Diversity of flora and vegetation in European cities as a potential for nature conservation in urban-industrial areas – with examples from Berlin and Potsdam (Germany)

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Abstract

Cities and urban-industrial conglomerations are continuously gaining importance as living spaces for humans. Sustainable urban development as well as nature conservation in cities are and will be the major tasks of the people living in densely populated areas. Cities have to be regarded as a new type of environment with species compositions and habitats peculiar to urban-industrial areas. This new type of environment can be highly diverse on the species and habitat level. Reasons for this are (1) the heterogeneity of settlement and land use patterns in cities, (2) the introduction and dispersal of non-native species directly or indirectly through transport and traffic, (3) the evolution of new taxa (speciation) on man-made sites within and outside settlements and (4) the floristic richness of a given surrounding geographical area.

Selected habitats in Berlin and Potsdam (NE-Germany) have been investigated with a focus on diversity of flora, vegetation and land use patterns. The correlation between the number of plant species and the diversity of land use patterns is shown with a transect from the centre to the outskirts of Berlin. In residential areas built in the 1920s and 1930s, the flora is studied from a historical and current perspective to assess their diversity of wild-growing indigenous and non-native plant species, wild-growing ornamental plant species and planted trees. ***Historical landscape gardens in Potsdam show a characteristic composition in flora and vegetation (e. g. meadows and lawns) very different from all other land use types in the city and its surroundings due to their historical garden design and the existence of semi-natural habitats. Biological diversity in cities should be recognized as an opportunity for nature conservation and a challenge for sustainable development of urban-industrial areas. Main principles of nature conservation in cities are discussed, which are closely related to the maintenance and development of biological diversity in cities, aiming at habitat as well as species diversity. These are (1) historical continuity, (2) urban ecological zonation on a small scale (city), (3) maintenance of land use diversity on a large scale (city districts, residential areas etc.), and (4) maintenance of local variety.***

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INTRODUCTION

Biological diversity (biodiversity) was introduced as a major objective in world-wide conservation strategies at the conference in Rio de Janeiro in 1992. It is quite recent knowledge that not only natural and semi-natural landscapes can be highly diverse in flora, fauna, and habitats, but that also urban and industrial areas show a wide variety of habitats, organisms, and communities.

Urban-industrial ecosystems differ from non-urban ones in a number of ways. Although most of the factors which affect ecosystems in the cities (e.g. climate, soil, water conditions, human impact) are comparable to those in non-urban areas, the combination of these factors creates unique urban-industrial ecosystems. So, the city has to be regarded as a "new type of environment" with species compositions and habitats peculiar to urban-industrial areas.

This contribution on biodiversity in European cities will focus on the species and habitat level with special regard to selected habitats in Berlin and Potsdam (NE-Germany). In addition to more natural landscapes, conservation of biodiversity in cities should be a major task for nature conservation. In this paper, recommendations are given, derived from the investigated habitats in Berlin and Potsdam.

SPECIES DIVERSITY IN EUROPEAN CITIES

Numbers of species in European cities are well documented. Species numbers of vascular plants correlate strongly with the population size and less strongly with the area of cities (Table 1, Pysek 1993). In small and medium-sized towns, between 530 and 560 species of ferns and flowering plants are usually found. Between 650 and 730 species are found in cities with 100,000 to 200,000 inhabitants, 900 and 1,000 species in cities with populations ranging from 250,000 to 400,000, and in cities with more than a million inhabitants, the number of species usually exceeds 1,300 (Klotz 1990).

There are various reasons for the high species diversity in urban-industrial areas:

- Urban agglomerations are very heterogeneous, consisting of a variety of settlement and land use patterns (Sukopp and Werner 1983; Sukopp 1998a). In many European settlements these patterns are qualitatively and quantitatively recorded employing habitat mapping (for Germany see Schulte et al. 1993).

- Historically, species which have been introduced into an area through human activity directly or indirectly, often begin their dispersal in urban areas and therefore occur there most frequently. For the city of Berlin, Kowarik (1992a) gives the most successful non-native tree species, occurring spontaneously in different habitats (Table 2). The most frequent non-native species on waste land, built-up areas, green spaces, forests and wetlands are Robinia pseudoacacia, Acer negundo and Prunus serotina. These trees were introduced from North America in the 18th and 19th century and it took from less than 50 to 180 years for them to spread over a wide range of areas and habitats within and outside settlements.

