Urban Ecosyst
DOI 10.1007/s11252-009-0097-8

Urban areas as hot-spots for introduced and shelters for native isopod species

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Abstract Isopod assemblages were studied in Budapest, capital of Hungary. The analyses of literary and field data revealed a high species richness (28 species), compared to the total species number (57) in Hungary. Habitats characteristics for the city were categorized as native forests, urban forests, gardens of Buda, gardens of Pest, public parks, densely built-up areas and botanical gardens. We hypothesized that isolated and diverse habitat patches in the city matrix of Budapest support the introduction and establishment of exotic species and the survival of native ones. The composition of assemblages varied among sampling sites, but were characteristic for the biotope categories. We concluded that forests, parks and gardens play an important role in the survival of native isopod populations. Species numbers were highest in the gardens of Buda and in the botanical gardens (both 17 species). The overall presence of cosmopolitan and disturbance-tolerant species indicates an ongoing homogenization process.

Keywords Soil fauna · Woodlice · Urban biodiversity · Species introduction · Taxonomic uniformity

Introduction

From the beginning of the 20th century onwards, urbanisation has become one of the greatest challenges in human history (Antrop 2000). The increasing rate of environmental alterations (i.e. urbanisation) has lead to the fragmentation of natural landscapes and to the increase of the uniformity in city structures: new landscapes and habitats are formed that do not occur elsewhere (Niemelä 1999; Mabelis 2005). Their attributes are rather functionally homogenous than diverse (Antrop 2004). Uniformity of urban areas causes similarities in environmental factors as well. For instance, the so-called "heat island" effect occurs in

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Published online: 17 March 2009

every investigated urban area, supporting heat domes or heat plumes above cities (Andreev et al. 2004; Sukopp 1990). Higher winter temperatures and regular irrigation in parks, gardens and even along roads support longer vegetation periods for plants in temperate cities, allowing a longer accessibility to food resources and favourable microhabitat conditions for animals (McKinney 2006).

The fragmented structure of urban ecosystems often supports a high diversity of habitat patches with different conditions, resources and disturbation levels. This trend can be similarly seen in several cities and gives opportunities for the maintenance of both native and introduced faunal populations, e.g. soil invertebrate species (e.g. Niemelä et al. 2000, 2002). On the other side, the massive habitat destruction promoted by city growth supports the establishment of species that are adapting to urban conditions. Replacing native species with non-natives promotes biotic homogenization, a process which plays an important role in shaping urban flora and fauna by increasing compositional similarity among cities world-wide (McKinney 2006; Olden and Rooney 2006). The study of urban flora and fauna has been intense in the past decades world-wide (e.g. Jedryczkowski 1981; Guntenspergen and Levenson 1997; Vuorisalo et al. 2003; Löfvenhaft et al. 2004; White et al. 2005) but the knowledge of the effects of urbanisation on soil dwelling invertebrates is far from being comprehensive. As members of the soil decomposer community, isopods play an important role in the nutrient turnover of terrestrial ecosystems (Hassall et al. 1987). Isopod assemblages often comprise relatively few species (<10) in a specific (urban and non urban) habitat (e.g. Farkas et al. 1999; Vilisics et al. 2008) but several species might gain high dominance with great abundances in disturbed areas (e.g. Hornung et al. 2007a; Vilisics et al. 2007). Ongoing faunistic and biogeographical studies on earthworms, diplopods and isopods showed that taxonomic uniformization processes can be detected on the urban soil invertebrates also in Europe. This review survey resulted that 14 isopod species were common and homogenizing (out of 46) on a continental scale in Europe (Szlávecz et al. 2008).

With an area of 525 km^2 and a population of 1, 650 000 inhabitants in 2006, the Hungarian capital city of Budapest is one of the large urban areas in Central- and Eastern Europe. The city shows a particularly high diversity of biotopes. Divided by the river Danube, Budapest comprises two major parts: The western side (Buda), characterised by the calcareous Buda Mountains and the eastern side (Pest), a sandy lowland. The various geographic traits affect the city structure: detached houses and gardens form a green belt on higher elevations, while the plain areas of Pest and the riverbank allow high densities of roads and buildings.

