Biomonitoring with Epiphytes: In search of indicator species for the impact of a large city

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Besides emissions, urban heat island is one of the metropolitan effects with significant impact on urban residents, which will continue to intensify because of global climate change. In this case study from Düsseldorf, an attempt was made to determine effects on epiphytic lichens and mosses along a gradient of increasing soil sealing and rising nighttime temperatures, and possibly to identify indicator species.

Methods

Along three contiguous transects (Fig. 1), 240 standard trees were selected (predominantly *Acer platanoides* and *A. pseudoplatanus*, a few *Fraxinus* and *Tilia*) that largely met the selection criteria of VDI 3957 Part 13 [1]. The frequency of all moss and lichen species as well as *Klebsormidium* and *Trentepohlia* algae was determined with grids in the four cardinal directions. Night temperature at the sites and their affiliation to one of the six locally possible climatopes (selected on the basis of soil sealing, built-up area and thermal situation, without industrial climatope) were taken from the climate analyses of Düsseldorf [2; 3]. Further relevant factors are e. g. the distance to the roadside and the intensity of motorized traffic, which was subjectively assessed in four classes.

Results

- Düsseldorf is home to many epiphytes! A total of 94 taxa were recorded on the 240 standard trees.
- Mosses and lichens of warm sites are more abundant (Spearman's Rs = 0.28), but species with lower species nighttime temperatures (SNTT in Table 1) grow together with significantly more companion species (Q value in Tab. 1; Rs = -0.79; both cases $p < 0.05$).
- Ecological pressure due to traffic emissions, soil sealing and overheating of sites acts in the same direction and reduces both species diversity and frequency sums of epiphytes (NMS, Fig. 2).
- For Düsseldorf, based on the indicator species analysis (INDVAL; Fig. 3), *Orthotrichum diaphanum, Phaeophyscia nigricans, P. orbicularis, and Klebsormidium* c.f. *crenulatum* may be regarded as **urbanotolerant species.**

Tab. 1: List of species detected on at least five trees.
H (%): percentage of trees with this species. **SNTT:** mean nighttime temperature (°C) at the locations where the species was recorded ("species temperature"); **Q-Value:** average number of concomitant species. **Spearman's rank correlation (Rs):** species frequency vs. nighttime temperature NTT (all locations; sorting criterion), **climatope type** (1 to 6 in terms of increasing urbanity: 1, open land; 2, park; 3, loose development; 4, suburban settlement; 5, urban; 6, metropolitan according to [3].), **distance from road edge**, or **Traff_Int** = traffic intensity (subjective in four classes: 1, zero; 2, resident's traffic only; 3, moderate, residents plus collector traffic, side street; 4, strong, constant city-like traffic, cars & trucks/buses). Values in bold: statistically significant, $p < 0.05$