With an increasing number of inhabitants, trade and traffic in and out of the city increase, and thus the proportion of non-native species in the flora increases (Pysek 1998). So, in addition to the native species which find adequate living conditions and remain in traditional habitats in the cities, the high species diversity in urban areas depends strongly on the occurrence of non-native species. Trepl (1995) states that there still will be a considerable increase in the number of non-native plants and animals in settlements as a consequence of the world-wide mixture of species.

- Various examples are documented for the genetic changes and the evolution of new taxa, which occur especially on man-made sites within and outside of settlements (Scholz 1993a; Sukopp and Scholz 1997). Table 3 lists several species, which most probably have evolved on anthropogenous sites within and outside European settlements. Closest relatives of these species can be found in Europe as well as in North America and Asia. New taxa on anthropogenous sites can evolve through isolation, hybridization and introgression (Anderson 1956; Jalas 1961; Stace 1975; Abbott 1992). In particular, the genus Oenothera, and the Taraxacum officinale and the Ranunculus auricomus complex seem to be in an evolutionary stage of rapid speciation. If their present and past distributions are strongly restricted to man-made sites, these taxa are called "anecophytes" (Zohary 1962; Sukopp 1998b). These newly evolved anecophytes do not have an original habitat in natural vegetation.

- Pysek (1989) states that floristic richness of a given surrounding geographical area may also influence the number of species in cities.

SPECIES AND VEGETATION DIVERSITY OF SELECTED HABITATS IN BERLIN AND POTSDAM

Investigation sites and methods

The investigation includes different sites in Berlin and Potsdam (Figure 1) with a transect (A to G) running from the center to the outskirts in the south-east of Berlin, residential areas of the 1920s and 1930s and parks in the city of Potsdam. Vegetation relevés (Braun-Blanquet 1964) in the parks of Potsdam were combined with floristic surveys in the residential areas of the 1920s and 1930s and the transect through the eastern part of Berlin within the study of species and vegetation diversity. The investigated transect (Figure 1) is based on the grid of the inventory of the flora of Berlin (Böcker 1994). The size of each study area within the grid is about 8 km^2. During the growing seasons of 1994 until 1997 all wild-growing vascular plant species were registered. Nomenclature mainly follows Wisskirchen and Haeupler (1998).

Land use types and habitats are differentiated according to "Biotope plan references for a populated area and its periphery" (Schulte et al. 1993). The species lists were evaluated using groups of phytosociologically and ecologically similar species (Kunick 1974). The information about the time of immigration was taken from Kowarik (1988). The assessment of threatened species refers to the Red List of Berlin (Böcker et al. 1991) and Brandenburg (Benkert and Klemm 1993).

Results

Transect through the eastern part of Berlin. The transect study is considering the diversity of land use types as well as the diversity of the flora. Figure 2 shows the correlation between both of these variables from the center to the outskirts of Berlin. In terms of land uses, the least heterogeneous areas were the densely built-up inner city areas and the outskirts with mainly forestry land use. Most different land use patterns were found in the study areas C, D, and E where urban structures are closely associated with open spaces like large parks, urban forests and larger wastelands. With the exception of the study area A in the city center, the number of vascular plant species is linked with the number of land use types.

The very high number of species in A, in spite of the low number of land use types, is based on the special situation of Berlin after the Second World War. Because of the political division of the city, a former freight station was closed and the area of 10 hectares became urban wasteland for many years. The area, which had suffered from intensive human impact, now became habitat for more than400 plant species including many rare and threatened species. But even on smaller or younger urban wastelands a large number of plant species grow. Within the transect survey, for example, more than 100 species were recorded on areas less than 1 ha.

With the exception of area A the results of the transect study (Figure 2) correspond well to the zonation of urban areas in relation to the decrease of human impact from the center to the suburbs, which were ascertained by Kunick (1974) for the area of former West-Berlin. He differentiated the city area into four zones characterized by floristic attributes (Table 4): 1) zone of high density development, 2) zone of low density development, 3) inner marginal zone, and 4) outer marginal zone. There is an increase of hemerochorous plants and therophytes, and a decrease of rare species from the suburbs to the center. In accordance with the "intermediate disturbance hypothesis" (Connell 1979) the highest number of species per square kilometer can be found in the transition zone between center and outskirts, where the mosaic of land use types is most heterogeneous.