Species introduction might pose a threat to the native Isopoda. In this process, botanical gardens and greenhouses play a key role (e.g. Korsós et al. 2002; Kontschán 2004; Vilisics et al. 2007), together with increasing human travel and goods exchange (concerning isopods see e.g. Lindroth 1957; Jass and Klausmeier 1990, 2000; Hornung and Szlávecz 2003). Our goal was to test how valid is the trend of introduction and faunal uniformity for different biotopes on a local scale within the metropolitan area of Budapest. We have made a comprehensive assessment of the terrestrial isopod fauna (Crustacea, Isopoda, Oniscidea) of the city of Budapest, including our own and previously published data. We paid special attention to characteristic sites that may support the native isopod fauna or, in turn, the establishment of introduced woodlice. We hypothesized that isolated and diverse habitat patches in the city matrix of Budapest support the introduction and establishment of exotic species and the survival of native ones. Great differences occur in the urban isopod faunal composition according to habitat nature (forests, public parks, gardens, densely inhabited zones) and the degree of human influences (native – urban). Habitat diversity is reflected in the composition of the isopod assemblages. The fragmented and diverse habitat network of a great city like Budapest may harbour species of different character: indigenous and introduced, habitat specialist and generalist species might constitute the species composition.

Materials and methods

Database

We analysed 100 records for isopod species presence and assemblage composition acquired from the latest publication of Korsós et al. (2002; 21 records), and by personal samplings (79 records) in Budapest. We applied manual time sampling of 10 min periods at each site, choosing the plot most diverse in shelters depending on local circumstances. Sampling was repeated at least twice in a year, during spring and autumn. Each possible hiding place was checked for animals (e.g. turning stones and logs, sorting leaf litter and debris). Hand sorting is a standard sampling method used for compiling detailed and reliable faunistic data (Vilisics and Farkas 2004; Sólymos et al. 2007; Vilisics et al. 2008). Our experiences proved that the efficiency of a less experienced collector had no influence on captured species' but only on specimen numbers (Vilisics and Nagy pers. com.). Here we used only presence/absence data of species numbers rather than quantitative specimen numbers. The sampling method (hand sorting) was similar to the former studies.

Valid species' names were taken from the nomenclature of Schmalfuss (2003).

Data analysis

We used the Sørensen-Dice index for pairwise comparison of habitats' similarities based on species composition. For overall comparison of habitats and for similarities of species' occurrences among habitats hierarchical cluster analyses was performed with Statistica 6.0 (Statsoft 1998) using presence/absence data applying complete linkage method with Euclidean distance measure.

Isopoda species categories

We classified the isopod species found in Budapest into four groups on the basis of a nature conservation view: divided into native (N), established introduced (EI), cosmopolitan (C) and introduced (I) species. Classification was based on the species' frequency of occurrence in 10×10 km UTM grids both by geographical regions and habitat types in Hungary [Vilisics et al. (2007); Hornung et al. (2007b, 2008)]. Native species (N) are of Holarctic and European origin; they occur mainly in rural habitats and disperse without any anthropogenic assistance in Hungary. Established introduced (EI) woodlice occurred exclusively in suburbs, gardens and parks. These species generally don't occur in undisturbed habitats and in areas under great human disturbance. Introduced species (I) are of Mediterranean and tropical origin and show a sporadic distribution in Hungary. Since they mainly live in botanical gardens and greenhouses, their presence and maintenance strongly depends on human activity. Cosmopolitan (C) isopods occur in most of the continents, in the northern and southern hemisphere as well. They dispersed from refugial places after the Pleistocene ice age or followed the human expansion, some of them arrived presumably by human agency. They differ from the native species in their relatively wide ecological tolerance and habitat preferences (Hornung et al. 2008).

Habitat categories

Manual sampling was performed in areas characteristic for the city of Budapest. We divided the sampling sites into seven categories. 1: native forests (11 records); 2: urban forests (8 records); 3: gardens of Buda (19 records); 4: gardens of Pest (10 records); 5: densely built-up city core (26 records); 6: public parks (18 records); 6: botanical gardens (8 records). For exact site locations see Fig. 1.