Species Name	H (%)	SNTT	Q-Value	Correlation (Rs) with species frequency			
				NTT	Climatope	Road_Dist	Traffic_Int
Parmelia sulcata	62.9	20.0	15.5	**-0.400**	**-0.557**	**0.340**	**-0.557**
Hypnum cupressiforme	23.8	**19.3**	17.0	**-0.396**	**-0.387**	**0.392**	**-0.293**
Punctelia jeckeri	64.2	20.0	15.7	**-0.386**	**-0.491**	**0.393**	**-0.509**
Punctelia subrudecta	69.2	20.1	15.0	**-0.370**	**-0.432**	**0.333**	**-0.406**
Lepraria incana	10.8	**19.0**	19.2	**-0.329**	**-0.305**	**0.345**	**-0.276**
Lewinskia affinis	55.0	20.0	15.7	**-0.314**	**-0.389**	**0.319**	**-0.330**
Flavoparmelia caperata	27.5	19.6	17.2	**-0.311**	**-0.359**	**0.263**	**-0.313**
Ramalina farinacea	16.3	**19.4**	17.1	**-0.291**	**-0.377**	**0.318**	**-0.404**
Physcia tenella	77.5	20.2	14.6	**-0.271**	**-0.457**	**0.330**	**-0.455**
Lecanora expallens	19.6	19.6	18.0	**-0.261**	**-0.376**	**0.280**	**-0.381**
Melanelixia subaurifera	46.7	20.0	15.6	**-0.257**	**-0.429**	**0.323**	**-0.402**
Trentepohlia sp.	6.3	**18.9**	17.5	**-0.237**	**-0.263**	**0.254**	**-0.281**
Polycauliona candelaria	16.7	19.7	17.3	**-0.230**	**-0.444**	**0.301**	**-0.369**
Melanohalea exasperatula	15.0	19.7	17.9	**-0.222**	**-0.293**	**0.235**	**-0.295**
Hypotrachyna revoluta	2.9	**18.4**	19.1	**-0.217**	**-0.184**	**0.143**	**-0.229**
Frullania dilatata	3.8	**18.7**	20.8	**-0.214**	**-0.255**	**0.186**	**-0.136**
Caloplaca obscurella	4.2	**18.9**	19.7	**-0.211**	**-0.234**	0.119	-0.090
Punctelia borreri	30.0	20.0	15.9	**-0.203**	**-0.128**	**0.186**	-0.078
Ulota bruchii	3.3	**18.8**	20.6	**-0.201**	**-0.175**	**0.192**	**-0.148**
Dicranoweisia cirrata	17.9	19.8	18.0	**-0.193**	**-0.238**	**0.191**	**-0.185**
Evernia prunastri	35.0	20.1	16.5	**-0.158**	**-0.372**	**0.234**	**-0.423**
Candelariella reflexa s. l.	65.0	20.2	15.3	**-0.146**	**-0.282**	**0.146**	**-0.281**
Xanthoria parietina	76.7	20.3	13.3	**-0.146**	**-0.180**	0.107	-0.030
Hypotrachyna afrorevoluta	6.7	19.7	19.2	**-0.141**	**-0.178**	0.126	**-0.178**
Candelaria concolor	85.8	20.3	13.8	**-0.138**	**-0.138**	**0.267**	-0.091
Melanelixia glabratula	3.3	**19.2**	17.5	**-0.134**	-0.074	0.083	-0.074
Amandinea punctata	47.5	20.2	14.7	**-0.131**	**-0.230**	**0.197**	**-0.148**
Pulvigera lyellii	5.8	19.7	17.9	**-0.128**	**-0.194**	**0.174**	**-0.151**
Lecanora compallens	2.1	**19.1**	17.0	-0.123	**-0.143**	-0.007	-0.026
Candelariella xanthostigma	2.9	**19.3**	20.0	-0.121	**-0.177**	0.071	**-0.163**
Physconia grisea	33.3	20.2	15.4	-0.116	-0.113	**0.135**	-0.097
Melanohalea elegantula	7.5	19.7	18.0	-0.114	-0.107	**0.150**	-0.103
Lecanora barkmaniana	5.4	19.9	18.8	-0.098	**-0.181**	0.084	**-0.144**
Ptycostomum moravicum	2.5	**19.6**	18.3	-0.080	-0.039	0.097	-0.056
Hypogymnia physodes	11.7	20.1	17.0	-0.074	**-0.222**	**0.138**	**-0.268**
Hyperphyscia adglutinata	49.6	20.3	13.3	-0.067	0.039	0.022	0.040
Flavoparmelia soredians	27.1	20.3	14.9	-0.059	-0.117	**0.134**	-0.024
Polycauliona polycarpa	7.9	20.2	15.8	-0.049	**-0.200**	0.074	**-0.187**
Physcia adscendens	62.1	20.4	13.4	-0.043	-0.101	0.008	-0.023
Parmotrema perlatum	11.3	20.2	17.3	-0.040	-0.086	0.045	**-0.164**
Grimmia pulvinata	10.8	20.3	15.6	-0.028	-0.092	**0.138**	0.014
Polyozosia hagenii s.s.	3.8	20.4	14.9	-0.012	-0.035	0.012	-0.045
Lecidella elaeochroma	3.3	20.5	17.9	0.009	-0.097	0.054	-0.025
Lecanora chlarotera	2.1	20.5	16.0	0.012	0.045	0.034	0.008
Physcia caesia	13.8	20.5	16.0	0.012	-0.077	-0.047	-0.028
Polyozosia dispersa	2.9	20.6	14.6	0.013	0.011	-0.002	0.108
Physcia dubia s. str.	2.9	20.6	14.7	0.034	-0.024	-0.097	0.024
Syntrichia papillosa	20.8	20.5	14.0	0.044	0.109	0.009	0.038
Candelaria pacifica	8.3	20.7	15.9	0.047	-0.075	**0.129**	-0.094
Klebsormidium spp.	16.3	20.6	13.3	0.099	**0.181**	-0.090	**0.193**
Orthotrichum diaphanum	54.6	20.5	12.7	**0.132**	**0.269**	**-0.178**	**0.267**
Phaeophyscia nigricans	22.1	20.9	12.0	**0.223**	**0.186**	**-0.219**	**0.235**
Phaeophyscia orbicularis	77.5	20.5	13.2	**0.238**	**0.294**	**-0.237**	**0.391**