Residential areas of the 1920s and 1930s in Berlin. In the "Golden 1920s," Berlin used to be a center of many famous building and garden architects of the century. A group called "Neues Bauen" was very remarkable for their way of dealing with plants by using them as green mediators between buildings and backyards (Kloss and Pitz 1985). These residential areas, built in the suburbs of Berlin, were the architectural answer to a disastrous situation in the inner city. In contrast to the densly built-up and highly populated city center the newly created residential areas sought to improve the quality of life and were thus characterized by wide-open, sunny, green, and colorful backyards. Even today the vegetation structures reflect the profound former influence of economic conditions and traditions in using and arranging plants.

In the investigated residential areas (75 hectares) 545 wild-growing vascular plant species and 243 planted tree and shrub species were recorded (Figure 3). On the one hand, species numbers were low on habitats with intensive gardening influence, like paths and street areas. On the other hand, highest species numbers were found on less intensively managed habitats like lawns with scattered trees, front gardens, and tenant gardens, which today are very often neglected. Furthermore, a positive correlation between the occurrence of endangered species (10% of the total flora) and less intensively managed habitats was found. Not only cultivated ornamental plants like Hepatica nobilis and Campanula glomerata belong to the endangered species, but also grass seeds like Avena fatua or seeds for meadows *rich in blossoming plants, e.g.* Salvia pratensis, Silene flos-cuculi *and* Pseudolysimachion spicatum *(Böcker et al. 1991).*

The reason for the relatively high diversity of flora can be seen in the different land uses during the last 70 years and the present variety of habitats. In 1920, the suburban area of Berlin was used for agriculture. Later, after building the residential areas, the garden architects formed the typical backyards. They created paths and front gardens with hedges of Ligustrum vulgare and different species of roses. The wide-open lawns are characterized by park tree species, which were typical for these decades, e.g. Salix alba "Tristis", Platanus *x* acerifolia *and* Prunus serrulata "Kanzan". Since the beginning of the Second World War the backyards changed into tenant gardens because of the necessity for self-support. Therefore, a great variety of fruit trees, e.g. Malus domestica, Prunus domestica, and Pyrus communis, are still found today (Maurer 1998). After the war, occasionally the inhabitants held on to their tenant gardens, but in most cases the old garden structures were reconstructed. Every land use period left floristic relicts, especially woody plant species. The spreading of crop and garden weeds or wild-growing ornamental plants from their original cultivation places led to the establishment of these species on other sites.

Meadows and lawns of historical landscape gardens in the city of Potsdam. Within European cities, historical landscape gardens represent a special type of habitat due to their age, origin, utilization, and their large size. Often they show a high variety of both semi-natural and anthropogenous habitats, different from the surrounding city environment. Some of the species and plant communities are almost exclusively limited to these large parks within the urban agglomeration. Because of their peculiarity they have been called "extrazonal elements" (in German: extrazonale Elemente) by Kowarik (1992b). These landscape gardens are refuges as well as potential centers of dispersal for rare and threatened plant species and plant communities. Relicts of historical management and plants used for ornamental purposes and escaped from their original habitat establish themselves in the semi-natural vegetation like park forests, forest edges and meadows (e. g. "Stinzenpflanzen", Bakker and Boeve 1985).

All parks investigated in Potsdam were designed by J. P. Lenné as landscape gardens at the beginning of the 19th century. In 1990, they were nominated by the UNESCO and subsequently inscripted onto the World Heritage List, as part of the castles and gardens of Berlin and Potsdam. With a focus on lawns and meadows, 7 plant communities were recorded with a total of 343 vascular plant and 29 bryophyte species. According to the Red List of Brandenburg (Benkert and Klemm 1993), 67 of the registered species are endangered or threatened by extinction. Many types of meadows, with their characteristic plant communities, have to be considered as elements of the historical Central European artificial landscape. Those meadows have become very rare in the landscapes of today due to land use change. In the landscape gardens they have been preserved, because of continuous traditional garden management (e. g. mowing the meadows only twice a year and no fertilizer being used).

