Perspectives in Plant Ecology, Evolution and Systematics 12 (2010) 235–244

Contents lists available at ScienceDirect

Perspectives in Plant Ecology, Evolution and Systematics

journal homepage: www.elsevier.de/ppees

Research article

Changes in the functional composition of a Central European urban flora over three centuries

Sonja Knapp [a,*], Ingolf Kühn [a], Jens Stolle [b], Stefan Klotz [a]

[a] UFZ, Helmholtz Centre for Environmental Research, Department of Community Ecology, Theodor-Lieser-Straße 4, 06120 Halle (Saale), Germany
[b] University of Halle, Institute of Biology/Geobotany, Am Kirchtor 1, 06108 Halle (Saale), Germany

ARTICLE INFO

Article history:
Received 24 September 2008
Received in revised form
20 October 2009
Accepted 2 November 2009

Keywords:
Alien species
Historical dynamics
Life-history traits
Urban ecology
Vascular plants
Vegetation dynamics

ABSTRACT

Documents on historical floras provide unique opportunities to analyze past changes and to show trends in biodiversity. We studied the historical and recent flora of the city of Halle in Central Germany. Our earliest records date back to the year 1687; the youngest were sampled in 2008. More than 20 other floras provide information for time in-between, covering *ca.* 320 years in total. We checked all historical plant occurrences for plausibility. The species turnover of 22% that took place in the study period should also yield changes in the functional composition of the flora. We identified native species and archaeophytes that went extinct since 1689 and 1856, respectively, and all neophytes that were introduced since 1689 or 1856. This 'double' calculation minimized the influence of so-called possible pseudo-absences. Contingency tables assisted to identify trait states which were associated with extinction or introduction. Time-series analysis identified temporal trends in trait state ratio development after testing for temporal autocorrelation. Within the study period, species of bogs, nitrogen-poor habitats or plants with helomorphic leaves got extinct more often than expected by chance. Species dispersed by humans, plants preferring nitrogen-rich or warm habitats, shrubs and trees, and species with mesomorphic leaves were, amongst others, over-represented among introduced neophytes. Land-use changes such as the transformation from agriculture to urban land use or the drainage of bogs are discussed as main drivers of these developments. Additionally, climatic changes, contamination of habitats and gardeners' preferences for specific plants are presumed to having caused floristic changes. Our study shows the vast influence humans had and still have on biodiversity by intentionally or unintentionally selecting specific functional plant types and thus changing the composition of the flora.

Introduction

Urbanization has shaped European landscapes for many centuries. The first towns already developed around 700 B.C. in the Mediterranean (Antrop, 2004). Since these early times, urbanization spread all over Europe which is today highly urbanized, with 72% of the total population living in urban areas (only Latin and Northern America have higher rates of urban population with 78% and 81%, respectively; United Nations, 2006). In the 18th century and especially in the 19th century, industrialization and trade caused the growth of many European towns and cities. However, the main phase of urbanization took place in the 20th century with its rapid developments in transportation techniques (Berry, 1990; Antrop, 2004; United Nations, 2006). The increased mobility, together with other factors, such as political frameworks, enabled urban sprawl, which was especially strong in the second half of the 20th century (Kasanko et al., 2006).

Urbanization changes landscapes profoundly. In Europe, land use often changed from agricultural to urban but also from semi-natural to urban (Kasanko et al., 2006). These changes have severe impacts on climate, biogeochemical cycles, hydrology and biodiversity (Vitousek et al., 1997): compared to rural surroundings the high heat capacity of buildings together with heating increases urban temperatures (Landsberg, 1981; Oke, 1982; Sukopp, 1998); the emission of pollutants from traffic, industries and heating changes the composition of the atmosphere (Berry, 1990); decomposition rates and nitrification rates increase in urban relative to rural forest stands (McDonnell et al., 1997); the high proportion of sealed surfaces reduces infiltration capacity and groundwater replenishment (Sukopp, 1998); proportions of native species decrease, while proportions of non-native species increase (Kühn et al., 2004a; Kowarik, 2008); compositional

* Corresponding author. Tel.: +49 345 558 5308; fax: +49 345 558 5329.
E-mail addresses: sonja.knapp@ufz.de (S. Knapp), ingolf.kuehn@ufz.de (I. Kühn), jens.stolle@botanik.uni-halle.de (J. Stolle), stefan.klotz@ufz.de (S. Klotz).

1433-8319/$ - see front matter © 2009 Rübel Foundation, ETH Zürich. Published by Elsevier GmbH. All rights reserved.
doi:10.1016/j.ppees.2009.11.001

similarity of species of urban regions differs from those of rural regions (Kühn and Klotz, 2006); moreover, the phylogenetic diversity of plant assemblages decreases (Knapp et al., 2008a).

It is clear from the characteristics of urban environments that not every species is able to persist there. Indeed, species with adaptations to disturbance, fragmentation, high temperature, or drought, i.e. species with traits that enable them to cope with urban conditions, are more frequent in cities than in the countryside (Wittig and Durwen, 1982; Lososová et al., 2006; Knapp et al., 2008b). Many of such differences in the functional composition of urban and rural species assemblages have been shown in space, and other studies showed that trait state composition also changes over time (Chocholoušková and Pyšek, 2003; Pyšek et al., 2004a, 2004b; van der Veken et al., 2004; Tait et al., 2005; Tamis, 2005; Lavergne et al., 2006).