Description of habitat types

Native forests [NF]

Located on the eastern slopes of the Buda Mountains, the protected oak-hornbeam and beech forests serve as a green background to the city. Although citizens frequently hike in

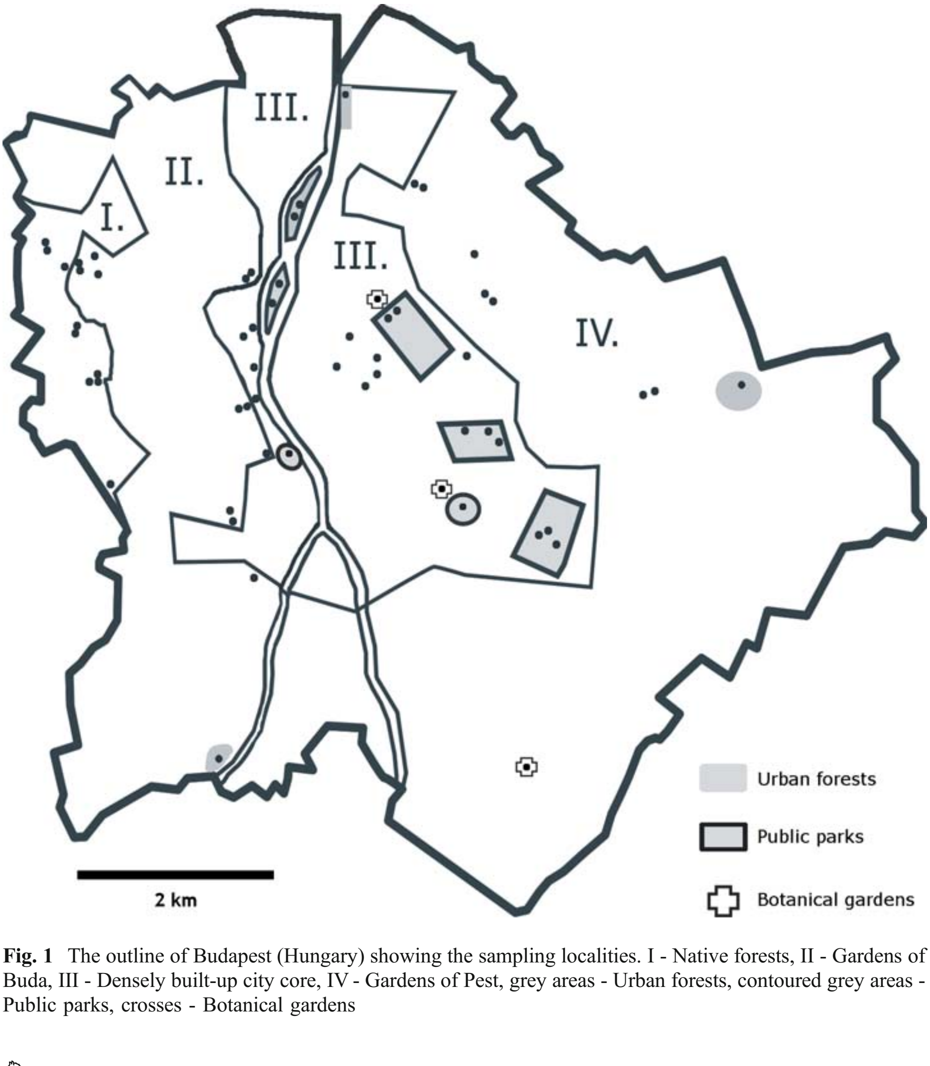

Fig. 1 The outline of Budapest (Hungary) showing the sampling localities. I - Native forests, II - Gardens of Buda, III - Densely built-up city core, IV - Gardens of Pest, grey areas - Urban forests, contoured grey areas - Public parks, crosses - Botanical gardens

the forests, the presence of the original, quasi-natural vegetation and the low level of fragmentation indicate that the area remained in the most natural conditions among all investigated habitats in Budapest.

Urban forests [UF]

Disturbed floodplain forests and fragments of tree plantations are considered here, that can be distinguished from native woods in many terms. Surrounded by roads, rails and buildings, these isolated fragments are diversified by non-native vegetation [e.g. *Ailanthus altissima* (Mill.) Swingle] and also are subjected to great human disturbance.

Gardens of Buda [GB]

Within the amenities of the Buda city side, a dynamically spreading garden suburb has been established including the existing remnants of native woods. The Castle District was also included in this category due to its geography and detached housing similar to the Buda garden area.

Gardens of Pest [GP]

The eastern suburbs of the city lay on the western edge of the Great Hungarian Plains. Intruded and fragmented by major roads, the area differs greatly from the green belt of the Buda side. Although the detached houses possess gardens with various crops and ornamental plants, no remnants remain from the native vegetation.