Plants characteristic of especially old parks are the so called "Grassamenankömmlinge" (Hylander 1943). "Grassamenankömmlinge" (grass seed invaders) are species which were introduced to the parks directly as seeds of foreign grasses or indirectly as impurities of seed material. Few species could survive until today and are characteristic of the meadows and lawns of old parks, thus clearly distinguishable from other agriculturally used grasslands. Anthropogenous import of these species ended with the beginning of better seed control at the end of the 19th century. Table 5 shows grass seed invaders and their occurrence in several parks of Potsdam and Berlin. Some are forest species like Poa chaixii and Luzula luzuloides, typical impurities of seed material from Poa nemoralis and Deschampsia flexuosa which were used for the creation of shady "forest meadows" under trees. However, most of these species are typical of meadows, introduced from southern Germany and from France or Switzerland. Some occur only very seldom outside the parks, others are restricted to the parks. Grass seed invaders have survived as cultural relicts of bygone gardening traditions. They are also witnesses for old forms of obtaining and using seed material, not practiced any more today. Today they enrich the flora of the parks.

RECOMMENDATIONS FOR CONSERVING SPECIES AND HABITAT DIVERSITY IN CITIES

Biological diversity in cities has to be recognized as an opportunity for nature conservation and a challenge for sustainable development of urban-industrial areas. The main principles of nature conservation in cities have been defined by Sukopp & Sukopp (1987). Some of them are closely related to the maintenance and development of biological diversity in cities, aiming at habitat as well as species diversity:

- Historical continuity: Primary ecotopes or those with a long history of the same kind of management are particularly valuable for nature conservation.

Landscape parks in cities with a long tradition of gardening management are good examples to illustrate this. Those relicts (species and communities) of the traditional cultural landscape could often survive there and these areas are now endangered through land use changes in a more and more intensively used modern cultural landscape. Especially, meadows and lawns in parks have a high value as a cultural heritage as well as for nature conservation in cities (Peschel 1998).

Moreover, the architectural spirit of the age strongly influences the design of green spaces as habitats for cultivated and wild-growing plant and animal species. For example, the value of the backyards of the residential areas of the 1920s and 1930s for nature conservation lies (1) in their numerous old fruit and park trees, (2) in their great diversity of wild-growing vascular plants with a focus on indigenous and endangered plants, and (3) in their heterogeneous habitat structures, which can be a potential center of dispersal for many plant and animal species in the city. Furthermore, the garden design is protected by law as a natural garden monument (Landesdenkmalamt Berlin 1995).

- Urban ecological zonation on a small scale (city): Remnants of natural and semi-natural ecosystems as well as ecosystems which depend on agricultural or forestry management are most easily maintained in the outer districts or on the fringes of cities. The inner city, where the effects of urbanization are more intense, can more easily support the specialized urban plant and animal communities.

The transition zone between the city center and the outskirts is characterized by the presence of near-natural habitat structures as well as sites strongly altered by man. Thus, the transition zone can be very diverse in terms of habitats and species.

- Maintenance of land use diversity on a large scale (city districts, residential areas, etc.): One of the main objectives of urban nature conservation strategies should be the avoidance of uniformity when managing traditional land use structures or creating new open space.

The leveling of site conditions is one of the most important causes for the decline of species (Sukopp 1994). Diversity of species and habitats should not only be achieved by increasing the amount of garden greenery, artificially created in cities. Especially in the inner city, temporary wasteland can provide space for a more or less large number of species and biological communities.

As it is shown by the investigation of selected habitat structures in Berlin and Potsdam, habitat and land use diversity are closely related to species diversity (Figure 3). Less gardening or management intensity can favor higher species numbers as is shown in habitat parcels like tenant gardens in residential areas.

- Maintenance of local variety: All places which are habitats for plant and animal species uncommon in the area, especially for rare and threatened species should be identified and protected.

The residential areas of the 1920s and 1930s in Berlin are described in the nature conservation program Berlin (*Arbeitsgruppe Artenschutzprogramm Berlin 1984*) as a habitat type of high importance for the existence of old useful and ornamental plants such as old fruit trees in the city. For example, plants of cottage gardens, like Carum carvi and Aquilegia vulgaris or plants typically cultivated for ornamental purposes in the 1920s and 1930s neighborhoods like Anemone blanda, illustrate the local variety of species.

