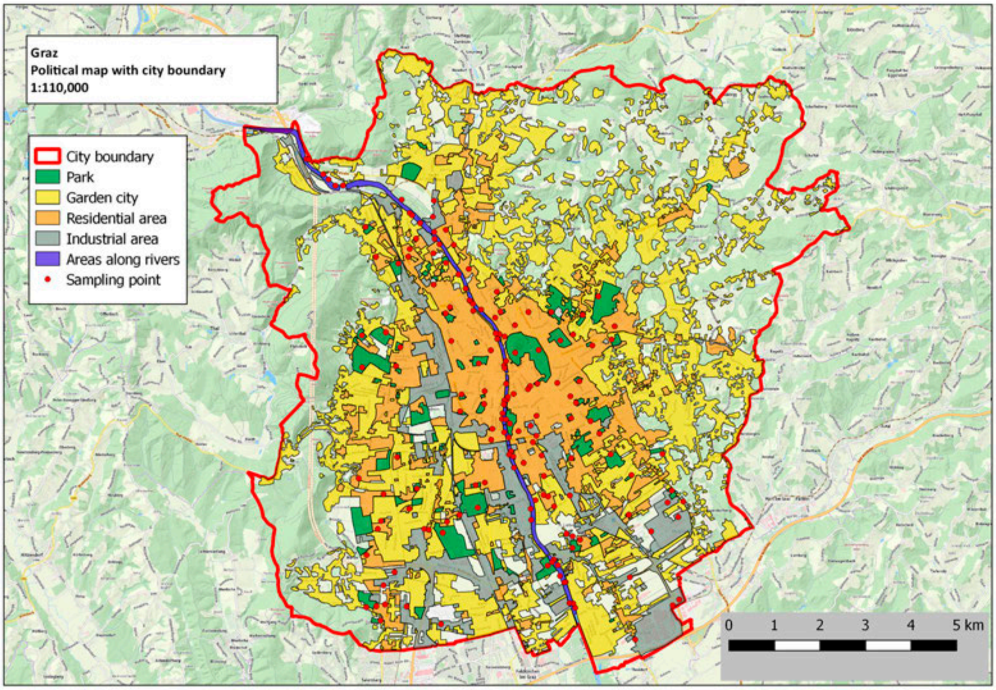

Fig. 3. The political map of Graz created with QGIS (QGIS Development Team 2014, political map of basemap.at) shows the official area of the city with the urban habitat types. The red points represent the sampled trees.

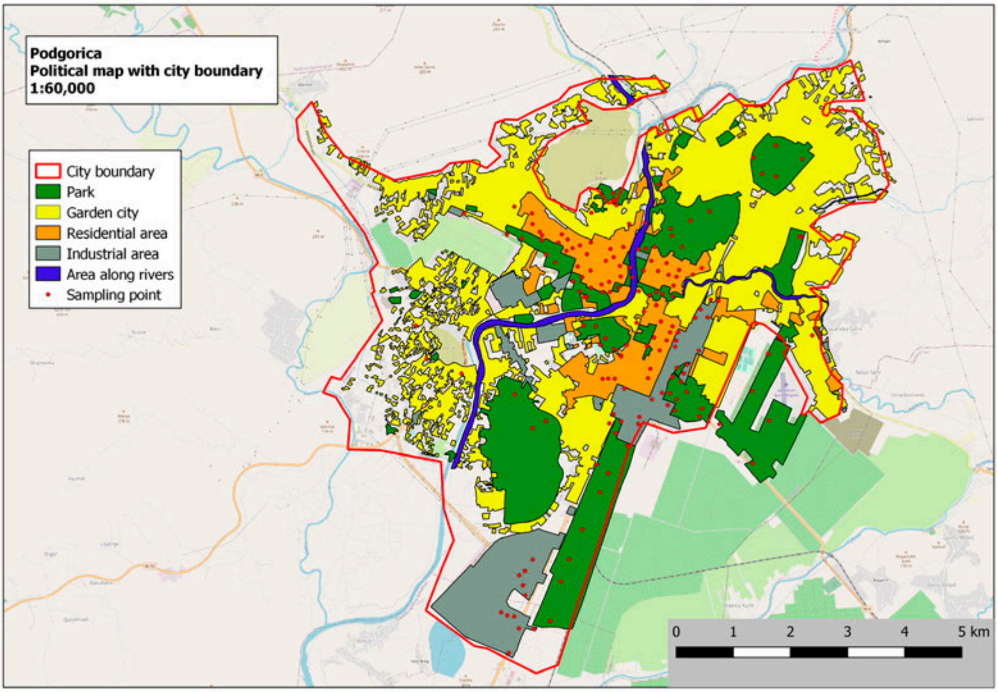

Fig. 4. The political map of Podgorica created with QGIS (QGIS Development Team 2014, political map of Map Server of Crne Gore) shows the area of the city which was considered in the study with the urban habitat types. The red points represent the sampled trees.

Table 1. Area size of the urban habitat types of Graz and Podgorica (in km² and percentage).

	Graz		Podgorica	
	km²	**%**	**km²**	**%**
Whole considered city area	127.5	100	54.3	100
Park	7.0	5.5	11.3	20.8
Garden city	54.6	42.8	19.3	35.6
Residential area	29.1	22.8	4.6	8.5
Industrial area	14.8	11.6	3.6	6.6
Areas along rivers	1.8	1.4	1.0	1.8
Sum of urban habitat type areas	**107.3**	**84.2**	**39.8**	**73.4**

our sampling to a specific group of deciduous tree species with high bark pH-value as recommended in FRAHM et al. (2007). First, there were no common tree species that were found in both cities; and second, we were interested in the influence of tree diversity on the epiphyte flora in general. Therefore, we included all available tree species in the study: in Graz only deciduous trees, but in Podgorica also conifers like *Pinus halepensis*, *Pinus nigra* or *Cupressus sempervirens* are very common and were chosen for sampling.

Although a stratified systematic sampling design was applied, the 30 sampling trees inside each urban habitat type had to be chosen subjectively in the field. The decision was based on the following parameters:

Bryophyte and lichen occurrence: The tree had to have at least small patches of bryophytes and/or lichens on the trunk at one of the four cardinal directions.

Solitary: The tree had to be solitary (free-standing, Frahm et al. 2007). Shading influence of other trees or buildings was noted. Here, 100-% meant no shading influence and thus a completely solitary tree. If the light was reduced by 20-%, 80-% free-standing was noted. Sometimes it was not easy to find a tree not influenced by shadow. Densely planted parks and porch-roof covered trees with 0-% were excluded.

Uprightness: The tree could not be inclined (Frahm et al. 2007). The angle of slope had to lie between 0 and 10 degrees. Only along the river Mur, trees with up to 20° obliqueness were sampled, as it was not possible to find upright trees there.

Trunk circumference: The trunk circumference had to range between 80 cm minimum and 210 cm maximum based on Frahm et al. (2007). We slightly raised the lower limit compared to Frahm et al. (2017) from 70 to 80 cm because our sample plots in every cardinal direction had a width of 20 cm.

Healthiness: The trees could not be injured, affected or damaged (Frahm et al. 2007).

In both cities, no tree fulfilled all these requirements. We therefore sampled the trees which fulfilled the largest possible number of requirements.

Number of sampled trees

We sampled 326 trees – 165 in Graz and 161 in Podgorica (Table 2), yielding 1304 plots, 326 in each cardinal direction. It was not possible to sample more than 30 trees in every urban habitat type. In Graz we sampled fewer trees in the Industrial area (lack of old enough trees) and only two trees in the Garden City (not open to the public). In Podgorica no trees in the Areas along rivers (not accessible and trunk circumference below minimum) and in Garden cities (not open to the public) were sampled.

Table 2. The number of trees sampled in Graz and Podgorica in the different urban habitat types is shown.

	Number of trees	
	Graz	**Podgorica**
Industrial area	19	51
Park	48	55
Residential area	48	55
Areas along rivers	48	0
Garden city	2	0
Sum	**165**	**161**

Sampling process

As sample plot we used a square with a size of 20 x 20 cm = 400 cm² = 0.04 m² (Berg et al. 2016). We positioned the lower margin of the square at a height of 140 cm in all four cardinal directions. This approach led to a more specific epiphytic flora than the 100 cm height recommended by Frahm et al. (2007). The lower the sample plot is positioned, the more species that prefer growing on the ground or on the trunk base are included in samples. With the help of a field template, we recorded all species with percentage cover in the plot. Poorly identifiable species were collected after checking them with a 10x hand lens. In addition to usual field data (like date, exposition, GPS coordinates), we collected the following specific variables: urban habitat type, tree species, trunk circumference [cm], distance to the next sealed area [m], solitariness [%] and uprightness [°].