Public parks [P]

Typical to Budapest, the major parks are located in the densely inhabited zones of the city. As spaces for public leisure and recreation, public parks are exposed to heavy disturbance (e.g. trampling, littering and dogs) by citizens. The vegetation is a mixture of planted and native deciduous trees, but in contrast to urban forests, subjected to regular management, like irrigation and leaf litter removal. Due to the similar management, we included cemeteries in this category as well.

Densely inhabited zones [DC]

Covering the majority of the capital, densely built-up areas are characteristic mainly for Pest and to a lower extent for south-Buda. Busy roads, high buildings and the lack of green areas are typical features of these areas. The last refuge of the soil fauna remain in the courtyards of apartment houses.

Botanical gardens [BG]

Established for scientific, educational and recreational reasons, botanical gardens include habitats of great diversity (e.g. greenhouses, stone gardens). Botanical gardens also harbour a notable amount of alien soil animals that might have been introduced with non-native plants.

Results

Based on our surveys and on the previously published data, the known isopod fauna of Budapest consists of 28 species, corresponding to 57% of the known Hungarian woodlice inventory (Table 1). Additionally, we found in our survey three species new to the Hungarian fauna [*Agabiformius lentus* (Budde-Lund, 1885), *Cordioniscus stebbingi* (Patience, 1907), *Paraschizidium coeculum* (Silvestri, 1897)]. The ranking of species by categories based on their Hungarian occurrence is given in Table 1. The up-to-date list of the terrestrial isopod fauna of Budapest consists of 12 native, three cosmopolitan, three established introduced and ten introduced elements.

Characterization of isopod species according to their occurrence at habitat level

Cluster analysis based on species occurrences (Fig. 2) indicate a separation of the isopods found in Budapest. According to their occurrences, isopods can be divided into two main clusters: frequent, common species (group A) and less frequent, "rare" species (B). Both native and alien species can be divided into generalists and habitat specialists. Native generalists are predominant in quasi-natural areas but they occur in human influenced environments, too. Typical and common species belonging to group A are *Armadillidium vulgare* (Latreille, 1804), *Porcellium collicola* (Verhoeff, 1907), *Platyarthrus hoffmannseggii* Brandt, 1833 and *Trachelipus rathkii* (Brandt, 1833). According to the above mentioned classification 43% of the species (12) belong to the native fauna: *P. hoffmannseggii*, *T. rathkii* and *P. collicola* are native generalists while *A. vulgare* is also a cosmopolitan one. These isopods (group A) constitute the basic isopod fauna of Budapest. They occur in nearly all urban habitat types. *Porcellio scaber* Latreille, 1804 and *Porcellionides pruinosus* (Brandt, 1833) are also common, frequent species but they are strictly bounded to human influenced biotopes (group C).

Rare or less frequent species form a distinct cluster (Fig. 2: B) regardless of their origins and distribution. *Androniscus roseus* (C. Koch, 1838), *Haplophthalmus montivagus* Verhoeff, 1941, *Orthomethopon planum* (Budde-Lund, 1885), *Protracheoniscus politus* (C. Koch, 1841), *Trachelipus nodulosus* (C. Koch, 1838) and *T. ratzeburgii* (Brandt, 1833)] represented the native habitat specialists. Within group B the isopods of the Buda side are arranged in one distinct group (D) distinguished from species of the habitats under higher urbanisation pressure (group E). Here we found inhabitants of the investigated public parks (*T. ratzeburgii, T. nodulosus*), of greenhouses and botanical gardens [(*Armadillidium nasatum* Budde-Lund, 1885, *Reductoniscus costulatus* Kesselyák, 1930, *Trichorhina tomentosa* (Budde-Lund, 1893), *H. montivagus, Buddelundiella cataractae* (Verhoeff, 1930)] and of the densely built-up city core [*Protracheoniscus major* (Dollfuss, 1903) and *Porcellio dilatatus* Brandt, 1933)]. Exotic species occurring only in gardens of Buda are of Mediterranean origin. The isopod fauna of botanical gardens is a mixture of exotic, established introduced and native ones.

Established introduced species are expanding by dispersion and seem to be successful colonizers of rural-suburban edge zones (E.g. *Porcellio spinicornis* Say, 1818, *Cylisticus convexus* (De Geer, 1778) and *Armadillidium versicolor* Stein, 1859).