We studied the development of the flora in the city of Halle in Central Germany over 320 years. The earliest available relatively complete floristic records for Halle date back to the year 1687, the most recent published records are from 2004. For the three centuries in-between, several floristic mappings are available, covering nearly the whole time-span. We are not aware of many other databases on terrestrial plants covering such a long time-span (but see Preston (2000) for Cambridgeshire and Middlesex, UK). This gives us an unique opportunity to study changes in plant species assemblages exposed to more than 300 years of urbanization. We hypothesize that changes over time reflect differences between urban and rural areas in space, with species adapted to urban characteristics increasing their proportion in the flora as urbanization intensifies.

Materials and methods

Study area

The city of Halle is situated in Central Germany, south-east of the Harz Mountains (city centre: 11°58′19″E, 51°28′59″N; Fig. 1). It covers an area of 135 km^2. With a mean annual temperature of 9 °C (range of mean monthly temperature *ca.* 0–19 °C) and an annual precipitation of 480 mm with a peak in summer, the climate is subcontinental and relatively dry, at least in the Central European context (Müller-Westermeier et al., 1999; 2001). The low precipitation is caused by the rain shadow of the Harz Mountains. Without anthropogenic influence, forests of sessile oaks (*Quercus petraea* Liebl.), hornbeam (*Carpinus betulus* L.), and lime-tree (*Tilia cordata* Mill.) would be the main zonal vegetation (Institut für Länderkunde Leipzig, 2003).

The river Saale flows through the city at an altitude of approximately 70 m a.s.l. Within the city area, the river divides in several arms, forming islands and giving room to floodplain forests. The northern part of the city is characterized by porphyric rocks that border the Saale valley. The south-western part of Halle is built on Triassic and Tertiary bedrock. The two parts are divided by a fault line, running directly through the city centre and giving rise to a salt spring from Late Permian (Wagenbreth and Steiner, 1982). The occurrence of salt was the basis for the development of Halle, besides the rich occurrences of lignite (Walossek, 2006). In the eastern part of the city area, older bedrocks are nearly completely overlaid by quaternary bedrock.

The dominant type of land-use change in our study area in the last 300 years has been urbanization, however, there are still also small agricultural and semi-natural areas left within the borders of the city. Although these are no urban habitats, they, too, have changed in the study period and are influenced by urbanization.

Data sources

Species data

We analyzed several recent and historical floras as well as smaller manuscripts with descriptions of plant occurrences of more than 18 authors and divided the data into seven time

Time	Population
1820	21,000
1900	156,600
1952	293,100
1990	309,400
2008	231,800

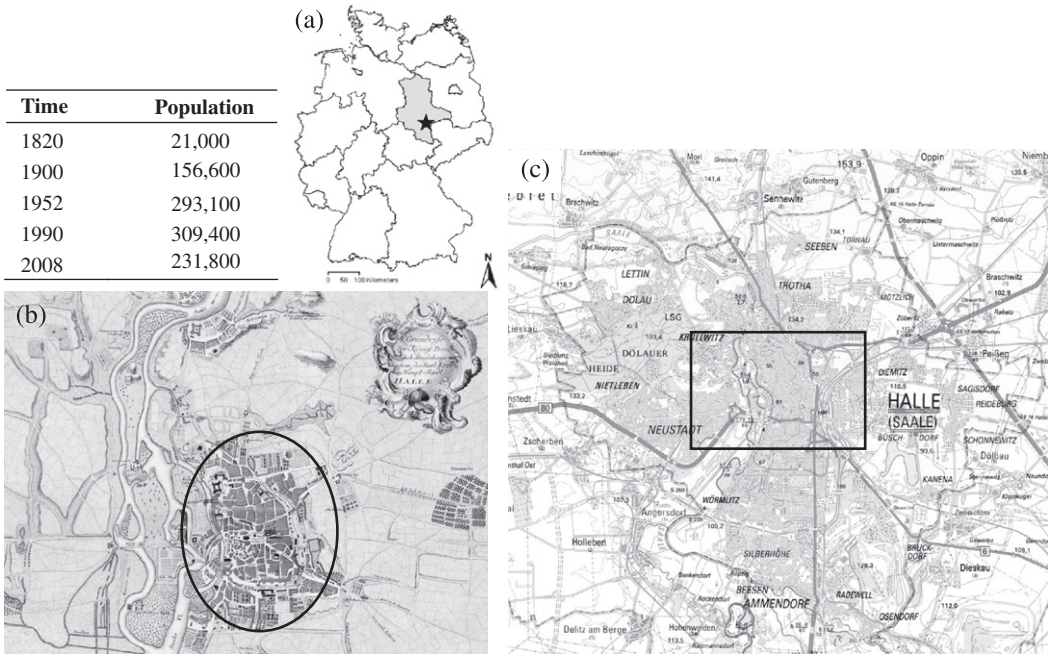

Fig. 1. Study area. (a) Location of the city of Halle (black star) in Central Germany, federal state Saxony-Anhalt (grey); (b) The city of Halle and its surroundings in 1740 – the circle roughly indicates the city area; (c) The city of Halle in 2002 – the rectangle shows the area of map (b). The small table shows the population development in the city with numbers from Stolle and Klotz (2004) for 1820, and http://www.halle.de (other numbers). Map (b) is the reprint of a historical city map (copper engraving attributed to Johann David Schleuen, 1740; the original copy of the map is stored in the German National Library Berlin, Preußischer Kulturbesitz.) Map (c) is the topographical map 1: 100 000 – TK 100 RK/Sheet 4 (Landesamt für Landesvermessung und Datenverarbeitung Sachsen-Anhalt, 2002).