Nomenclature references

The nomenclature of bryophytes follows Hodgetts & Lockhart (2020), the nomenclature of lichens follows Nimis et al. (2018), and the nomenclature of trees Roloff & Bärtels (2014).

Statistical analysis

All collected data were stored in Turboveg for Windows 2.0 (Hennekens & Schaminee 2001). The dataset was analyzed with the software Juice 7.0 (Tichý 2002) and PAST 2.17 (Hammer et al. 2001). Synoptic tables were presented using the percentage frequency of the species. We estimated species preference for a cluster with the help of the species fidelity (Chytrý et al. 2002), implemented in Juice. Fidelity was calculated as phi-value with a threshold phi > 19 marked in the tables. For any correlation analysis we used the non-parametric Spearman's rank correlation with a two-tailed t-test. We applied the Kruskal–Wallis test for comparing cover values or species data. As level of significance we took $p<0.01$. We also used Ellenberg´s soil reaction indicator values for bryophytes and lichens (Ellenberg et al. 2001) weighted by species cover.

Results

Floristic results

The full species list presented in Table 3 (bryophytes) and Table 4 (lichens) includes 112 species: 43 bryophytes and 69 lichens. Taxa determined at genus level only are included in the list when no other species of that genus could be found, like *Bacidia* spec. and *Cladonia* spec. Individuals determined at genus level are only included in statistical analysis of species numbers and cover, but excluded in the synoptic floristic analysis. Including these taxa, our list counts 44 bryophyte taxa, 79 lichen taxa and a total of 123 taxa. On the species level, in Graz we found 27 epiphytic bryophytes and 38 lichens, and in Podgorica 29 epiphytic bryophyte species and 52 lichen species.

We found 14 bryophyte species only in Graz, 16 only in Podgorica and 13 in both cities (Table 3). Among the epiphytic bryophytes only found in Graz were e.g. *Leskea polycarpa*, *Lewinskya speciosa*, *Nyholmiella obtusifolia*, *Orthotrichum stramineum*, *Pseudoamblystegium subtile*, *Pylaisia polyantha*, *Radula complanata*, *Syntrichia virescens* and *Zygodon viridissimus*, species adapted to a more balanced temperate climate. *Didymodon rigidulus*, *Schistidium crassipilum* and *Syntrichia ruralis* occur normally mainly on walls and concrete, typical urban habitats. Examples for epiphytic bryophytes only occurring in Podgorica are *Cryphaea heteromalla*, *Fabronia pusilla*, *Habrodon perpusillus*, *Leptodon smithii*, *Lewinskya acuminata*, *Orthotrichum tenellum*, and *Syntrichia pagorum*. All these are characterized by a southern distribution. Species with a focus on rocky substrates in Podgorica are *Grimmia pulvinata* and *Lewinskya rupestris*. Remarkable is the epiphytic occurrence of Cinclidotiaceae-species, *Dialytrichia mucronata* and especially *Cinclidotus fontinaloides*. The latter was found epiphytic in 15 plots (2.3 % of all plots in Podgorica) on seven trees (4 % of all trees in Podgorica).

We found 17 lichen species only in Graz, 31 only in Podgorica and 21 in both cities (Table 4). Epiphytic lichens only found in Graz during our study are *Lecania cyrtella*, *Lecania fuscella*, *Lecania naegelii*, *Lecanora carpinea*, *Melanohalea exasperatula*, *Phaeophyscia nigricans*, *Physcia stellaris*, *Punctelia jeckeri*, *Ramalina pollinaria*, and *Xanthomendoza huculica*. Lichens found only in Podgorica are the cyanolichens *Collema furfuraceum*, *Collema*

Table 3. Full species list of 43 bryophytes found on tree bark in Graz (**G**) and Podgorica (**P**) during this study**, bold numbers** indicate, that this species has been found in only one city.

	G	P			G	P
Total number of plots	660	644		*Lewinskya acuminata*	.	**66**
Bryophyte species number	27	29		*Lewinskya affinis*	78	1
Mean species/plot	5,2	5,1		*Lewinskya rupestris*	.	**15**
Mean cover%	26	21		*Lewinskya speciosa*	**29**	.
Mean bryophyte species/plot	2,7	3,0		*Lewinskya striata*	1	22
percentage bryophyte species/plot%	48	51		*Metzgeria furcata*	.	**1**
Mean bryophyte cover%	11	15		*Nyholmiella obtusifolia*	**250**	.
				Orthotrichum diaphanum	407	229
Amblystegium serpens	**28**	.		*Orthotrichum patens*	32	1
Bryum argenteum	.	**2**		*Orthotrichum pumilum*	328	151
Cinclidotus fontinaloides	.	**15**		*Orthotrichum stramineum*	**2**	.
Cryphaea heteromalla	.	**1**		*Orthotrichum tenellum*	.	**84**
Dialytrichia mucronata	.	**39**		*Pseudoamblystegium subtile*	**2**	.
Dicranoweisia cirrata	.	**28**		*Ptychostomum capillare* agg.	2	9
Didymodon rigidulus	**1**	.		*Ptychostomum moravicum*	1	1
Eurhynchium striatum	.	**1**		*Pulvigera lyellii*	2	70
Fabronia pusilla	.	**75**		*Pylaisia polyantha*	**129**	.
Frullania dilatata	5	59		*Radula complanata*	**14**	.
Grimmia pulvinata	.	**5**		*Schistidium crassipilum*	**1**	.
Habrodon perpusillus	.	**101**		*Syntrichia laevipila*	2	215
Homalothecium sericeum	.	**19**		*Syntrichia pagorum*	.	**220**
Hypnum cupressiforme	12	83		*Syntrichia papillosa*	328	310
Isothecium alopecuroides	**1**	.		*Syntrichia ruralis*	**2**	.
Leptodon smithii	.	**62**		*Syntrichia virescens*	**1**	.
Leskea polycarpa	**96**	.		*Zygodon viridissimus*	1	.
Leucodon sciuroides	2	28				

nigrescens, *Collema subflaccidum*, and *Scytinium lichenoides* which occur in humid sites, further *Amandinea punctata*, *Lecanora symmicta*, *Lecanora leuckertiana*, *Mycobilimbia epixanthoides*, *Parmelina pastillifera*, *Parmelina quercina*, *Parmotrema perlatum*, *Physcia dubia*, *Physconia perisidiosa*, *Punctelia borreri*, *Punctelia subrudecta*, *Rinodina pyrina*, and *Trapeliopsis flexuosa*, and the Mediterranean *Physcia biziana*.

Lichens new for Montenegro:

The five lichen species *Agonimia opuntiella*, *Caloplaca cerinelloides*, *Candelariella viae-lacteae*, *Catapyrenium psoromoides* and *Mycobilimbia epixanthoides* are new for Montenegro.

Agonimia opuntiella was found on seven different sites (on *Styphnolobium japonicum*, N42,43837, E19,26282; on *Cupressus sempervirens*, N42,43962, E19,25032; on *Acer platanoides*, N42,4265, E19,22252; on *Melia azedarach*, N42,44233, E19,25028; on *Tilia tomentosa*, N42,4421, E19,26467; on *Robinia pseudoacacia*, N42,44222, E19,26912; and on *Cupressus sempervirens*, N42,43892, E19,25432).

Caloplaca cerinelloides was determined on three tree species (on *Cupressus sempervirens*, N42,4268, E19,26268; on *Celtis australis*, N42,44547, E19,2452; and on *Melia azedarach*, N42,43013, E19,26805).

Candelariella viae-lacteae was found on nine sites: on *Cupressus sempervirens*, N42,4268, E19,26268; on *Celtis australis*, N42,4468, E19,2435; on *Acer saccharinum*, N42,42538, E19,25371; on *Melia* *azedarach*, N42,4347, E19,27503; on *Melia azedarach*, N42,4274, E19,27055; on *Melia azedarach*, N42,43013, E19,26805; on *Tilia tomentosa*, N42,42377, E19,2571; on *Cupressus sempervirens*, N42,41817, E19,25993; and again on *Cupressus sempervirens*, N42,41925, E19,26022.

Catapyrenium psoromoides was found on seven sites on *Tilia tomentosa*, N42,44133, E19,25665; on *Pinus nigra*, N42,43853, E19,26546; on *Melia azedarach*, N42,44298, E19,24756; on *Melia azedarach*, N42,44855, E19,23958; on *Melia azedarach*, N42,38876, E19,23022; on *Tilia tomentosa*, N42,4421, E19,2646; and on *Robinia pseudoacacia*, N42,44222, E19,26912.

