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Urbanization and homogenization – Comparing the floras of urban and rural areas in Germany

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ARTICLE INFO

Article history:

Received 27 October 2004

Received in revised form

26 May 2005

Accepted 2 June 2005

Available online 20 October 2005

Keywords:

Alien plant species

Biotic homogenization

Germany

Native plant species

Urbanization

ABSTRACT

The process of urbanization has resulted in an expansion of alien plant species and declines of native species, in particular already rare species. These processes may cause a greater similarity between different urban regions, i.e. biotic homogenization. We explored the relationship between urban regions and homogenization for plant species in Germany using (i) all plant species, (ii) only native species, (iii) all alien species and only those introduced (iv) before or (v) after 1500, respectively. We used the database FLORKART for species distribution on a 6 min latitude \times 10 min longitude (ca. 130 km²) scale. We calculated mean similarities for the 60 “most urbanized” cells. We then resampled 60 randomly drawn “less urbanized” cells and 60 “rural” cells and compared these results to the “most urbanized” cells taking distance effects into account. Urbanization does not have an overall effect on homogenization of all species, but native species as well as pre-1500 alien plant assemblages show effects of homogenization while post-1500 alien plant assemblages show the opposite effect. On a regional scale, urbanization is not unequivocally related to homogenization. This might be different when extending the analysed range across several bioclimatic regions. Specific urban habitats, or what remains of them, require special protection and management if the trend towards homogenization is to be avoided.

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1. Introduction

Urbanization acts in many ways on existing biodiversity (Sukopp and Werner, 1983; Gilbert, 1989; Wittig, 1991; Collins et al., 2000; Pickett et al., 2001), e.g. by altering quality of air, water, and soil (Sukopp and Starfinger, 1999), temperature regime and rainfall patterns (Landsberg, 1981; Oke, 1982), habitat fragmentation and disturbance (Kowarik, 1995). Although urbanization results in native habitat destruction and is regarded as a major threat to biodiversity (Wilson, 1988; Thompson and Jones, 1999; McKinney, 2004a; Liu et al., 2003), cities are richer in plant species than surrounding areas

(Walters, 1970; Haeupler, 1975; Klotz, 1990; Pyšek, 1993, 1998; Kowarik, 1995; Dobson et al., 2001; Blair, 2001; McKinney, 2002b; Araújo, 2003; Hope et al., 2003). This could in part be ascribed to the influx of alien species (McKinney, 2004b, 2002b; Kühn et al., 2004b) both from intentional and unintentional introductions, but also due to natural factors as at least in some regions cities were built up in areas of natural heterogeneity which supports natural biodiversity (Kühn et al., 2004b).

Thus there are several contrasting processes that can be observed: (i) introduction of often ubiquitous alien plant species (i.e. biological invasion), (ii) decline or extirpation of

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doi:10.1016/j.biocon.2005.06.033

native species, and (iii) a remaining high species richness of native species, based on those that are common. The increase in abundance and range expansion of common (alien and native) species and especially their translocation and the decrease in abundance and range contraction (or even extinction) of rare species will lead to biotic homogenization (Elton, 1958; McKinney, 2006), i.e. distinct biota will become more similar in species composition. However, ecological processes leading to biotic homogenization are not restricted to biological invasions but may result from other environmental modifications (McKinney, 2006; Olden and Poff, 2004a, 2003), such as urbanization. The degree of homogenization depends on taxonomic identities and of species in an assemblage as well as the rate and spatial pattern of species turnover (Olden and Poff, 2004b). In this account we do not focus on alien species as drivers of homogenization but on urbanization itself. There are some studies on homogenization for various taxa, e.g. vascular plants (Rejmánek, 2000; Weber and Pyšek, 2001; McKinney, 2004b; McKinney and Lockwood, 2001), snails (Cowie, 2001), freshwater faunas (Rahel, 2002) including fish (Rahel, 2000; Duncan and Lockwood, 2001), amphibians and mussels (Duncan and Lockwood, 2001), as well as marine biota (McKinney and Lockwood, 1999). However, little has been worked so far on the relationship between urbanization and homogenization prior to this special issue (e.g. Blair, 2001, on butterflies and birds).