The introduced category is represented by ten alien species, amounting to 35% of the total isopod species (Table 1). Three species are classified as cosmopolitans, upon their world-wide distribution, which includes both natural and man-made habitats: *A. vulgare, P. scaber* and *P. pruinosus*. They are among the most frequent ones also in Budapest.

Table 1 List and occurrence of isopod species found in the investigated habitat categories of Budapest (according to Hornung et al. 2008)

Family	Species	Status	NF	UF	GB	GP	P	DC	BG
Trichoniscidae	*Androniscus roseus*	N		+				+	+
	Buddelundiella cataractae	I			+				+
	Haplophthalmus danicus	N	+	+	+		+	+	+
	Haplophthalmus mengii	N	+	+	+			+	+
	Haplophthalmus montivagus	N							+
	Hyloniscus riparius	N	+	+	+		+	+	+
Styloniscidae	*Cordioniscus stebbingi*	I							+
Platyarthridae	*Platyarthrus hoffmannseggii*	N	+	+	+	+	+	+	+
	Platyarthrus schoblii	I		+	+				
	Trichorina tomentosa	I							+
Agnaridae	*Orthometopon planum*	N	+						
	Protracheoniscus major	I						+	
	Protracheoniscus politus	N	+	+	+				
Cylisticidae	*Cylisticus convexus*	EI	+	+	+		+	+	+
Porcellionidae	*Porcellio dilatatus*	I						+	
	Porcellio scaber	C			+	+	+	+	+
	Porcellio spinicornis	EI			+				
	Porcellionides pruinosus	C		+	+	+		+	+
Trachelipodidae	*Agabiformius lentus*	I			+				
	Porcellium collicola	N	+	+	+	+	+		+
	Trachelipus nodulosus	N					+		
	Trachelipus rathkii	N	+	+	+	+	+		+
	*Trachelipus ratzeburgii**	N					+		
Armadillidae	*Reductoniscus costulatus*	I							+
Armadillidiidae	*Armadillidium nasatum*	I							+
	Armadillidium versicolor	EI			+		+		
	Armadillidium vulgare	C	+	+	+	+	+	+	+
	Paraschizidium coeculum	I			+				
	Native species	12	8	8	7	3	7	5	8
	Cosmopolitan species	3	1	2	3	3	2	3	3
	Established introduced species	3	1	1	3	0	2	1	1
	Introduced species	10	0	1	4	0	0	2	5
	Total	28	10	12	17	6	11	11	17

Remark: Data includes the records of Korsós et al. 2002. The species lists overlap with the exception of *T. ratzeburgii* (marked with * in the Table)

N - native, C - cosmopolitan, EI - established introduced, I - introduced

Habitat categories: NF - native forests, UF - urban forests, GB - gardens of Buda, GP - gardens of Pest, P - public parks, DC - densely built city core; BG - botanical gardens

Species richness of habitat types

The main habitat types of Budapest harbour characteristic isopod assemblages of high species diversity with various origins (Fig. 3). Next to some synanthropic and common