Mycobilimbia epixanthoides was found once on *Paulownia tomentosa* (N42,4444, E19,25525).

Table 4. Full species list of 69 lichens found on tree bark in Graz (**G**) and Podgorica (**P**) during this study**, bold numbers** indicate that this species has been found in only one city.

	G	P			G	P
Total number of plots	660	644		*Lepraria incana*	**1**	.
Lichen species number	38	52		*Lepraria rigidula*	**1**	.
Mean species/plot	5,2	5,1		*Lepraria* spec. div.	.	**14**
Mean cover %	26	21		*Melanelixia glabratula*	2	1
Mean lichen species/plot	2,5	2,0		*Melanelixia subaurifera*	**1**	.
percentage lichen species/plot %	46	42		*Melanohalea exasperatula*	**12**	.
Mean lichen cover %	15	7		*Mycobilimbia epixanthoides*	.	**1**
				Myriolecis dispersa	1	6
Agonimia opuntiella	.	**8**		*Myriolecis hagenii*	1	1
Amandinea punctata	.	**120**		*Normandina pulchella*	1	40
Bacidia spec.	**2**	.		*Parmelia sulcata*	20	2
Caloplaca cerinelloides	2	5		*Parmelina pastillifera*	.	**5**
Candelaria concolor	239	189		*Parmelina quercina*	.	**1**
Candelariella aurella	**1**	.		*Parmelina tiliacea*	1	1
Candelariella cf. *medians*	**1**	.		*Parmotrema perlatum*	.	**1**
Candelariella reflexa	246	194		*Pertusaria flavida*	.	**1**
Candelariella viae-lacteae	.	**16**		*Phaeophyscia nigricans*	**35**	.
Candelariella xanthostigma	5	14		*Phaeophyscia orbicularis*	386	211
Catapyrenium psoromoides	.	**9**		*Phlyctis argena*	.	**2**
Catillaria nigroclavata	24	21		*Physcia adscendens*	228	16
Cladonia spec.	.	**1**		*Physcia aipolia*	.	**1**
Collema furfuraceum	.	**12**		*Physcia biziana*	.	**74**
Collema nigrescens	.	**3**		*Physcia dubia*	.	**1**
Collema subflaccidum	.	**9**		*Physcia stellaris*	**10**	.
Flavoparmelia caperata	.	**1**		*Physcia tenella*	17	2
Fuscidea stiriaca	.	**1**		*Physciella chloantha*	162	66
Hyperphyscia adglutinata	41	35		*Physconia perisidiosa*	.	**11**
Hypogymnia tubulosa	**1**	.		*Physconia distorta*	3	6
Lecania cyrtella	**8**	.		*Physconia grisea*	1	3
Lecania fuscella	**11**	.		*Punctelia borreri*	.	**3**
Lecania naegelii	**6**	.		*Punctelia jeckeri*	**2**	.
Lecanora allophana	.	**3**		*Punctelia subrudecta*	.	**4**
Lecanora argentata	.	**3**		*Ramalina pollinaria*	**3**	.
Lecanora carpinea	**10**	.		*Rinodina pyrina*	.	**4**
Lecanora chlarotera	1	10		*Scytinium lichenoides*	.	**9**
Lecanora glabrata	.	**1**		*Trapeliopsis flexuosa*	.	**5**
Lecanora leuckertiana	.	**24**		*Xanthomendoza huculica*	**3**	.
Lecanora symmicta	.	**5**		*Xanthoria parietina*	129	35
Lecidella elaeochroma	14	15				

Graz and Podgorica shared 13 bryophyte species (e.g. *Frullania dilatata*, *Leucodon sciuroides*, *Lewinskya striata*, *Orthotrichum patens*, *Orthotrichum pumilum*, *Ptychostomum moravicum*, *Pulvigera lyellii*, *Syntrichia laevipila* and *Syntrichia papillosa*) and 21 lichen species (e.g. *Caloplaca cerinelloides*, *Candelaria concolor*, *Candelariella reflexa*, *Hyperphyscia adglutinata*, *Lecanora chlarotera*, *Melanelixia glabratula*, *Myriolecis dispersa*, *Myriolecis hagenii*, *Normandina pulchella*, *Parmelina tiliacea*, *Physciella chloantha*, and *Xanthoria parietina*). The most frequent species of both cities are shown in Table 5.

Epiphytic diversity and cover of Graz and Podgorica

Among all plots of this study, 72% contained both bryophytes and lichens. In Graz 16% and in Podgorica 10 % of all plots consisted only of bryophytes, and 19% in Graz and 12% in Podgorica consisted only of lichens. The cover values of the plots showed a positive correlation with species richness (rho=0.59), and moreover, the cover values of bryophytes was positively correlated with bryophyte richness (rho=0.79), and the cover values of lichens was positively correlated with lichen richness (rho=0.77). Lichen cover was not associated with bryophyte richness (rho=0.08), and bryophyte cover was not associated with lichen richness (rho=-0.04). The median of species cover of all plots was 18%, and 95% of all plots had cover values below 65% (Figure 5).

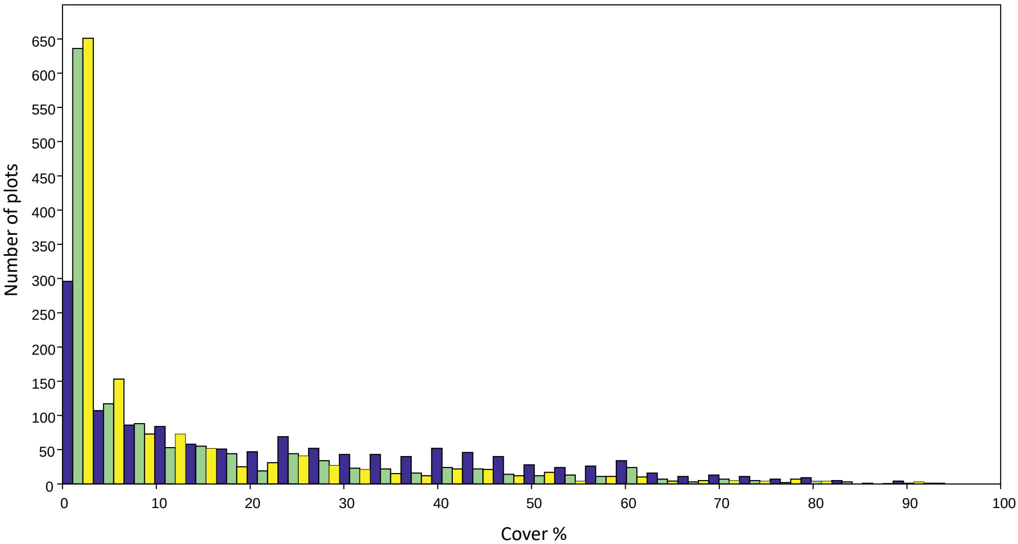

Fig. 5. Histogram of the cover values of all species (blue), bryophytes (green) und lichens (yellow). N = 1304, Bins = 28. Only trees with epiphyte cover were sampled.

With 5.2 in Graz, the mean species number per plot (α-diversity) was very similar to Podgorica (5.1) – there was no significant difference. The total species number of all plots (γ-diversity) was higher in Podgorica (90 species) than in Graz (72 species). The mean epiphytic cover in Graz (26%) was significantly higher than in Podgorica (21%). The absolute and relative bryophyte species numbers did not differ significantly, but the bryophyte cover was significantly higher in Podgorica (Table 3). Regarding lichens, absolute and relative species numbers per plot as well as lichen cover were significantly higher in Graz, while the total species number was higher in Podgorica (Table 4).

Within the urban habitat types, the mean species number per plot showed some significant differences. Table 5 is a shortened synoptic table of frequent species of all habitat types in the two cities. The table includes the most frequent species of our study in the lowest rows. Some floristic differences are visible, because some of the moderately frequent species showed a focus in one city (biogeographical region) or in one particular urban habitat. The Industrial area and the Parks in Graz had a higher α-diversity than those in Podgorica. The α-diversity of the Residential areas of Podgorica was higher. In all urban habitat types, the total number of species was higher in Podgorica. The mean cover of epiphytes in the Industrial areas was significantly higher in Graz. The epiphytic cover of Parks and Residential areas did not differ significantly.