- Accordingly, **urbanophobic species** are: *Dicranoweisia cirrata, Hypnum cupressiforme, Lewinskia affinis, Amandinea punctata, Candelariella reflexa* s. l. *Evernia prunastri, Flavoparmelia caperata, Hypogymnia physodes, Lecanora barkmaniana, Lecanora expallens, Lepraria incana, Melanelixia subaurifera, Melanohalea exasperatula, Parmelia sulcata, Physcia tenella, Polycauliona candelaria, Punctelia jeckeri, P. subrudecta, Ramalina farinacea*, and *Trentepohlia* spp.
- The frequencies of these indicators largely follow the gradients of emissions and heat or drought stress, even tracing the "beneficial" effect of small parks in the overheated town center (Fig. 4).
- In grid squares with at least six inspected trees, mean frequency sums (FSUM) of urbanophobic species are closely correlated with the FSUM of reference lichens according to VDI 3957 Part 13 (Spearman's Rs = 0.88). The FSUM of urbanotolerant species is the opposite (Rs = -0.64; both cases $p < 0.05$; Fig. 4).
- While VDI 3957 Part 13 emphasizes the different eutrophication tolerance of lichens and defines nationwide (!) air quality classes, urbanotolerant and urbanophobic indicator mosses and lichens model the spatial variability of environmental stresses typical for large cities on a small scale. Moreover, these indicators allow a statistically substantiated delineation (see Fig. 5) of areas with deviation from the "norm" to be expected, e.g., according to technical measurements.