With respect to nature conservation, high diversity of flora, vegetation and habitats in settlements may be considered as very valuable. But also other aspects should be taken into account, especially when assessing anthropogenous plant invasions and their consequences (Eser 1998). There might be risks and conflicts when introduction and establishment of non-native plants take place. For example, Ambrosia artemisiifolia, introduced from North America and occurring on fields and wasteland in Europe, is known to be a threat to human health. Very "aggressive" pollen of this plant causes not only widespread hay fever, but also asthma and bronchitis (Hohla et al. 1998, Kopecký 1990).

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Table 1: Numbers of vascular plants in different-sized European cities (Brandes & Zacharias 1990)

Cities	total numbers of inhabitants	inhabitants per km^2	area in km^2	numbers of vasc. plants
Saarlouis	38,500	895	43	535
Wolfenbüttel	ca. 50,000	1,190	42	553
Neumünster	80,000	1,111	72	553
Salzgitter	115,500	516	224	650
Göttingen	129,800	1,109	117	723
Wolfsburg	130,000	640	203	670
Osnabrück	164,000	1,378	119	657
Braunschweig	250,000	1,302	192	962
Halle	325,000	2,425	134	946
Wuppertal	ca. 400,000	1,333	300	981
Warschau	1.380,000	3,209	430	1,109
Wien	1.600,000	3,865	414	1,362
Berlin (former western part)	2.140,000	4,449	481	1,374

Table 2: Most frequent non-native tree speices, which occur spontaneously in different habitats in the city of Berlin (data basis: 1,383 vegetation relevés and species lists): ● = highest frequency, ⊙ = medium frequency, ○ = low frequency (according to data from Kowarik 1992a).

Species	waste-land	built-up area	green space	forest	wetland
Robinia pseudoacacia	●	●	●	●	●
Acer negundo	●	●	●	●	●
Prunus serotina	⊙	○	○	●	●
Quercus rubra	○		●	●	●
Aesculus hippocastanum	○	●	○	●	
Ailanthus altissima	⊙	⊙	⊙		
Populus alba	●	○		○	
Malus domestica	○	⊙	○	○	
Taxus baccata		○	⊙	○	
Populus x *canadensis*	⊙			○	
Prunus domestica		○	○	○	
Juglans regia			○	○	
Laburnum anagyroides		○	○		
Pyrus communis				○	
Prunus mahaleb	○				
Ulmus pumila			○		
Larix decidua				○	
Picea abies				○	

Table 3: Taxa which most probably have evolved on anthropogenous sites (e. g. wasteland, dumps and rubbish places, lawns) within and outside settlements in Europe (segetal species are not included).

Taxon	Family	Closest relatives in ...	References
Corispermum leptopterum (ASCHERS.) ILJIN	Chenopodiaceae	North America?	Köck 1986
Epilobium bergianum SKVORTSOV	Onagraceae	North America	Skvortsov 1995
Epilobium pseudorubescens SKVORTSOV	Onagraceae	North America	Skvortsov 1995
Leonurus intermedius J. HOLUB	Lamiaceae	East Europe	Holub 1993
Oenothera div. spec.	Onagraceae	North America	Renner 1946
several species of Ranunculus auricomus agg. L.	Ranunculaceae	Europe	Jalas 1961, Marklund & Rousi 1961
Reynoutria x bohemica	Polygonaceae	East Asia	Alberternst 1998
Senecio cambrensis ROSSER	Asteraceae	South and West Europe	Stace 1975, Abbott 1992
Senecio vulgaris L.	Asteraceae	South and West Europe	Comes et al. 1997, Kadereit 1984
"Solidago anthropogena"	Asteraceae	North America	Scholz 1993b
several species of Taraxacum officinale agg. (sect. Vulgaria)	Asteraceae	Europe	Sterk 1987
Xanthium albinum (Widd.) H. SCHOLZ	Asteraceae	North America	Widder 1923

Table 4: Floristic attributes (vascular plants) of different urban zones of former West-Berlin (data from Kunick 1974).