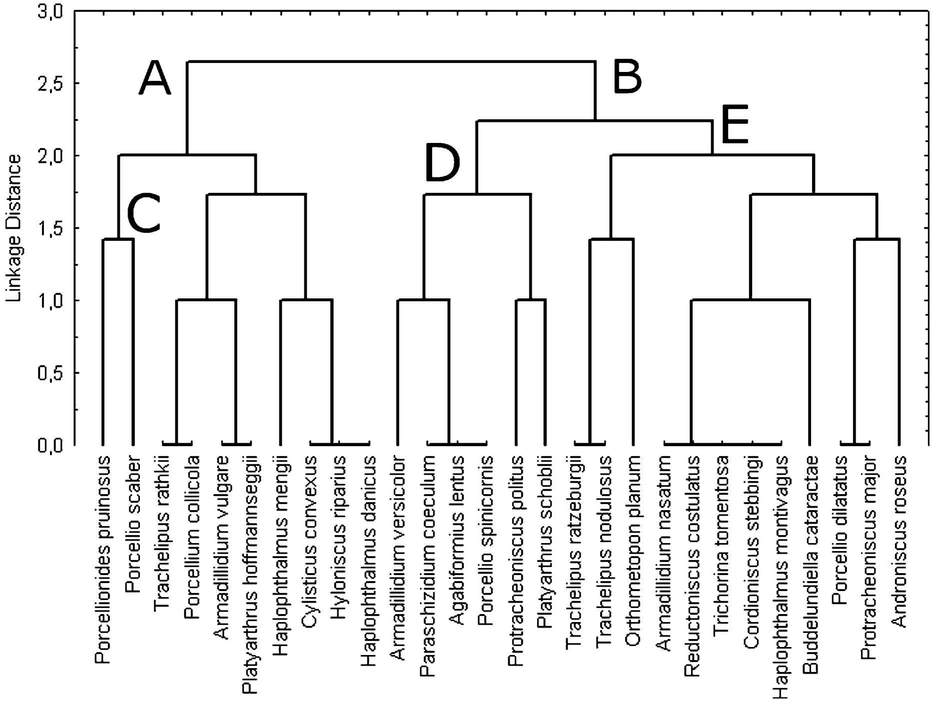

Fig. 2 Dendrogram of the hierarchical cluster analysis showing similarities among species occurrences according to their presence or absence in the investigated habitat types of Budapest. A - common generalists, B - less frequent, rare species, C - species restricted to synanthropic habitats, D - rare species of Buda (gardens or native forests), E - woodlice living in parks, greenhouses and botanical gardens and densely built-up areas

native isopods, we found viable populations of less frequent species often referred to as indicators, either of species introduction (exotic spp) or of high conservation value (native and habitat specialist spp). The highest overall species richness was found in the gardens of Buda and in the botanical gardens (both with 17 species), while the lowest species richness was found in the gardens of Pest (6) (Table 1; Fig. 3).

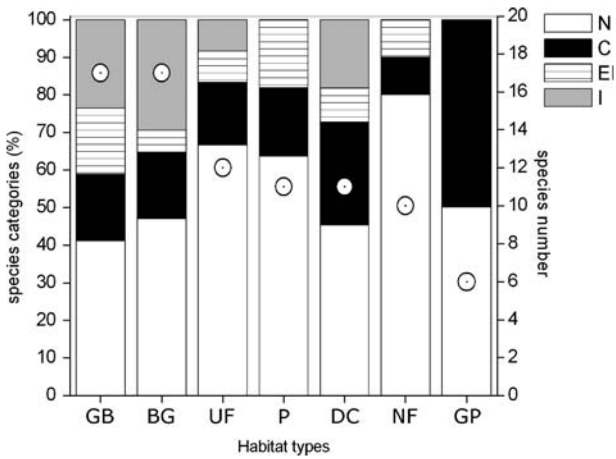

Fig. 3 Species richness and proportion of species categories in the investigated habitat types of Budapest. Status: N - native, C - cosmopolitan, EI - established introduced, I - introduced. Circles indicate species numbers found in the habitat types. Habitat categories: NF - native forests, UF - urban forests, GB - gardens of Buda, GP - gardens of Pest, P - public parks, DC - densely built-up city core, BG - botanical gardens

Table 2 Sørensen-Dice similarities between isopod assemblages of the investigated habitat types in Budapest

	UF	GB	GP	P	DC	BG
NF	0,82	0,64	0,50	0,67	0,57	0,60
UF	-	0,73	0,56	0,61	0,70	0,70
GB	–	–	0,52	0,64	0,55	0,60
GP	–	–	–	0,59	0,47	0,50
P	–	–	–	–	0,55	0,60
DC	–	–	–	–	–	0,70

Habitat categories: NF - native forests, UF - urban forests, GB - gardens of Buda, GP - gardens of Pest, P - public parks, DC - densely built-up city core, BG - botanical gardens. See text for further details.

Sørensen-Dice indices (Table 2) revealed the highest similarity between the native and urban forests (82%). The lowest one was experienced between the gardens of Pest and the densely built-up areas (47%) as an effect of the differences in species richness (GP: 6 and DC: 11) and the low number (4) of common species. In the case of BG and NF there is a considerable difference in their species richness (10 and 17, respectively) sharing eight common species. Nevertheless, due to the presence of common native generalists, similarity was also notable between species composition of the native forests and the gardens of Buda (64%). Generally, similarities in isopod assemblages between habitat types were rather high, between 50 and 70%. In accordance with the calculated Sørensen-Dice indices, the results of the hierarchical cluster analysis (Fig. 4) show a high similarity between the native and urban forests (NF, UF). Gardens of Buda (GB) join this cluster. Densely built-up areas (DC) form a common group with public parks (P) and gardens of Pest (GP). The higher