There were some differences between bryophyte and lichen number and cover concerning the different habitat types (Table 5). In the Industrial areas, the bryophyte species number was higher in Graz, while the bryophyte cover was slightly, but significantly lower. The main differences between the industrial areas were found in the lichens, which showed significantly higher relative species number and much higher cover in Graz. Parks had more lichen species and cover in Graz, while in Podgorica, the bryophyte cover was significantly higher in Parks, but there were no significant differences in species number. Epiphytic communities in Residential areas were characterized by higher bryophyte numbers and cover in Podgorica; and by higher lichen species numbers and covers in Graz.

Comparing the epiphyte diversity in different urban habitat types within each city, the mean species number of Areas along rivers in Graz was significantly lower than in all other urban habitat types. The mean species cover generally showed no significant differences. Parks and Areas along rivers showed the lowest cover values. In Podgorica, there was no significant difference in the mean species number between the Residential areas and the Parks. In Industrial areas, the α-diversity was significantly lower. The mean species cover of all urban habitat types was significantly different: highest in Residential areas, followed by Parks and lowest in Industrial areas.

We indicated the urban influence by the distance of the sampling tree to the next sealed area. This value resulted in a weak but significant negative correlation with the mean species number and cover in both cities, implying that the proximity of sealed surfaces correlates positively with species diversity as well as with mean cover values. This indicates that the epiphytic flora in Graz and Podgorica was richer in the city centers than in the more open and less sealed marginal city zones.

The role of tree species

We sampled 38 tree species, 22 in Graz, and 25 in Podgorica (Table 6). The tree species composition was different in both cities, and only nine tree species were sampled in both cities. Industrial areas were generally less diverse. While in Graz the Residential area was especially tree species poor, in Podgorica it was especially diverse (Table 6).

For statistical analysis, we have chosen tree species with more than eight sampled individuals only (Table 7). As an exception, we combined all oak species into one *Quercus*-column consisting of ten individuals of the four oak species *Quercus ilex*, *Quercus robur*, *Quercus pubescens* und *Quercus trojana* (Table 7).

Table 5. Shortened synoptic table of percentage frequency of species in the urban habitat types of Graz and Podgorica. Frequency values with phi > 19 are framed. We omitted all species with less than 10 % frequency in any column. IA = Industrial area, P = Parks, RA = Residential area, AR= Areas along rivers, GC = Garden city. The same bold formatting in the header data indicates significant differences in the data pairs of same habitat type in the two cities.

Percentage synoptic table		**Graz**					**Podgorica**		
	%	**IA**	**P**	**RA**	AR	GC	**IA**	**P**	**RA**
Number of plots		76	192	192	192	8	204	220	220
Mean species number of plots		**6,4**	***5,7***	**5,9**	3,6	6,4	**3,3**	***4,8***	**7,0**
Total number of species		32	44	41	41	17	49	64	67
Mean species cover %		**33**	23	31	21	41	**14**	20	29
Mean bryophyte number		**2,2**	3,2	**2,8**	2,4	3,4	**1,6**	2,8	**4,6**
Mean lichen number		**4,2**	***2,5***	**3,1**	1,3	3,0	**1,7**	***2,0***	**2,3**
Rel. bryophyte number %		33	51	**46,9**	51	48	35	49	**66,8**
Rel. lichen number %		**67**	46	**50,5**	34	52	**53**	43	**33,2**
Mean cover bryophytes %		**6**	***9***	**9,9**	16	10	**7**	***16***	**21,1**
Mean cover lichens %		**29**	***14***	**22,4**	5	33	**8**	***5***	**9,3**
Tree species sampled		8	14	8	13	2	11	15	18
Xanthoria parietina	164	67	11	27	2	13	6	4	6
Lecanora carpinea	10	12	1	.	.	.	.	.	.
Lewinskya speciosa	29	11	6	5	.	.	.	.	.
Phaeophyscia nigricans	35	9	2	13	.	.	.	.	.
Leskea polycarpa	96	.	11	5	34	.	.	.	.
Physciella chloantha	228	13	16	18	44	13	8	7	16
Physcia spec. div.	83	1	3	3	4	38	10	9	10
Lewinskya affinis	79	7	17	5	14	38	.	1	.
Parmelia sulcata	22	4	6	2	.	13	1	1	.
Frullania dilatata	64	.	1	.	1	13	1	18	9
Hypnum cupressiforme	95	.	1	1	5	.	2	24	12
Syntrichia pagorum	220	.	.	.	.	.	19	26	57
Orthotrichum tenellum	84	.	.	.	.	.	6	6	26
Lewinskya acuminata	66	.	.	.	.	.	7	3	20
Dialytrichia mucronata	39	.	.	.	.	.	2	3	13
Nyholmiella obtusifolia	250	26	47	45	25	50	.	.	.
Pylaisia polyantha	129	5	24	8	32	13	.	.	.
Orthotrichum patens	33	7	10	1	2	13	.	1	.
Pulvigera lyellii	72	.	1	.	.	.	1	20	12
Leptodon smithii	62	.	.	.	.	.	1	17	11
Fabronia pusilla	75	.	.	.	.	.	4	16	14
Syntrichia laevipila	217	.	.	.	1	.	21	33	45
Habrodon perpusillus	101	.	.	.	.	.	2	20	24
Physcia biziana	74	.	.	.	.	.	7	11	16
Normandina pulchella	41	.	.	.	1	.	1	10	8
Amandinea punctata	120	.	.	.	.	.	30	20	7
Orthotrichaceae spec.	76	4	4	3	6	13	5	6	11
Physcia adscendens	244	66	39	49	3	50	2	3	2
Orthotrichum diaphanum	636	72	66	84	30	75	42	10	55
Phaeophyscia orbicularis	597	99	63	79	18	63	21	23	54
Syntrichia papillosa	638	33	57	57	41	63	29	35	79
Orthotrichum pumilum	479	51	57	63	28	63	15	9	46
Candelariella reflexa	440	63	42	45	13	75	23	50	17
Candelaria concolor	428	45	36	47	21	38	18	17	52

Table 6. Number of sampled tree species in Graz (G) and Podgorica (P). Bold tree species names were sampled in both cities, bold numbers are tree species with more than eight sampling trees in one city.

	Graz						**Podgorica**			
Tree species	**N**	**IA**	**P**	**RA**	AR	GC	**N**	**IA**	**P**	**RA**
Acer campestre	2		2							
Acer negundo	2	2								
Acer platanoides	**37**	10	11	12	4		3		1	2
Acer pseudoplatanus	**11**		5	3	2	1				
Acer saccharinum	1	1					2			2
Aesculus hippocastanum	**9**	1	1	5	1	1	2		2	
Alnus glutinosa	1		1							
Broussonetia papyrifera							5		1	4
Castanea sativa	1		1							
Celtis australis							7	1	1	5
Cupressus sempervirens							**38**	14	12	12
Frangula alnus	1				1					
Fraxinus excelsior	**23**		8	5	10		1			1
Gleditsia triacanthos							1			1
Juglans regia	5	1	1	1	2		1		1	
Koelreuteria paniculata							1		1	
Ligustrum lucidum							4	3		1
Liriodendron tulipifera							1			1
Melia azedarach							**15**	4	2	9
Paulownia tomentosa							4	1	1	2
Pinus halepensis							**46**	23	22	1
Pinus nigra							3		3	
Platanus orientalis							2	1		1
Populus nigra	6				6					
Populus tremula	2		1		1					
Prunus avium	1	1								
Prunus serrulata	1		1							
Quercus ilex							1			1
Quercus pubescens							3		3	
Quercus robur	3		1	2			1			1
Quercus trojana							2		2	
Robinia pseudoacacia	2	2					3	1		2
Salix babylonica	1				1					
Salix fragilis	**9**				9					
Styphnolobium japonicum	**16**		4	6	6		4	1	2	1
Tilia cordata	**27**	1	10	14	2		1	1		
Tilia tomentosa							**10**	1	1	8
Ulmus glabra	4		1		3					
Sum	165	19	48	48	48	2	161	51	55	55

The composition of the epiphytic communities on the different tree species is presented in Table 7. The communities of the tree species were not strongly separated, and only a few epiphyte species showed a clear preference for one tree species, like *Amandinea punctata* for *Pinus halepensis* and *Scytinium lichenoides* for *Aesculus hippocastanum*. In general, the epiphyte species composition overlapped largely among tree species.