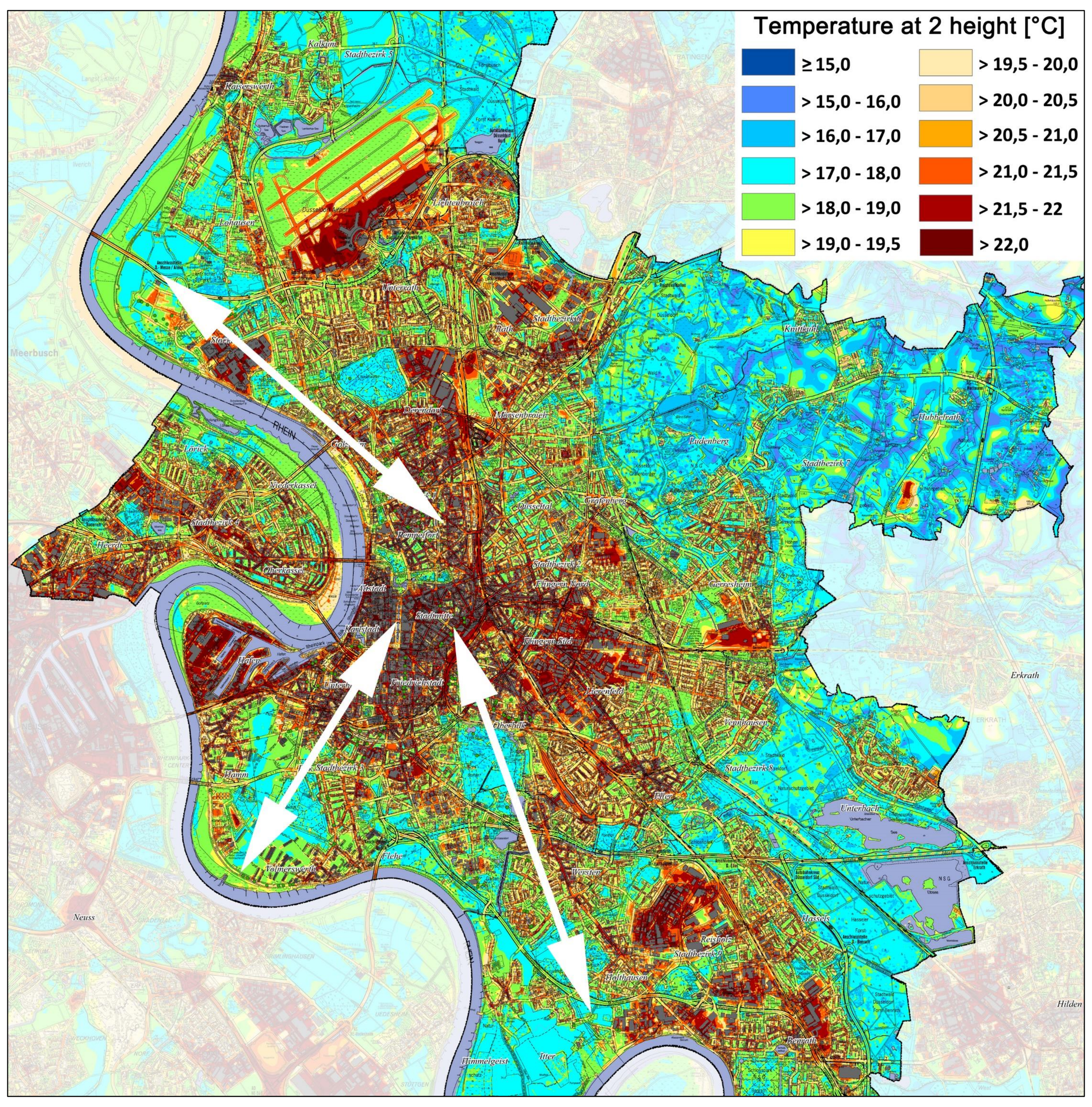

Fig. 1: Temperature in the Düsseldorf municipality at a height of 2 m in a standard night in June 2019 at 04:00 a.m.
Raster-based model results [2]. The white arrows show the location of the three transects.