In this paper, we focus on the spatial relationship between urbanization and taxonomic homogenization (*sensu* Olden et al., 2004) of local floras on a regional scale: we tested whether areas with high proportion of urban land cover are more similar to each other than areas with less or even little proportions of urban land cover with respect to vascular plant species classified into five not mutually exclusive groups: (i) all species, which comprise of (ii) only natives, (iii) all alien plant species which could be partitioned into those that immigrated (iv) prior to 1500 and (v) after 1500. In this way we examine alien species not as a driver of biotic homogenization but alien plant assemblages as a respondent to urbanization as well.

2. Materials and methods

2.1. Data sources

Species composition in grid cells in Germany was taken from the database FLORKART maintained by the German Federal Agency for Nature Conservation. This is the largest and most comprehensive database on plant distribution in Germany as it incorporates several more regional databases and was collated from several mapping schemes involving thousands of volunteers and from literature reviews. Data entries are classified into three periods: pre-1950, 1950–1979, since 1980. Mapping started in the 1960s with most emphasis in the 1980s and 1990s; furthermore many records from literature date back to the 19th century. Some parts of Germany lack sufficient record after 1980 because further mapping did not receive funding. Restricting our dataset to the period since 1980 would lead to biased distribution patterns and so a bias of similarity patterns. For this reason we used all datasets

after 1950. Yet, on average, ca. 82% (S.D. 17.5%) of the data of city grid cells are from after 1980. Similarly, an average of ca. 80% (S.D. 23.5%) of the non-city data is from after 1980 (Kühn et al., 2004b). The resolution we used is 6 min latitude \times 10 min longitude (ca. 130 km²), dividing Germany into 2995 grid cells, hereafter called “cells”. More information on FLORKART could be found in Kühn et al. (2004b) and plant distribution maps are in Haeupler and Schönfelder (1989), Benkert et al. (1996) and provided by FloraWeb (<http://www.floraweb.de>).

Mapping intensity still proved to be heterogeneous throughout Germany. We therefore restricted the analysis to those cells that were sufficiently well mapped. As there is no information on mapping quality, we chose 50 “control species” that are common and for which it is reasonable to expect that they occupy every cell. In this way, cells with less than 50 control species were not used in analyses (Kühn et al., 2004b). Using all cells (including the less well mapped ones with less than 50 control species) would lead to a considerable bias in our analyses as less well mapped areas are usually in rural areas and the number of mapped post-1500 alien species (see below) increases with mapping intensity. This reduction in mapping bias resulted in omitting ca. 1/3 of the cells, leaving 1928 cells for analysis.

Information on native and alien plant species as well as immigration status (being introduced either before or after 1500) were taken from the database BioFlor on biological and ecological traits of the flora of Germany (Klotz et al., 2002; Kühn et al., 2004c, see also <http://www.ufz.de/bioflor>). Following a long tradition in Central European floristic research (Holub and Jirásek, 1967; Schroeder, 1969; Sykora, 1990; Hill et al., 2002; Preston et al., 2002; Pyšek et al., 2004) we distinguish between alien plant species that immigrated before the discovery of the Americas (pre-1500 alien plant species or so-called “archaeophytes”) and those that immigrated after the discovery of the Americas (post-1500 alien plant species or so-called “neophytes”) in BioFlor (Kühn and Klotz, 2002). Both groups of alien plant species differ markedly in ecology, mode of introduction and/or distribution patterns (Pyšek et al., 2002; Kühn et al., 2003). For these reasons they were analysed separately. We only used information on those alien species that are naturalized (following Richardson et al., 2000; Pyšek et al., 2004) in Germany because casual species do not reproduce successfully, are not a permanent component of the flora and so unlikely to promote homogenization or impose a threat to native species. Combined data of FLORKART and BioFlor resulted in 2164 native plant species, 235 pre-1500 alien plant species, and 477 post-1500 alien plant species making up the species pool available for our analysis.