Table 7. Shortened synoptic table of percentage frequency of epiphytes on tree species with more than eight individuals. Frequency values with phi > 19 are framed. We omitted all species with less than 10 % frequency and phi < 19 in any column. **Sfr** = *Salix fragilis*, **Fex** = *Fraxinus excelsior*, **Apl** = *Acer platanoides*, **Aps** = *Acer pseudoplatanus*, **Tco** = *Tilia cordata*, **Tto** = *Tilia tomentosa*, **Que** = *Quercus*, **Cse** = *Cupressus sempervirens*, **Pha** = *Pinus halepensis*, **Ahi** = *Aesculus hippocastanum*, **Maz** = *Melia azedarach*, **Sja** = *Styphnolobium japonicum*. N = Frequency of the species. % Graz = share of samples from Graz. EIV-R = Ellenberg's indicator values for soil reaction.

	N	**Sfr**	**Fex**	**Apl**	**Aps**	**Tco**	**Tto**	**Que**	**Cse**	**Pha**	**Ahi**	**Maz**	**Sja**
N of plots		36	96	160	44	112	40	40	152	184	44	60	80
% Graz		100	96	93	100	96	0	30	0	0	82	0	80
Mean species number		3,5	5,2	6,8	5,5	5,6	7,9	7,6	5,1	2,4	5,5	8,3	4,3
Species Cover %		26	31	30	26	24	33	21	28	9	22	35	27
EIV-R		6,89	6,83	6,78	6,63	6,71	6,3	6,12	6,2	5,07	6,57	5,87	6,42
Pylaisia polyantha	111	72	26	19	2	13	.	3	.	.	5	.	14
Leskea polycarpa	76	72	27	9	2	2	.	.	.	.	7	.	5
Radula complanata	11	14	2	1	2	.	.	.	.	.	.	.	1
Physciella chloantha	187	56	39	19	27	13	25	15	16	1	30	12	14
Amblystegium serpens	19	14	5	3	2	2	.	.	.	.	.	.	1
Pseudoamblystegium subtile	2	6	.	.	.	.	.	.	.	.	.	.	.
Nyholmiella obtusifolia	224	17	58	47	43	25	.	5	.	.	27	.	33
Phaeophyscia orbicularis	475	6	44	86	57	76	68	55	33	3	52	43	38
Lewinskya speciosa	28	.	4	11	2	4	.	3	.	.	.	.	.
Lecanora carpinea	10	.	.	6	.	1	.	.	.	.	.	.	.
Lecanora spec.	5	.	1	1	7	.	.	.	.	.	.	.	.
Physcia adscendens	212	.	20	48	32	55	.	15	1	5	18	.	19
Dialytrichia mucronata	27	.	.	.	.	4	35	10	.	.	.	8	.
Orthotrichum tenellum	65	.	2	4	.	3	40	13	4	4	2	28	.
Syntrichia papillosa	521	22	61	56	61	47	88	58	63	5	64	72	63
Normandina pulchella	38	.	1	.	.	1	20	18	3	3	5	15	.
Habrodon perpusillus	90	.	.	1	.	.	38	40	16	2	14	28	8
Leptodon smithii	55	.	.	.	.	.	15	25	13	1	14	13	5
Frullania dilatata	56	.	.	1	2	1	5	23	3	14	2	15	3
Leucodon sciuroides	27	.	.	.	.	2	3	23	1	.	.	17	4
Collema nigrescens	2	.	.	.	.	.	.	5	.	.	.	.	.
Homalothecium sericeum	19	.	.	.	.	.	5	18	3	.	.	10	.
Collema subflaccidum	7	.	.	.	.	.	.	18	.	.	.	.	.
Syntrichia laevipila	176	.	4	5	.	2	68	28	57	1	2	45	11
Fabronia pusilla	63	.	.	1	.	.	23	10	24	1	2	12	4
Syntrichia pagorum	182	.	.	5	.	2	68	28	65	3	.	42	6
Physconia perisidiosa	11	.	.	.	.	.	.	.	6	1	.	.	.
Amandinea punctata	111	.	.	.	.	.	3	.	2	54	.	13	.
Scytinium lichenoides	8	.	.	.	.	.	.	3	.	.	16	.	.
Hypnum cupressiforme	84	8	1	2	.	.	10	15	5	17	.	35	8
Lewinskya acuminata	51	.	3	1	.	3	18	13	3	5	.	28	1
Physcia biziana	52	.	.	1	.	3	15	13	9	3	2	27	.
Lewinskya striata	23	.	.	1	.	.	8	5	.	2	.	20	1
Candelariella viae-lacteae	11	.	.	.	.	.	5	.	2	.	.	10	.
Lecidella elaeochroma	24	.	.	4	9	3	.	5	.	.	.	15	.
Lecanora chlarotera	8	.	.	.	.	.	.	.	.	1	.	12	.
Lewinskya rupestris	13	.	1	.	.	.	5	3	.	.	.	10	4
Pulvigera lyellii	66	.	2	.	.	.	8	30	5	10	.	32	5

	N	Sfr	Fex	Apl	Aps	Tco	Tto	Que	Cse	Pha	Ahi	Maz	Sja
N of plots		36	96	160	44	112	40	40	152	184	44	60	80
% Graz		100	96	93	100	96	0	30	0	0	82	0	80
Mean species number		3,5	5,2	6,8	5,5	5,6	7,9	7,6	5,1	2,4	5,5	8,3	4,3
Species Cover %		26	31	30	26	24	33	21	28	9	22	35	27
EIV-R		6,89	6,83	6,78	6,63	6,71	6,3	6,12	6,2	5,07	6,57	5,87	6,42
Grimmia pulvinata	4	.	.	.	.	.	.	3	.	.	.	5	.
Ptychostomum capillare agg.	8	.	2	.	.	.	.	.	1	.	.	7	.
Catapyrenium psoromoides	6	.	.	.	.	.	5	.	.	.	.	7	.
Physconia perisidiosa	8	.	.	1	.	1	.	5	.	.	.	7	.
Orthotrichum diaphanum	498	11	53	78	73	72	53	30	51	7	57	28	50
Candelariella reflexa	390	6	18	49	41	56	10	53	28	47	59	33	15
Orthotrichum pumilum	387	14	60	65	64	46	63	38	24	1	52	17	36
Candelaria concolor	352	.	34	53	41	39	53	50	24	9	43	55	35
Xanthoria parietina	123	.	9	32	9	19	5	25	1	1	11	13	14
Physcia spec. div.	64	6	3	3	.	.	.	13	10	6	16	22	5
Lewinskya affinis	62	8	15	15	11	8	.	8	.	1	5	.	1
Orthotrichaceae spec.	55	6	1	5	.	5	18	10	4	3	14	7	6
Catillaria nigroclavata	37	.	1	4	7	1	.	10	.	5	7	13	1
Phaeophyscia nigricans	32	.	.	5	14	14	.	5	.	.	.	.	.

Our α-diversity data differ remarkably between tree species. A Kruskal-Wallis test found four significantly different groups (Figure 6). The group with lowest species diversity consisted of *Pinus halepensis* only, with a mean species number of 2.4. The next group included *Salix fragilis* and *Styphnolobium japonicum*, with mean species numbers of 3.5 and 4.3. The next group consisted of *Fraxinus excelsior*, *Acer pseudoplatanus*, *Tilia cordata*, *Cupressus sempervirens*, and *Aesculus hippocastanum* with mean species numbers between 5.1 and 5.6. The group with the highest species diversity comprised *Acer platanoides*, the *Quercus*-species, *Tilia tomentosa* and *Melia azedarach*, with mean species numbers between 6.8 and 8.3.

As a hint regarding the pH-value of the tree bark, we used Ellenberg's indicator values for soil reaction (EIV-R). We found three significant groups. The first group consisted of *Pinus halepensis* only, with a mean EIV-R of 5.07. The medium group included *Tilia tomentosa*, the *Quercus*-species, *Cupressus sempervirens*, *Melia azedarach*, and *Styphnolobium japonicum* with an EIV-R between 6.12 and 6.42. The group with the highest EIV-R included *Salix fragilis*, *Fraxinus excelsior*, *Acer platanoides*, *Acer pseudoplatanus*, *Tilia cordata* and *Aesculus hippocastanum*, with indicator values between 6.57 and 6.89.

Epiphyte cover was more or less the same among the trees (mean cover 21–35 %), with the single exception of the conifer *Pinus halepensis* (mean cover 9 %).

Correlation between tree trunk circumference and epiphyte diversity

The circumference of the trees between 80 and 215 cm showed no correlation with species number in our dataset. We checked this for Graz and Podgorica, and for the four tree species on which more than 100 plots were sampled (Table 8). All rank correlation coefficients were near zero, only *Cupressus sempervirens* showed a slight tendency towards a correlation with a p-value of 0.056 – but the correlation was negative. We got the same result by grouping the tree circumferences into three categories (<= 125 cm, >125 –170 cm and >170 –215 cm, data not shown).