Floristic Attributes	Zones			
	1 high density development	2 low density development	3 inner margin	4 outer margin
species per km^2	380	424	415	357
number of rare species per km^2	17	23	35	58
hemerochorous species [%]	49.8	46.9	43.4	28.5
native species [%]	50.2	53.1	56.6	71.5
therophytes [%]	33.6	30.6	33.4	18.9

Table 5: Grass seed invaders ("Grassamenankömmlinge") in landscape gardens and parks of Potsdam and Berlin (○ = records before 1960; ● = records after 1960).

Grass seed invaders	Park Sanssouci	Park Babelsberg	Neuer Garten	Pfaueninsel	Schloßpark Charlottenburg	Tiergarten	Klein- Glienicke
Bromus erectus	●	●	●	●	●	○	●
Trisetum flavescens	●	●	●	●	●		●
Arrhenatherum elatius	●	●	●	●	●	●	●
Sanguisorba minor	●		○		●	●	
Galium pumilum				●		○	
Leontodon saxatilis	○			●	○		
Crepis nicaeensis	○				○		
Thlaspi caerulescens	●	●	●				●
Poa chaixii	●	●	●	●	●	○	●
Luzula luzuloides	●	●		●		○	●
Dactylis polygama	●	●	●	●			●
Teucrium scorodonia	○	●		○		○	
Myosotis sylvatica	●			●			●
Festuca heterophylla	●					○	
Phyteuma nigrum	●	●				○	
Hieracium glaucinum	●				●		●