Data on land cover was taken from “Corine Land Cover” maps (see <http://dataservice.eea.eu.int/dataservice/> for more information) provided by the Federal Statistical Office of Germany (Statistisches Bundesamt, 1997) and transformed by the German Federal Agency for Nature Conservation into the grid format that we used. We defined cells with more than 1/3 urban land cover as “most urbanized” cells ($N = 60$), those with less than 1/3 urban land cover as “less urbanized” cells ($N = 1868$), and those with less than 5% urban land cover as “rural” cells ($N = 1099$). It should be noted that “rural” cells

are included in “less urbanized” cells. The cut-off level of 1/3 was chosen for the following reasons: The number of comparisons between N cells is $N(N - 1)/2$, it thus increases overproportionally. Having set N too high (i) results in too many comparisons which are time-consuming and (ii) results in too many cells occurring too close together so that effects of spatial autocorrelation (Fortin et al., 1989; Lichstein et al., 2002) may play a role. Having a cut-off level of 1/3 urban land cover resulted in exactly 60 cells which is in the same order of magnitude as in a related study on plant species richness of cities (Kühn et al., 2004b). This choice is time efficient and minimizes the effects of spatial autocorrelation.

2.2. Data analysis

There is a plethora of indices to measure similarity (or dissimilarity) of communities or assemblages (Legendre and Legendre, 1998). Jaccard's coefficient is one of the best-known (Legendre and Legendre, 1998) and was widely used in studies on biotic homogenization (McKinney and Lockwood, 2001 and references therein). This is computed as

$$S_{ja} = a/(a + b + c),$$

where a is the number of species shared between two cells and b and c are the numbers of species exclusively in either one or the other cell. Unfortunately, if there are large differences in richness between cells, similarities are small (Lennon et al., 2001). A suitable index to focus more precisely on compositional differences and not differences in species richness is Simpson's index (Brown and Lomolino, 1998; Lennon et al., 2001):

$$S_{si} = a/(a + \min(b, c)).$$

Koleff et al. (2003) tested some basic properties of 24 similarity indices (including Jaccard and Simpson). Simpson's index performed best in most of the tests. Although we calculated similarities using both coefficients, we only present the results of Simpson's similarities in detail.

For comparative reasons we calculated both indices of similarity for the following groups of plant species: (i) all species, (ii) native species, (iii) all alien species, (iv) pre-1500 alien species (v) post-1500 alien plant species.

Similarity indices were calculated for all 60 “most urbanized” cells and 60 randomly sampled “less urbanized” cells and “rural” cells, respectively, resampled 999 times. We calculated significant differences between the “most urbanized” cells and the (i) “less urbanized” cells and (ii) the “rural” cells from the confidence interval (CI) of the z standard deviate

$$z = (\text{observed value} - \text{mean}(\text{resampled values})) / \text{standard deviation}(\text{resampled values}),$$

where the observed value is the mean of the similarity indices of the “most urbanized” cells and the resampled values are the 999 means of each of 60 randomly sampled cells.

We preferred this resampling method over ordinary regression of similarities on an urban gradient for several reasons: (i) sample sizes between the different urbanization classes differs in two orders of magnitude, (ii) this procedure is less sensitive to effects of spatial autocorrelation and (iii) it does not calculate with inflated degrees of freedom (ordinary sta-

tistics on distance matrices use $N(N - 1)/2$ “data points” resulting from only N “cases”).

The similarities of the species composition within cells may decrease with increasing distance (McKinney and Lockwood, 2001). We therefore plotted this relationship of similarity indices against distance, measured as the Euclidean distance between cells (given in “grid cell distances”; one “grid cell distance” ~ 11.4 km), by transforming the two-dimensional distance matrices to one-dimensional vectors. Regressions could be computed from these vectors. For the sample regression of the 60 “most urbanized” cells we used a conservative approach and calculated the significance of the slope using $N - 2 = 58$ degrees of freedom instead of $(N(N - 1)/2) - 2 = 1768$. However, within the resampling process we did not compute the significance for each single slope.