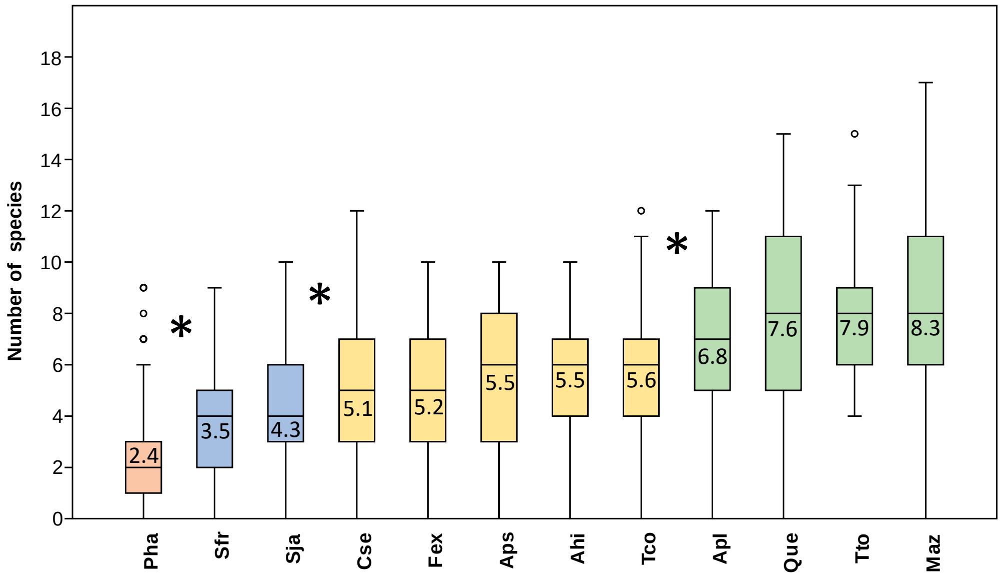

Fig. 6. Boxplots of epiphytic species numbers of the plots of the 12 most frequent tree species in the study, ordered according to the mean species number. The stars indicate significant differences (p=0.01), same colors indicate groups without significance differences. For further parameter see Table 7. Pha = *Pinus halepensis*, Sfr = *Salix fragilis*, Sja = *Styphnolobium japonicum*, Cse = *Cupressus sempervirens*, Fex = *Fraxinus excelsior*, Aps = *Acer pseudoplatanus*, Ahi = *Aesculus hippocastanum*, Tco = *Tilia cordata*, Apl = *Acer platanoides*, Que = *Quercus*, Tto = *Tilia tomentosa*, Maz = *Melia azedarach*.

Table 8. Rank correlation table of tree trunk circumference and species richness. N = number of plots. Rho = Spearman's correlation coefficient, Percentage frequency synoptic table of epiphytes on tree species with more than eight individuals. **N** = Number of plots, **G** = Graz, **P** = Podgorica, **Apl** = *Acer platanoides*, **Tco** = *Tilia cordata*, **Cse** = *Cupressus sempervirens*, **Pha** = *Pinus halepensis*.

	All data	**G**	**P**	**Apl**	**Tco**	**Cse**	**Pha**
N	1304	660	644	160	112	152	184
Rho	-0.024	-0.049	0.002	0.115	0.039	-0.155	0.056
p-value	0.368	0.205	0.944	0.147	0.68	0.056	0.442

The role of exposition

Our dataset shows that most epiphyte species preferred the North and the West sides of the trunks, and here also the highest epiphyte cover was found (Figure 7). However, bryophytes are the only drivers of this effect. The same approach for lichen richness and cover showed no differences (data not shown). Figure 7 presents a striking difference between the North-West-side and the South-East-side of the trunk. All differences between North and East, and South and West were significant, while a significant difference between South and East side was detectable only once, and never between North and West side. The hypothesis that most epiphytic bryophytes grow in the northwestern direction is supported by this study.

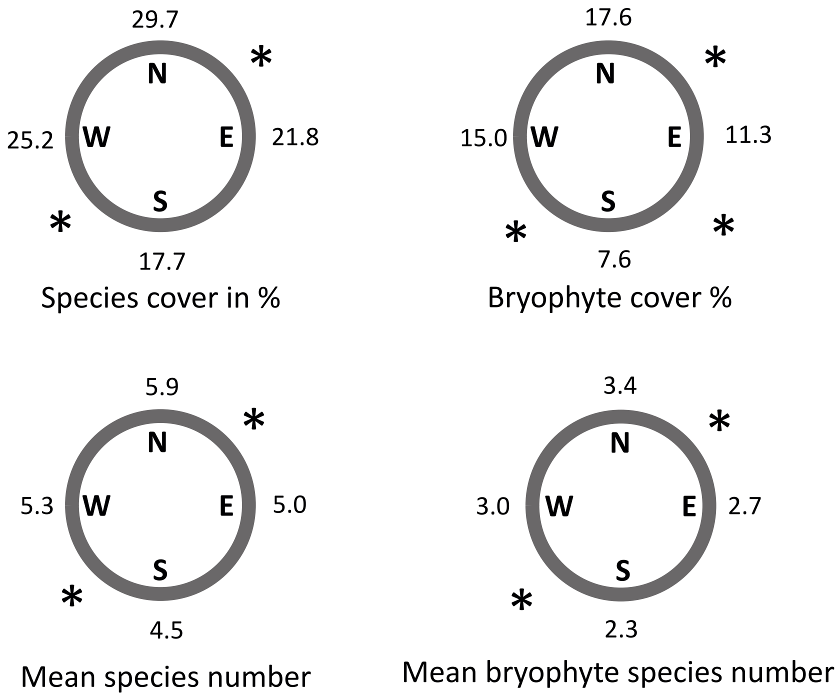

Fig. 7. Mean species and bryophyte number and cover in the four cardinal directions. N = North, E = East, S = South, W = West. The stars indicate significant differences (p=0.01). All differences between North and South are significant, all differences between West and East are not (not displayed). N = 326 in each chart.

Discussion

Floristic results

We presented cryptogam community data borrowing elements of a stratified systematic sampling design, and of a preferential sampling design normally used by bryologists and lichenologists. The latter is the best to cover as many species as possible, but our sampling design allows some statistical analysis, which would not be possible otherwise. Our data provide a better understanding of the complete epiphyte species diversity in the two cities, but the large number of singletons (species found only once), especially among lichens, is an indicator that our species list is far from complete (see Xu et al. 2012). Further, we checked the epiphytic habitat on the trunks at eye level only, and this represents only a certain fraction of the whole diversity of epiphytes on a tree (Kiebacher et al. 2016).

Before we started this study, we did not expect the bryophyte flora to be this rich in Podgorica. It is known that the Mediterranean area is species-poor in bryopytes (Frahm 2010, Sabovljević et al. 2001). But Montenegro is the exception to the rule, mainly because the Mediterranean part of the country is small and most parts are covered with various mountains. Podgorica has twice as much precipitation as Graz, and some parts of Montenegro have precipitation amounts comparable with Norway. Contrary to Norway, almost all precipitation falls in the winter months, so that the mosses and lichens have to tolerate the dry and hot summer. Species with a boreal-temperate distribution prefer moderate and balanced montane climate, like *Lewinskya speciosa*, *Nyholmiella obtusifolia*, *Orthotrichum stramineum*, *Pseudoamblystegium subtile*, *Zygodon viridissimus*, *Melanohalea exasperatula*, *Physcia stellaris*, *Ramalina pollinaria*, and *Xanthomendoza huculica*, are missing in Podgorica. The Mediterranean bryophyte flora and lichen biota are particular rich in Podgorica, with frequent occurrences of *Fabronia pusilla*, *Habrodon perpusillus*, *Leptodon smithii*, *Lewinskya acuminata*, *Catapyrenium psoromoides*, *Lecanora leuckertiana*, *Physcia biziana*, *Physconia perisidiosa* and *Punctelia borreri*, for instance.

Another reason for the higher species numbers in Podgorica could be edge effects of the city structure, where urban habitats are embedded in 27% of (semi-)natural areas inside the city borders, compared with 16 % in Graz.

On the other hand, most of the epiphytes occur in both cities. These are widely distributed species, which typically occur in conditions like in Graz with its central European climate with submediterranean climate influences, and Podgorica with its moderate Mediterranean climate. Especially all lichens found in Graz could potentially occur in Podgorica because of their wide distribution ranges (Wirth et al. 2013, Nimis et al. 2018).