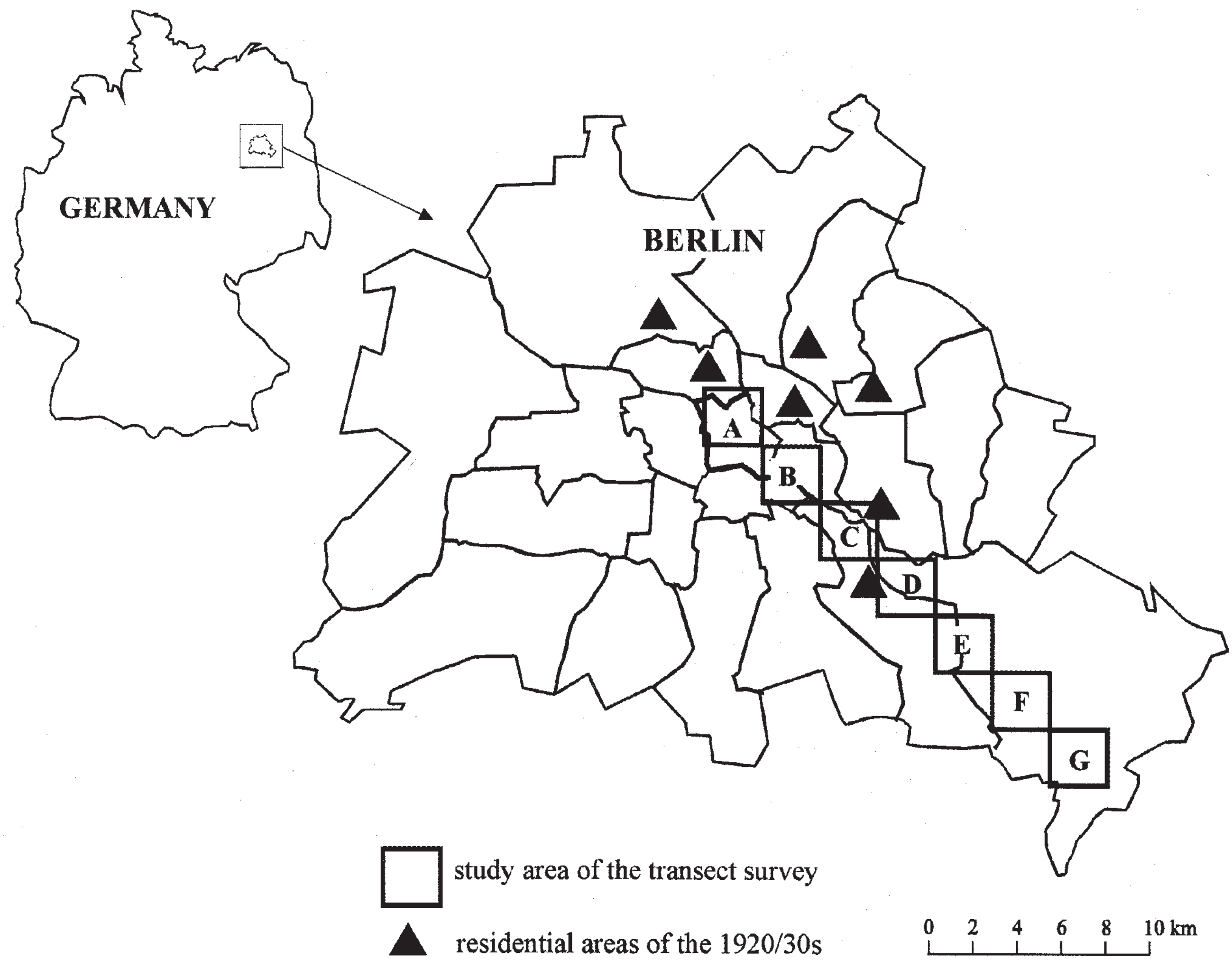

Figure 1: Location of investigated transects and residential areas of the 1920/30s.