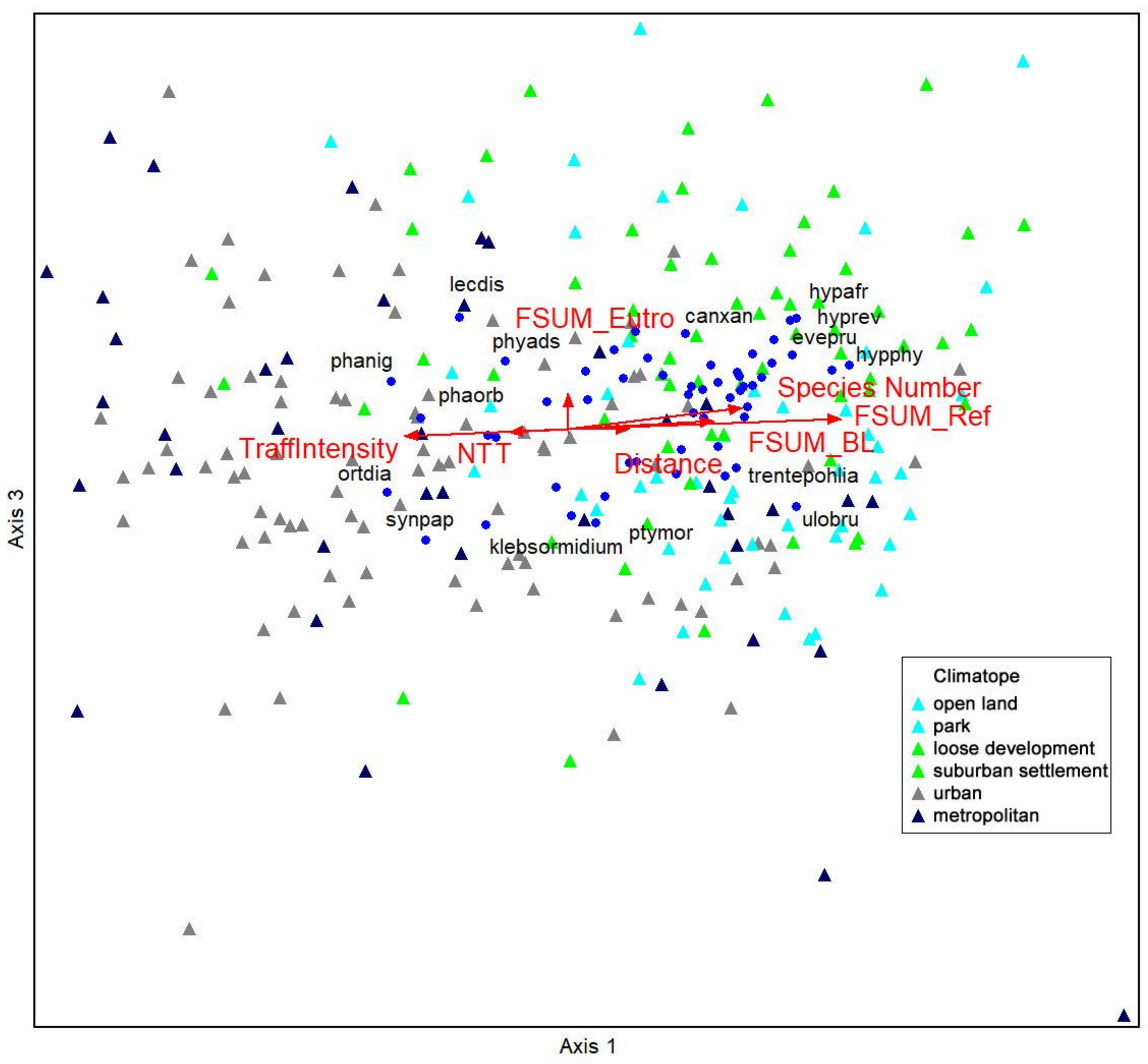

Fig. 2: NMS: traffic intensity, nighttime temperature (NTT), species number and frequency at the stands.
Data basis: Epiphytes recorded on standard trees in Düsseldorf 2019. **Traffic intensity**, subjective in four classes, see legend to Tab. 1. **Climatopes:** 1, open land; 2, park; 3, loose development; 4, suburban settlement; 5, urban; 6, metropolitan according to [3]. **FSUM**, frequency total of bryophytes and lichens (FSUM_BL), of eutrophication tolerant species (FSUM_Eutro, [1]) or of reference species (FSUM_Ref, [1]). **Distance** from roadside verge. **Species Number** of lichens and bryophytes. Blue dots: species. NMS was done with PCORD7 [4].