Many studies of urban epiphytes have focused on changes of the epiphyte flora in industrial and post-industrial times. In various cities, the bryophyte diversity and abundance increased as the SO_2 impact nowadays is lower than in the last 150 years (Frahm 2009). In Katowice city in Poland, an increase in *Orthotrichum* and *Ulota* species was detected (Stebel & Fojcik 2016). In Halle/S., Richter et al. (2009) discovered the same trend of an increase of bryophyte stands and species numbers. Our results can be used as starting point for comparable studies in the future.

Cinclidotus fontinaloides as an epiphyte in Podgorica

A surprising result was the occurrence of *Cinclidotus fontinaloides* in 15 plots of Parks and Residential areas in Podgorica. European species of the family Cinclidotaceae are known as epilithic plants in floodplains and near river waterlines at places with frequent inundation (Philippi 1968, Frahm 2006). In this habitat, they change the substrate occasionally and occur rarely on the bark of floodplain trees and dead wood. *Dialytrichia mucronata* (39 plots in Podgorica) is the only representative of the family, which is frequent on floodplain softwood trees like *Salix alba* and *Populus nigra* (Oesau 2007). Outside of direct floodplain influence, *Cinclidotus*-species are more or less unknown. We could find two publications on their epiphytic occurrence on bark, where it was presented as a remarkable case, one from the west coast of Ireland (Coker 2014), the other from Southeast France (Hugonnot & Celle 2015). We found *Cinclidotus fontinaloides* in epiphytic synusiae of urban trees far from any inundation influence. Its growth there could be connected with air humidity, promoted by fog or high precipitation. The first find in Ireland exhibits the predominantly high air humidity, and southeastern France is also one of the wetter areas of the Mediterranean region, with annual precipitation of around 850 mm. That the precipitation is mainly restricted to the winter months seems to be no problem for *Cinclidotus fontinaloides*. According to Frahm (2006), *C. fontinaloides* grows on higher places than other *Cinclidotus*-species, and seems to be able to use air humidity better than *C. riparius*.

Epiphyte diversity and cover differences between Graz and Podgorica

The high proportion of plots with both bryophytes and lichens (72%) is remarkable, as in phytosociology bryophyte communities and lichen communities are approached as separate fields. Probably it is time for some updates in classification of cryptogam-rich communities

(Berg et al. 2019). Cover is positively correlated with species diversity, because competition for space does not apply in such open habitats. Only increasing bryophyte cover leads to a parallel decrease in the lichen species number.

A higher total species number (γ-diversity) in Podgorica with the same species number per plot (α-diversity) means a higher species turnover (ß-diversity), or simply a higher heterogeneity between the plots. Conifer trees like *Pinus halepensis* with poor epiphyte flora are lacking in Graz, but decrease the mean species number in Podgorica and increase the variation among plots. A higher epiphyte cover in Graz is plausible, considering the more balanced climate throughout the year, and the lack of sparsely colonized tree species like *Pinus halepensis*.

The differences in epiphyte cover and diversity between the urban habitats can partly be explained by differences in the species composition of urban trees. Most of the trees in the Industrial area of Podgorica are conifers with lower cryptogam species cover and diversity. Therefore, the species richness and cover of epiphytes in the Industrial areas of Graz is significantly higher than in Podgorica, but it is generally low, because old trees are lacking in most Industrial areas in Graz. Concerning Parks, we expected this habitat type to serve as hotspots of urban epiphyte diversity, but, unexpectedly, Residential areas in both cities served as hotspots. A higher tree diversity is not the reason because this does not apply to Podgorica. It seems that a combination of environmental factors, including shadowing of solitary trees by buildings, and fertilization by dust, could explain this phenomenon mainly found in bryophytes (Stapper 2014, Stapper et al. 2011). It is unexpected that in the Areas along the river Mur in Graz, both epiphyte number and cover is lower than in any other urban habitat in Graz. Floodplain forests are generally considered good habitats for epiphytes. The periodic inundation regime results in nutrient-rich, special conditions with deposited suspended particles on the bark, which support pleurocarpous mosses like *Leskea polycarpa*, while acrocarpous small mosses and especially slow growing lichens avoid such conditions. In the literature, *Salix* species are described as epiphyte-rich trees (Wirth 2002, Stebel & Fojcik 2016). In the Mur floodplain in Graz, we find *Salix fragilis* as the deciduous tree with the lowest epiphyte diversity in our study.

In this study, some significant differentiation of species diversity among the urban habitat types could be shown within one city. In Graz, the species number of Areas along rivers was significantly lower. In Podgorica, Industrial areas have a significantly lower α-diversity. The reason for that is the dominance of pine trees in these areas, which harbor mainly species-poor epiphytic communities.

The influence of an urban environment on the epiphytic biodiversity deviates strongly from what we expected, thinking of the “lichen desert zone” in the city centers of the time of acid rain around the 1980s. In our study the proximity to the next sealed area shows a positive correlation with epiphytic biodiversity. This is in line with our findings discussed before, that Residential areas today, without coal heating and with strongly reduced pollutants in the cities, provide suitable conditions for epiphytes to colonize city trees up to the centers of the cities. Comparative studies concerning the effects of air pollution on lichens and bryophytes (Pescott et al. 2015) show that the alteration of influence of SO_2, NO_x and NH_3 over the last decades has an enormous impact on communities and species occurrence. The slight increase of epiphytic diversity in correlation with proximity of sealed areas supports that traffic (NH_3-pollution, streets which are also sealed areas) does not necessarily lead to a decline in species abundance or cover. Some species are even supported by traffic-related pollutants (Stapper & Kricke 2004, Paoli et al. 2013). However, Larsen et al. (2006) showed that very high levels of transport-related pollutants lead to a decrease in species number and cover.

In terms of maintaining and increasing epiphytic biodiversity in cities, our results suggest that urban structure is no longer as important due to the decrease in urban air pollution. Trees should be used everywhere and in large quantities as an important means of improving the urban climate for the inhabitants, especially in heavily sealed areas. This will in any case improve the settlement opportunities for epiphytic bryophytes and lichens in the city, regardless of the urban habitat type.

Tree species have an important influence on epiphyte diversity

As just reported from *Salix fragilis*, not all of our results confirm established rules. The pH-value of the bark has a strong influence on bryophyte diversity (Larsen 2006, Manzke 2009, Tyler & Olsson 2016), suggesting that epiphyte species diversity decreases with increasing acidity of the bark. This pattern is not fully evident using indicator values for soil reaction of bryophytes and lichens (Ellenberg et al. 2001). Assigning the indicator values and the mean species numbers of the trees (see Table 7) in two columns, then *Pinus halepensis*, *Cupressus sempervirens*, *Acer pseudoplatanus*, *Aesculus hippocastanum*, *Tilia cordata*, and *Acer platanoides* stand perfect in a line of increasing indicator values for soil reaction and increasing species numbers. On the other hand, *Styphnolobium japonicum*, but *Fraxinus excelsior* too, show high Ellenberg's indictor values, but the species number is much below the expected value. Finally, *Melia azedarach*, *Tilia tomentosa* and the *Quercus* species have higher species numbers than their indicator values would suggest. These results should however not be over-interpreted. Ellenberg's indicator values do not replace pH-measurements of the bark. They are made for Central Europe, whereas Podgorica with its wet winter and dry summer might be a completely different story. It is known, that the pH-value of the bark oscillates with rain and drought events, rain floods along the trunk, dust from building and demolition, transport-related substances as well as with the exposition and inclination of the particular region of the trunk (Frahm 1998, Larsen 2006). Therefore, pH-value on one side can be four units higher than on the other side of a tree trunk (Manzke 2008). In 1979 (Kienzl & Härtel 1979) the pH-range of tree species in Graz differed from the center to the peripheral regions of the city, but more recent data are missing. Other factors, like the surrounding air quality can have an impact on epiphytes, especially in urban environments (Frahm 2007, Pungin et al. 2017). And, two of the tree species are planted and not autochthonic (*Styphnolobium japonicum*, and *Melia azedarach*); here, unknown biotic interactions can play a role. Our study shows that some lichen and bryophyte species have preferences for specific tree species. The examined trees were situated in different areas under different urban habitat situations. Besides pH of the bark, other specific characteristics of the tree species too, like water storage capacity or structure of the bark could have an impact on species diversity (Spier et al. 2010).