If “most urbanized” cells were randomly distributed across Germany, the distance effect on similarity would be negligible. As “most urbanized” areas are not randomly distributed across Germany but much closer, we corrected for distance by using the residuals of the regression of similarities on distance as a measure of similarity accounted for distance (McKinney and Lockwood, 2001). To preserve the original differences in similarity values between the five plant species groups, we placed their similarities simultaneously in the regression model.

Cities are not randomly distributed (Kühn et al., 2004b) and in particular located in areas below 300 m a.s.l. (58 of 60 “most urbanized” cells). We therefore performed the analyses twice: (i) for all cells and (ii) restricted to the cells below 300 m a.s.l.

Performing multiple tests on the same data set increases the α -error (rejecting the correct null hypothesis). To avoid this problem, we used sequential Bonferroni correction (Rice, 1989) on all error probabilities in a table calculated for one coefficient of similarity. This method, however, is also debated (Cabin and Mitchell, 2000; Moran, 2003; Garcia, 2003). We therefore provide both the original and the adjusted error probability.

All analyses were performed using free software R (R Development Core Team, 2004, <http://www.r-project.org>).

3. Results

The average number of native species is higher in the “most urbanized” cells (mean native species richness 543.9 ± 79.5 , $N = 60$) than in “less urbanized” cells (mean native species richness 524.6 ± 90.7 , $N = 1868$) or “rural” cells (mean native species richness 507.6 , $N = 1099$). The range of values of the two latter groups is higher due to a much larger sample size (Fig. 1A). Alien species provide similar results: They are more species rich in “most urbanized” cells (pre-1500 alien plant species: 112.8 ± 18.1 , post-1500 alien plant species: 85.2 ± 14.1) than in “less urbanized” cells (pre-1500 alien plant species: 91.0 ± 21.4 , post-1500 alien plant species: 41.1 ± 19.7) or “rural” cells (pre-1500 alien plant species: 85.1 ± 20.2 , post-1500 alien plant species: 34.4 ± 14.7).

Calculating the species proportions by dividing the numbers of species within a cell by the total number in the species pool for each of the three respective groups (Fig. 1B) shows that the mean proportion of native species ranges between

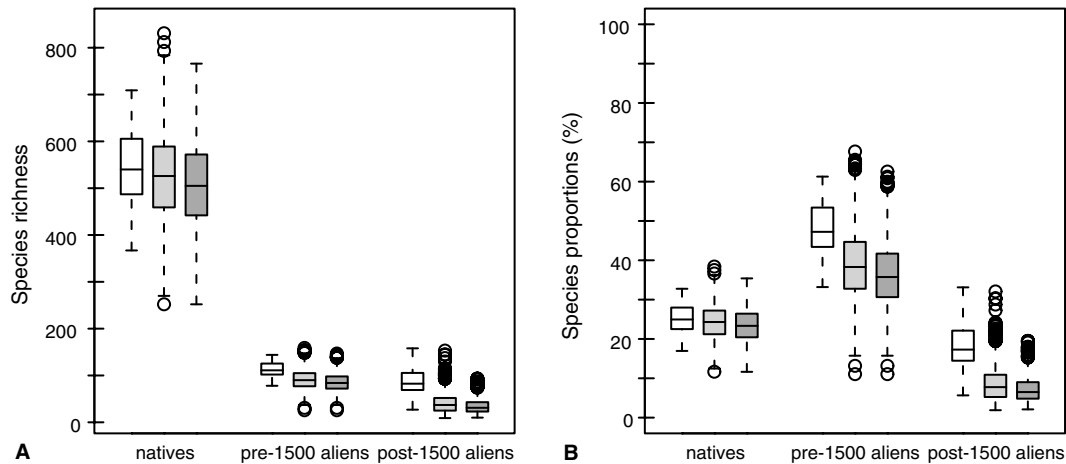


Fig. 1 – (A) Species richness and (B) relative proportion of the regional species pool of native, pre-1500 alien and post-1500 alien plant species. White bars represent “most urbanized” cells (urban land cover >33.3%, N = 60), light grey bars represent “less urbanized” cells (urban land cover ≤33.3%, N = 1868), dark grey bars represent “rural” cells (urban land cover ≤5%, N = 1099). Provided are median species richness (line), 25–75% quartiles (boxes) and ranges (whiskers). Open circles are provided if extreme values are more than 1.5 times the interquartile range of the box. The species pool is defined by the number of all species recorded in the database FLORKART for that respective status group (i.e. 2164 natives, 235 pre-1500 alien plant species, 477 post-1500 alien plant species).