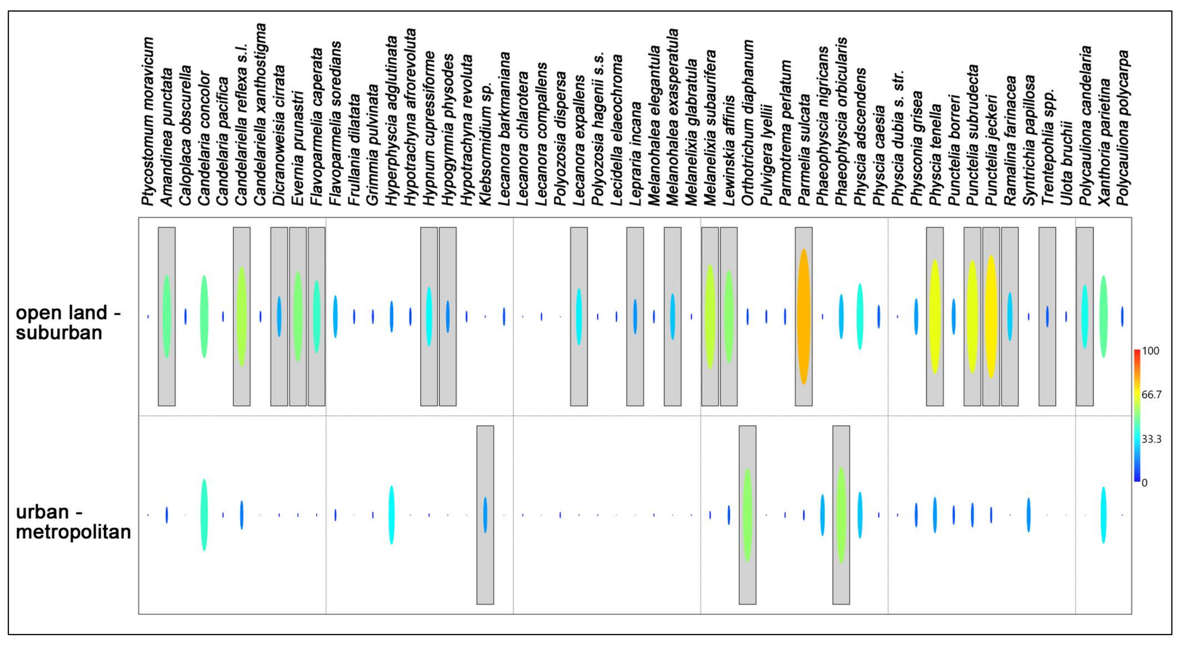

Fig. 3: Identification of species indicative of different groups of climatopes using indicator species analysis (INDVAL; Dufrene & Legendre 1997).
Epiphytes recorded on at least fife trees are respected. Two climatope groups were formed for the calculation, "open-land to suburban" (cooler, lower surface sealing) and "urban to metropolitan" (warmer, high sealing, low evaporation). The industrial climatope was excluded altogether. Boxed ellipses: $p < 0{,}05$, Bonferroni-corrected. INDVAL was calculated with PAST 4.09 [5].

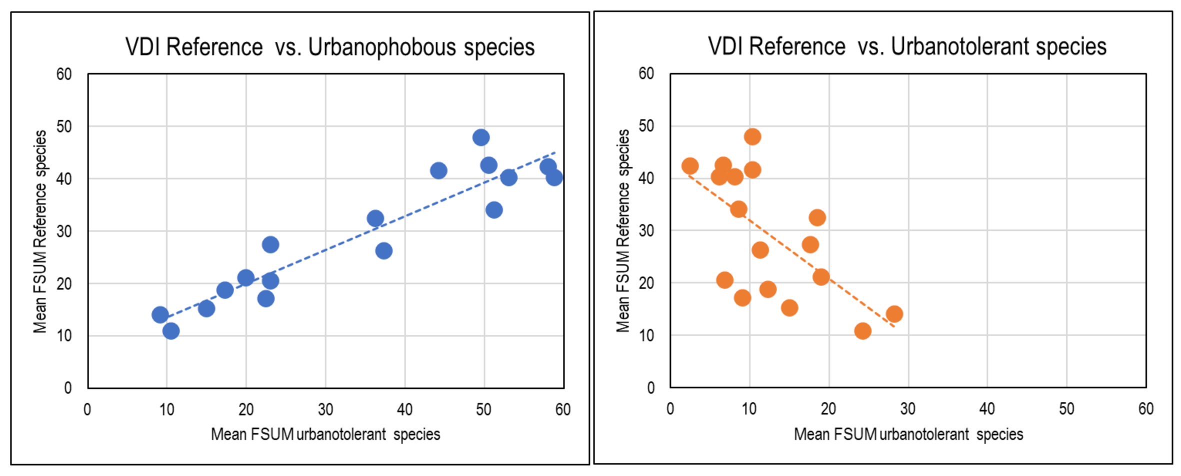

Fig. 4: Comparison of urbanophobic and urbanotolerant moss and lichen species with reference lichen species according to VDI 3957 Part 13.
The points show the mean frequency sums in 17 Gauss-Krüger grid squares in which at least six standard trees were inspected.