Tree circumference has no influence on α-diversity

Circumference is a common proxy used to estimate the age of trees (Johannson et al. 2007). It is common knowledge that thick trees harbor more bryophyte and lichen species than thin ones. According to the general rule that the number of species increases with the area, this is certainly true, because thick trees provide more space, and more niches or ecological gradients too. Plot based approaches, like ours, Dietrich & Scheidegger (1996), Engel et al. (2003) or Johannson et al. (2007), regularly find no connection between circumference of a tree and species α-diversity. We can conclude that age and size of the trees can be important for general species richness but has no influence on the diversity of standardized parts of the bark. Old trees can harbor more epiphytic communities, but, in our data, the cover and species richness of the communities stayed the same during the trees' life cycle, although the roughness and structure of the bark, its pH-value, or the content of water, nutrients or of secondary metabolites could change.

Bryophytes prefer Northwest-exposition, lichens do not care

It is an oral tradition that bryophytes in Austria always grow on the north-west side of tree trunks. In this study, we found statistical evidence for that. There are two lines of evidence to back it up. One is, that in our temperate climate the tree trunk side mostly influenced by weather events is the side which is exposed to the west. The other one highlights the influence of the sun with warm-dry conditions in the East and South, and shading-cold conditions in the West and North (because the warmest time is in the afternoon, the west side stays moist and cool longer in the morning, while the east side warms up quickly in the morning and does not cool down again in the afternoon due to the high air temperatures). Our data support the second idea, because in the cities, the weather side is strongly modified by the arrangement of high buildings, while the temperature profile is more or less the same, with warmer afternoons. It has to be noticed that the rule only works if you consider statistical results of several plots – not with a single tree in the field. The result that bryophytes grow significantly more in northern and western exposition is supported by Fudali (2019).

Results of other studies in Temperate-Mediterranean cities of Europe

Ehrendorfer et al. (1971) investigated the epiphytic lichens in correlation with air pollution in Graz during the years 1967 and 1968. They found a drastically reduced lichen diversity and cover in the city (67 epiphytic lichen species in Graz instead of 108 known from the literature). The authors divided the city in five different zones according to the occurrence of specific species. These zones cannot be found anymore in our data today. Zone I and II were not part of our study (forests, agricultural areas). Zone V they called "lichen desert" which is not detectable in Graz anymore. Only the species of Zone II and III are relevant for our study (like *Parmelia sulcata*, *Physcia adscendens*, *Phaeophyscia orbicularis*, *Xanthoria parietina*, *Physcia stellaris*). The air pollution in the time of the 1971 study was strongly dominated by SO_2 which was the most important factor for lichen distribution. The SO_2-level in Graz is much lower today, and other factors drive the diversity and cover of lichens. We found 22 species in Graz that were missing in 1967 and 1968, e.g. *Caloplaca cerinelloides*, *Catillaria nigroclavata*, *Lecania naegelii*, *Melanelixia glabratula*, *Melanelixia subaurifera*, *Melanohalea exasperatula*, *Normandina pulchella*, *Parmelina tiliacea*, *Physconia distorta* and *Punctelia jeckeri*.

Wilfling et al. (2003) compared the old studies of Graz with new data, which the conclusion that the air quality has improved, but that there are still some more heavily loaded areas. The authors assigned different areas in the south of Graz to different clusters of pollution. On 345 sample sites, 107 lichen taxa could be determined. The most common species correspond to those of our study. Grill et al. (1988) determined more than 100 epiphytic lichen species in Graz. With the preferential collecting design, more species could be located. We found fewer lichen species with the standardized sampling design.

Trinkaus (2001) investigated population development of *Xanthoria parietina* in Graz. *Xanthoria parietina* colonized more sites in 2001 in comparison with 1986 (Grill et al. 1988), probably because of improved air quality, but potentially also due to eutrophication as well. The species is nitrophilous and can also be found along roads with high traffic. In our study, *X. parietina* occurred on 61 trees out of 165 in all five urban habitat types.

Table 9. Different studies of epiphytic bryophyte and lichen diversity in European cities.

Country	City	Authors	Results epiphytes (sampling year/s)	Comments
Austria	Graz	current study	27 epiphytic bryophyte species (2017) 38 epiphytic lichen species (2017)	
Austria	Vienna	Türk & Christ (1986)	60 epiphytic lichen species (1983)	nitrophilous species were frequent; lichen species composition was comparable with Graz
Germany	Düsseldorf	Stapper & Kricke (2004), Stapper (2014)	23 epiphytic bryophyte species (2004) 76 epiphytic lichen species (2004) 73 epiphytic lichen species (2014)	
Germany	Cologne	Sabovljević & Sabovljević (2009)	143 taxa of bryophytes including only 20 species of typical epiphytes (2004 to 2006)	
Germany	Munich	Vorbeck & Windisch (2002)	43 epiphytic lichen species (1984) 57 epiphytic lichen species (2000)	
Poland	Wroclaw	Fudali (2019)	38 epiphytic bryophyte species (2013 to 2016)	Sampled 0.8 m to 1.2 m above the ground; highest species diversity was found in urban green areas (89 % of all species).
Poland	Opole	Leśniański (2010)	16 epiphytic lichen species (1992 to 2008)	
		Górka & Sokól (2015)	12 epiphytic lichen species (2013 to 2014)	98 trees sampled, sensitive species were absent in the city.
Poland	Cracow	Słaby & Lisowska (2012)	39 epiphytic lichen species (2007 to 2009)	
Poland	Wroclaw	Fudali & Szymanowski (2019)	25 epiphytic bryophyte species (2013 to 2016)	on alien tree trunks
Poland	Katowice	Stebel & Fojcik (2016)	25 epiphytic bryophyte species (2010 to 2015)	
Italy	Rome	Munzi et al. (2006)	102 epiphytic lichen taxa (1982 to 2003)	
Great Britain	London	Davies et al. (2005)	14 epiphytic bryophyte species (2002 to 2003) 74 epiphytic lichen species (2002 to 2003)	only *Fraxinus excelsior* was sampled
Serbia	Niš	Stamenković & Cvijan (2003)	42 epiphytic lichen taxa (2002)	city center was described as lichen desert zone
Serbia	Belgrade	Savić (1998)	43 epiphytic lichen taxa (1993 to 1995)	Sampled selectively on old representative trees, from the ground up to a height of 0.5 m.
Montenegro	Podgorica	Current Study	29 epiphytic bryophyte species (2017) 52 epiphytic lichen species (2017)	
Portugal	Lisbon	Sérgio et al. (2016)	23 epiphytic bryophyte species (1980 to 1981) 39 epiphytic bryophyte species (2010 to 2011) 69 epiphytic lichen species (1980 to 1981) 114 epiphytic lichen species (2010 to 2011)	sampling grid 100 bis 150 cm above the ground
Russia	Kaliningrad	Pungin et al. (2017)	42 epiphytic lichen species (2016)	129 trees sampled; 13 lichen species are described as indicator species for eutrophication
Russia	Moscow City	Biazrov (2007)	43 epiphytic lichen species (1988 to 1991) 64 epiphytic lichen species (2006)	trees and bushes were surveyed from the base up to the height of 2,5 m
Ukraine	Kyiv	Dymytrova (2009)	20 epiphytic bryophyte species (2006 to 2008) 65 epiphytic lichen species (2006 to 2008)	272 sampling plots, base up to 1.5 m above ground. Industrial areas show lowest and inner parks show highest epiphytic richness.

In Europe, there are already a number of studies on the cryptogamic flora of cities, some specifically on the epiphyte flora. An overview of the number of species found is given in Table 9. Some of these studies are partly comparable with our study. The sampling method differs in many ways: preferential sampling design, different height and size of sampling grid, tree species, tree number, distribution of the trees in the city, detected variables in the field, and time effort. Main results of many studies, like the general number of epiphyte species, and the higher diversity in urban green areas and the low diversity in industrial zones, were confirmed by our study.

A general judgement of the contribution of epiphytes to urban biodiversity is difficult, because species numbers differ between published studies using different methods, aims and time effort for sampling. Our epiphytic lichen numbers are lower than in other comprehensive studies, probably due to our restrictive sampling design. Today more than 100 epiphytic lichen species can be expected in most central European cities using a preferential sampling design because of the improved air quality (Stapper 2014). The number of epiphytic bryophytes is comparable to other European cities.

Our research has shown, in addition to some new findings on the lichen flora of Montenegro, that the epiphyte flora of urban habitats not only strongly depends on climate, but also on the tree species composition and the formation of urban habitat types. Urban parks are highly important for the epiphyte flora. There is obviously a pool of common epiphytic bryophytes and lichens in Europe, and the mean number of species per plot was also similar between the cities. Although we did not expect it, Podgorica had a higher total species number, a higher cover of epiphytic bryophytes, and a lower cover of epiphytic lichens than Graz.

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