25.1% and 23.5%, that of pre-1500 alien plant species is considerably higher (48–36.2%) and mean proportion of post-1500 alien plant species is lowest (17.9–7.2%).

The land cover classes in Germany are depicted in Fig. 2. Almost two thirds of all cells have ≤5% urban land cover and are termed here as “rural”, more than one third of the

cells have 5–33.3% urban land cover (“less urbanized” cells). These two classes make up almost 98% of the cells.

The mean similarity for the “most urbanized” cells (not correcting for distance) is often higher than “less urbanized” or “rural” cells. However, similarities decrease significantly with an increase of distance between cells (Fig. 3). This would not matter should the “most urbanized” cells be randomly distributed throughout Germany. However, mean Euclidean distance of “most urbanized” cells is lower than for randomly simulated distances (Fig. 4). Urban areas in Germany tend to

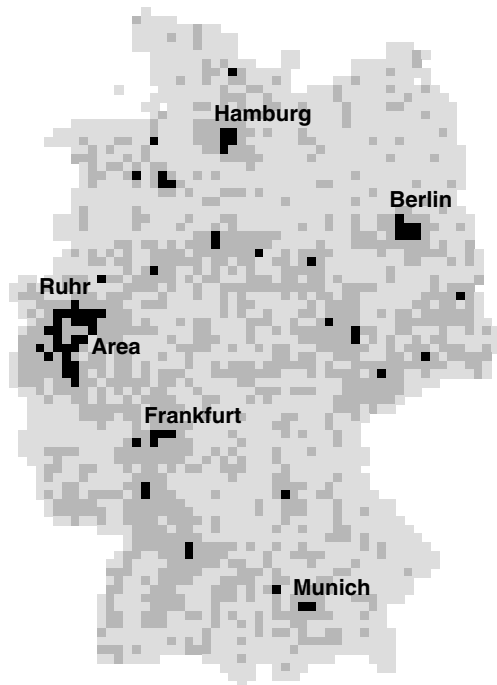


Fig. 2 – Distribution of relative urban land cover in Germany. Light grey cells have 5% or less urban land cover, dark grey cells have more than 5% urban land use up to 33.3% and black cells have more than 33.3% urban land cover.

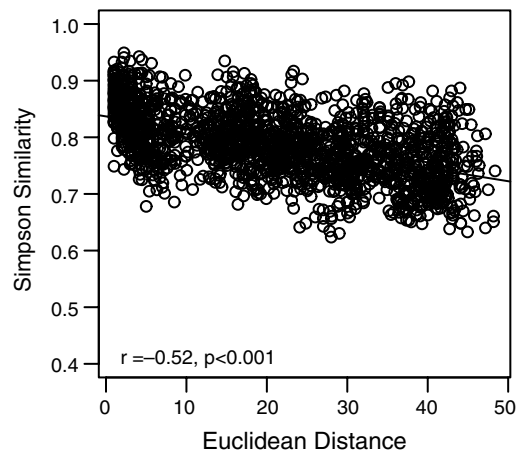


Fig. 3 – Regression of vectorized Simpson's similarity index on vectorized Euclidean Distances between cells, i.e. matrices are plotted as vectors. *r*: Correlation coefficient (=standardized slope); *p*: error probability, calculated with N = 60 (number of cells), i.e. 58 degrees of freedom, and not with inflated N = 1770 (number of resulting similarities or distances), i.e. 1768° of freedom.