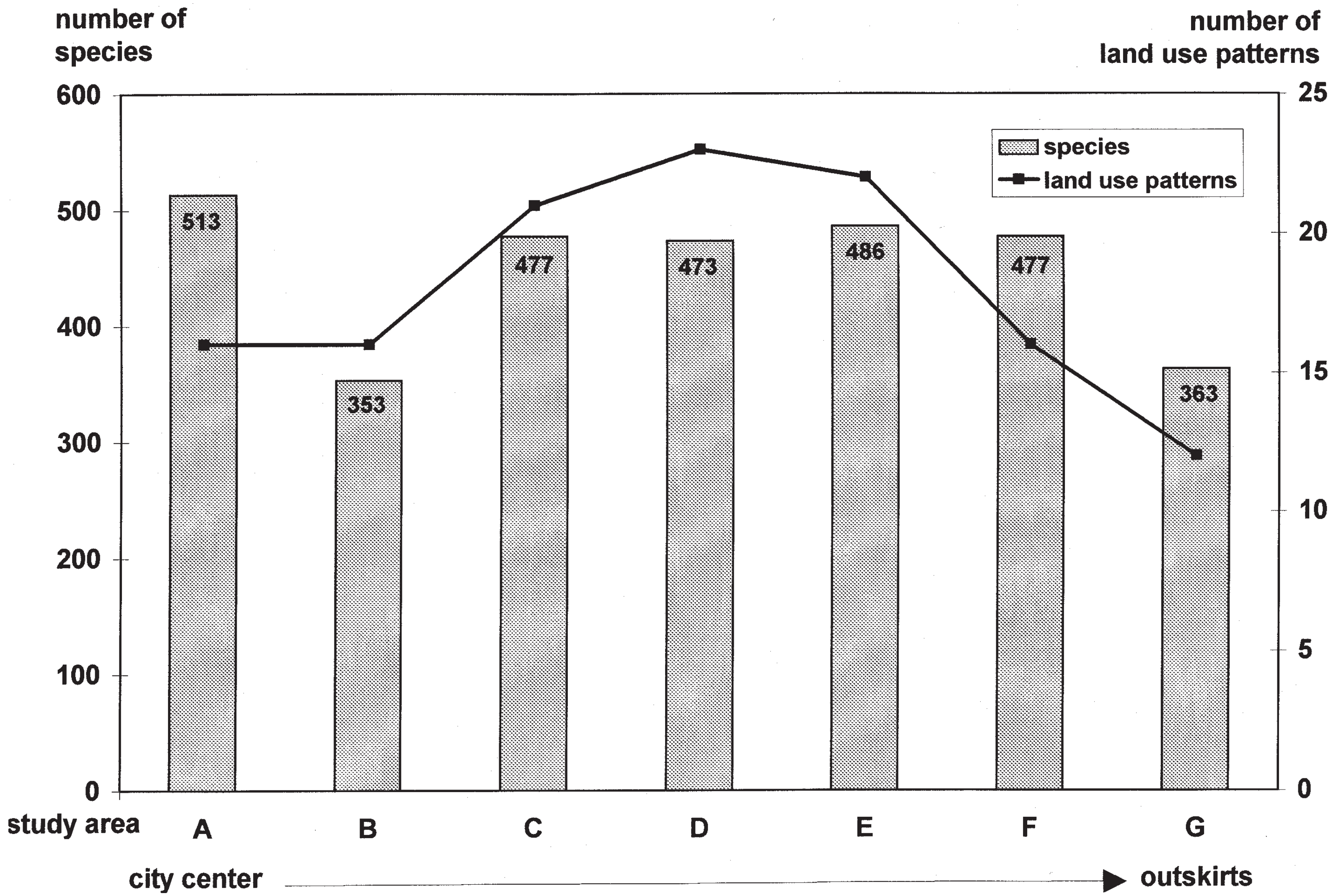

Figure 2: Correlations between flora diversity and land use types from city center to outskirts of Berlin.

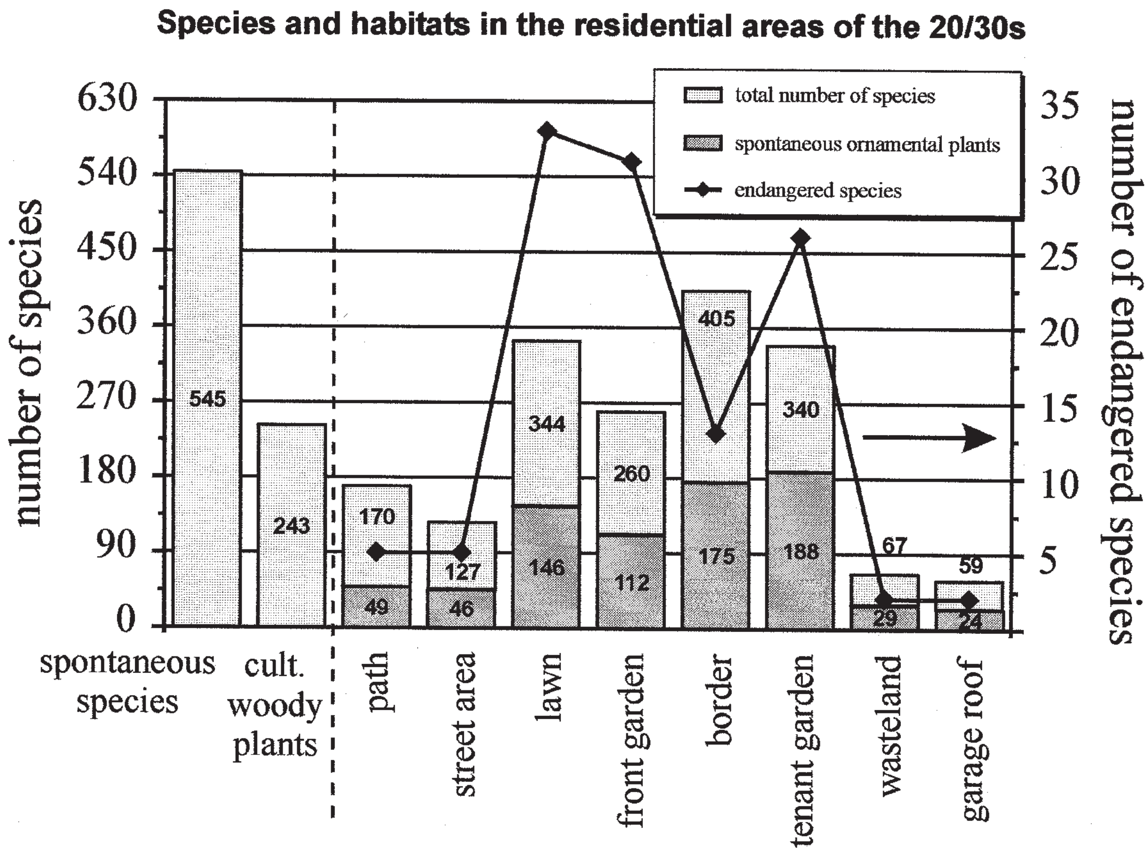

Fig. 3: Species numbers and numbers of endangered species (vascular plants) in the various habitat structures in residential areas of the 1920s and 1930s.