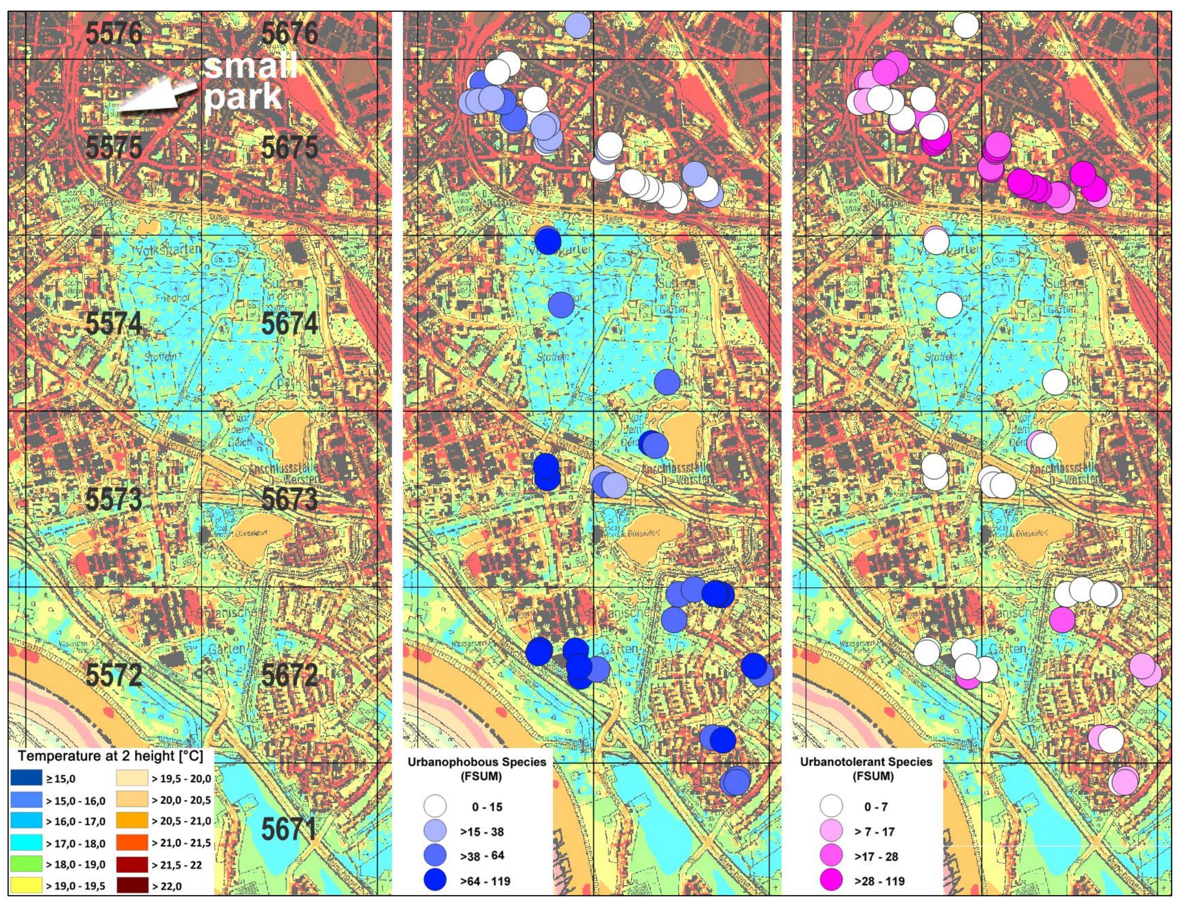

Fig. 5: Spatial variability of the respective frequency totals of urbanophobic and urbanotolerant species in grid squares of the of the southern transect.
Grid spacing 1 km. Exemplary grid square comparison regarding urbanophobic species frequency (blue dots): 5575 higher than 5675: $p < 0.01$; or 5575 smaller than 5672: $p << 0.001$ (Mann-Whitney U test).

References

[1] VDI (Verein Deutscher Ingenieure [ed.]) 2005: VDI-Richtlinie 3957 Blatt 13, 2005: Biologische Messverfahren zur Ermittlung und Beurteilung der Wirkung von Luftverunreinigungen auf Flechten (Bioindikation). - Kartierung der Diversität epiphytischer Flechten als Indikator der Luftgüte. - Beuth, Berlin, 27p.
[2] GEO-NET Umweltconsulting GmbH, Hannover, on behalf of the administration of the state capital Düsseldorf, 2019.
[3] Stadt Düsseldorf 2012: Klimaanalyse für die Landeshauptstadt Düsseldorf. Landeshauptstadt Düsseldorf, Umweltamt [ed.], 288p.
[4] McCune, B. and M. J. Mefford. 2016: PC-ORD. Multivariate Analysis of Ecological Data. Version 7. MjM Software Design, Gleneden Beach, Oregon, U.S.A.
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Supported by the Office for the Environment of Düsseldorf.

The author uses this data in a panel of the Commission on Clean Air of the VDI & DIN, which currently develops a new guideline on bioindication of urban climate effects. Comments are highly welcome. Poster presented at the BLAM conference in Graz, Austria, June 2022.

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