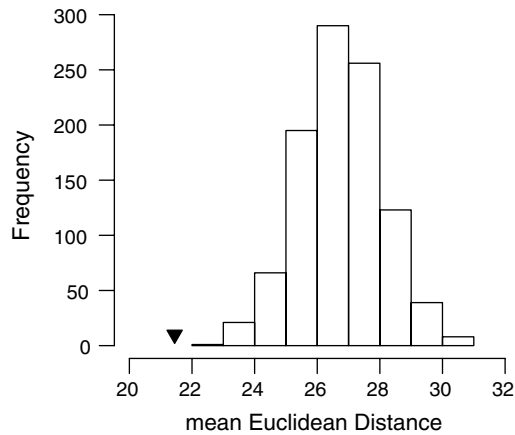


Fig. 4 – Histogram of the mean Euclidean distance of 60 cells randomly sampled 999 times. The mean Euclidean distance among the “most urbanized” cells (urban land cover >33.3%, $N = 60$) is indicated by the black triangle. Euclidean distance is measured in cells.

be clustered more centrally and seldom occur near borders with other states.

Simpson’s similarities restricted to cells below 300 m a.s.l. and corrected for geographical distance are presented in Table 1. The analysis shows that Simpson’s similarities of all plant species in assemblages from “most urbanized” cells are significantly higher than those from “less urbanized” or “rural” cells. For the different groups, however, the pattern is more differentiated. Simpson’s similarities of native plant assemblages are significantly higher for “most urbanized” cells than for “less urbanized” cells. The total alien species similarities are significantly lower for “most urbanized” cells than for “less urbanized” or “rural” cells, yet both groups of alien plant species provide different results: pre-1500 alien plant species are significantly more similar for “most urbanized” cells than for “rural” cells – so having a similar pattern to native plant species – whereas post-1500 alien plant species are significantly less similar within “most urbanized” cells than within other cell classes.

The basic trends of the results remain stable when using (i) original error probabilities or Bonferroni corrected error prob-

abilities, (ii) using all cells instead of only those occurring below 300 m a.s.l., and (iii) using Jaccard’s similarities instead of Simpson’s similarities. However, these differences are less pronounced when all cells are used in calculations (including those above 300 m a.s.l.) and we found that in our analyses the discriminating power of Jaccard’s similarities is often lower than for Simpson’s similarities.

The general trend in our study shows that pre-1500 alien plant species assemblages are most similar to each other while in contrast post-1500 alien plant species assemblages are least similar to each other; native plant species assemblages were intermediate.

Summarizing, similarities of total floras, native floras and pre-1500 alien floras are more similar in urbanized cells which supports the idea of homogenization. Complete alien floras and post-1500 alien floras are less similar in urbanized cells leading to differentiation.

4. Discussion

This study revealed that urbanization has led to homogenization for native plant species and for pre-1500 alien plant species. Post-1500 alien plant species assemblages were more heterogeneous within “most urbanized” cells than in “less urbanized” or “rural” cells. This pattern could simply arise from a positive relationship between similarity indices and species richness. Wolda (1981) performed extensive simulations on similarity indices and found that there was a strong dependence of sample size with species richness. Most similarity indices increase as the proportion of sampled species of the totally available species pool approaches unity (Wolda, 1981), this holds true for Simpson’s similarity. Thus, by chance, the similarities of the “most urbanized” cells should always be higher than those of the other classes. However, this was not the case for the post-1500 alien plant species (or for both groups of alien species when pooled). Furthermore Simpson’s similarity had the best overall performance of the tests of Koleff et al. (2003). We therefore conclude that our results were not unduly biased by this property of the index we used.

It is not only the statistical behaviour of indices but also the chosen scale that is relevant for the outcome of such anal-

Table 1 – Calculation of modified Simpson’s similarities restricted to cells below 300 m a.s.l. with different proportions of urbanization in Germany with correcting for distance effects

	Urban land cover >33.3%, $N = 60$	Urban land cover \leq 33.3%, $N = 1868$				Urban land cover \leq 5%, $N = 1099$			
	Similarity	Similarity	z Score	p	p_{adj}	Similarity	z Score	p	p_{adj}
Simpson’s similarities									
Total species	-0.0002	-0.016	3.407	0.001	0.002	-0.013	2.832	0.005	0.009
Natives	0.011	-0.017	4.640	<0.001	<0.001	-0.013	3.918	<0.001	<0.001
Total alien species	0.004	0.012	-2.159	0.031	0.043	0.005	-0.242	0.809	0.809
Pre-1500 alien species	0.083	0.067	2.303	0.021	0.043	0.059	3.331	0.001	0.003
Post-1500 alien species	-0.097	-0.046	-3.774	<0.001	0.001	-0.038	-4.466	<0.001	<0.001

Tests were calculated after 999 randomizations against cells with >1/3 urban land cover. N : sample size, z score: standard normal deviate, p : two-tailed error probability, p_{adj} : two-tailed error probability after sequential Bonferroni correction (Rice, 1989); positive z scores represent homogenization, negative z scores represent differentiation.

yses. Following Scheiner et al. (2000), scale could be separated into *sampling unit* (e.g. plot), *grain* (level of resolution), *focus* (level at which the analyses take place) and *extent* (span of the geographic area of the samples). For our analyses, the last three components were relevant. We chose a medium *grain* for our analysis, this was successful in answering many ecological questions about distribution pattern and environment with different *focus* and similar *extent* (countries of comparable size) than this analysis (Heikkinen et al., 1998; Roy et al., 1999; Lennon et al., 2000, 2001; Warren et al., 2001; Hill et al., 2001; Heikkinen et al., 2004) and with similar *focus* and *extent* as well (Deutschewitz et al., 2003; Kühn et al., 2003, 2004a; Kühn et al., 2004b). While the *grain* of our analyses has been found to be suitable, it is especially *extent* which is crucial for the results. Our results would clearly change depending on the spatial extent and focus (e.g. either the globe or a region). We consider that the range expansion of alien species and decrease of native species will almost inevitably lead to homogenization on the global scale (Weber and Pyšek, 2001; Collins et al., 2002). We could show homogenizing effects of urbanization for native plant species assemblages, pre-1500 alien plant species assemblages and also for all species pooled together. Even without requiring biological invasions this process could be explained, e.g. by the extirpation of different usually rare species following urbanization (Olden and Poff, 2004a). On the global (or continental) scale urbanization will lead to homogenization also among exotic species' assemblages as the same suit of exotics could be found in many cities (McKinney, 1998). However, on local and regional scales, species richness may be increased following range expansions of alien species (Sax et al., 2002; Sax and Gaines, 2003). This might lead to more heterogeneous assemblages, termed differentiation (Olden and Poff, 2004a), e.g. arising either from invasion of different species or extinction of the same species in different regions. Rejmánek (2000) and McKinney (2002a) observed differentiation depending on the distance between study areas. This may also be explained another way: urban areas promote post-1500 alien species while pre-1500 alien plant species are associated with good arable soils (Kühn et al., 2003). Hill et al. (2002) termed species that are more frequent within urbanized areas than elsewhere were "urban specialists". The proportion of post-1500 alien plant species out of the total species pool is much lower than that of pre-1500 alien plant species within and outside "most urbanized" areas. However, the number of archaeophytes is limited by definition so it cannot increase, in contrast to neophytes, for which there is a continuing influx (Pyšek et al., 2003). If we assume that urban areas provide a wider range of habitats that become colonized by a lower proportion of potential species, this could result in a more heterogeneous flora. This pattern might even be enhanced shall there be only a small number of post-1500 alien plant species that are able to sustain outside urban land uses (e.g. *Impatiens parviflora* in moist oak-hornbeam forests). Furthermore, all of our studied areas are within the same bioclimatic region. Given that a high number of very ubiquitous species occur within a variety of bioclimatic or biogeographic regions, could lead to some large scale homogenization (McKinney and Lockwood, 2001) that might not be detected when investigating below that critical scale. This could explain the different

results obtained for birds and butterflies along an urban–rural gradient in North America (Blair, 2001). While there is a strong biogeographic gradient between those two areas, we did not find such a gradient, which in turn resulted in much higher similarities among the German locations than among the US ones. Similarly, in neighbouring states Rejmánek (2000) discovered lower similarities of exotics compared to natives but in distant states it was the other way round.

Here we have compared the floras of more and less urbanized areas. Other, natural factors might covary with urbanization. This is because cities are not randomly distributed but occur in hotspots for natural plant species richness (Kühn et al., 2004b). For this reason it is not possible to ascribe "urbanization" being the cause for this pattern. As with native plant species richness, the observed patterns might be a consequence of the natural species compositions of the areas studied because of natural environmental factors such as geology. It would be useful if we could know the species compositions of areas yet to be urbanized. Then we could test if a "space for time" substitution is possible. However, because historical data for many areas is scant or lacking, the earlier knowledge of the species composition in area that now have become urbanized is poor. Klotz and Il'minskich (1988) studied the temporal change of the urban floras of Halle (Central Germany) and Kazan (Russia, Republic of Tatarstan) which are from two bioclimatic regions. Both cities had fairly complete historical plant species lists (Kazan: 1900; Halle: 1848) and relatively recent plant species lists (Kazan: 1980; Halle: 1983) and both have a comparable species number in total. Both cities showed a comparably high species turnover (almost 50%) over time, with much more turnover for alien plant species (which invaded) and much less for natives (where some were extirpated). More interestingly in this context is the dynamic considering the change in similarities of the species compositions of both cities in time: while some increase the similarity of native species assemblages of the two cities was observed, almost no decrease in similarities regarding pre-1500 alien plant species assemblages and a more pronounced decrease in the similarities of post-1500 alien plant species assemblages was observed. Overall, the similarity remained much the same over time for both cities when all data were pooled. Despite the cities occurring within two different climatic zones and being separated by more than 2500 km, there was no effect of homogenization. The pattern of spatial homogenization as described in this study and of temporal homogenization as described in the case study of Klotz and Il'minskich (1988) are quite similar so that we hypothesize that changes over time will be reflected by patterns in space. A space for time substitution is therefore possible.

4.1. Conclusions: urbanization, homogenization and conservation

While biotic homogenization is often regarded as a sole consequence of biological invasions we could show that urbanization also has an effect. Both urbanization and invasion jointly have a differentiating effect on plant species composition. Possible explanations for the patterns found for natives and pre-1500 alien species may be due to an increase in common native

plant species and declines and local extinctions of different rare native species by urbanization. The differentiation of post-1500 alien assemblages could be explained by invasion of different alien species within different urban regions (Olden and Poff, 2004a). These processes require attention when drawing up conservation plans for urban regions. German cities are very rich in native plant species and include red-list species due to natural heterogeneity. Specific habitats, or what remains of them, require special protection if the trend towards homogenization is to be avoided. Biological invasions are generally regarded as having negative impacts, but do add to species richness; and some alien species are able to survive adverse conditions within urban areas where native plants are unable to survive (Wittig, 1991). Cities may also act as a source of propagules that may enable range expansion into more rural areas. A promising approach is to raise the awareness of city residents on the importance of remnants of native habitats (McKinney, 2006) and involve them in general management so to improve environmental conditions allowing native plant species better advantages in urban areas.

Acknowledgements

We would like to thank Mike McKinney for inviting us to this special issue. The German Federal Agency for Nature Conservation, namely Hans Fink und Rudolf May, provided FLORKART and land use data. Herbert Sukopp pointed out that cities are usually located in areas below 300 m a.s.l. Mike McKinney, Petr Pyšek and two anonymous referees provided very valuable comments on the manuscript. Dan Michin improved our English.

This work was funded by the UFZ – Umweltforschungszentrum Leipzig-Halle through the programme topic 5.1 (Mankind and Global Change: cities and contaminated land) of the “Helmholtz Research Field ‘Earth and Environment’” and the EC within FP 6 Integrated Project ALARM: Assessing Large scale environmental Risks with tested Methods (GOCE-CT-2003-506675).

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