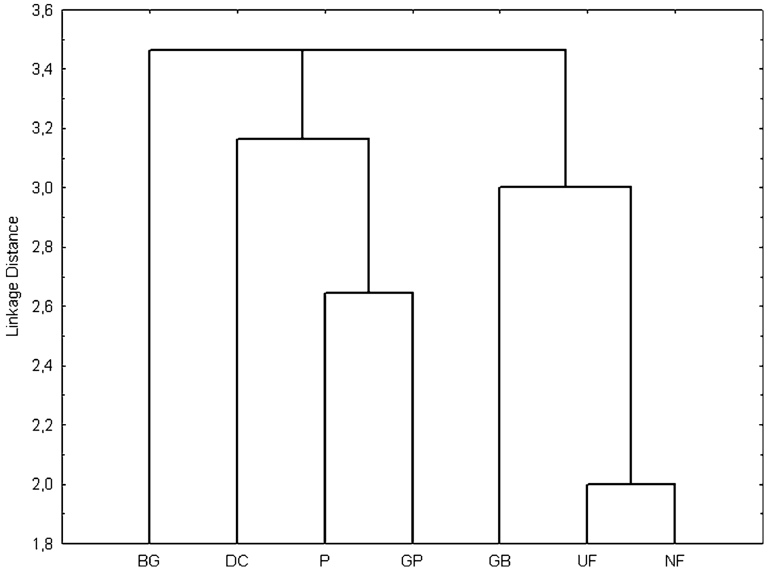

Fig. 4 Dendrogram of the hierarchical cluster analysis showing similarities of habitat types according to isopod species composition. Habitat categories: NF - native forests, UF - urban forests, GB - gardens of Buda, GP - gardens of Pest, P - public parks, DC - densely built-up city core, BG - botanical gardens

similarity between the latter two habitats is likely due to the lack of introduced species and relatively low numbers of native species. The investigated botanical gardens (BG) represent a separate group due to their special, mainly introduced fauna.

Discussion

The first comprehensive data on the terrestrial isopod fauna of Budapest was published by Korsós et al. (2002) describing 18 isopod species from the metropolitan area. The present findings and the previous list overlapped. Our study proved the occurrence of 28 species including the previously published ones. Only the presence of *T. ratzeburgii* was not confirmed during our investigation (signed by asterisk in Table 1).

The survey revealed high species richness compared to other studies in Central and Eastern European urban habitats e.g. Bucharest, Romania: 14 species (Giurginca 2006); Olomouc, Czech Republic: 17 species (Riedel et al. 2009). The great differences between Budapest and Bucharest in species numbers can be explained by the dissimilar sampling methods (manual sampling vs. pitfall trapping) and differences in habitat types sampled (parks in Bucharest). In Olomouc, four habitat types (parks, "ruderal, abandoned sites", "natural sites" and a greenhouse) were investigated with manual sampling, pitfall trapping, leaf litter and soil extract. Parks are the only common basis for comparison among the three mentioned studies. In parks of Olomouc and Bucharest, the reported isopod species are 14 (11 in the present study), with an overlap of eight species (Sørensen-Dice similarity index= 0.64). Concordant to our results, Riedel and his co-authors (in press) found mostly Holarctic and cosmopolitan species along with some Central European isopods in public parks. The occurrence of specific faunal elements in Bucharest [*Platyarthrus atanassovi* Verhoeff, 1936, *Trachelipus rhinoceros* (Budde-Lund, 1885), *Cylisticus transsilvanicus* Verhoeff, 1908] mirrors the distinct zoogeographical region.

Vilisics (2007) postulates that the three exotic species new to the Hungarian fauna were introduced by humans. The distribution of *P. hoffmannseggii*, on the other side, due to its myrmecophilous nature, is probably driven by its ant host and might appear in all possible biotope types suitable for the certain ant species (Gruner 1966).

The human mediated introduction of alien elements of the Budapest fauna could be traced back in some cases, e.g. *Platyarthrus schoblii* Budde-Lund, 1885 that was found in nearly all colonies of *Lasius neglectus* van Loon, Boomsma and Andrásfalvy, 1990 (Hymenoptera: Formicidae) (Tartally et al. 2004). This invasive and polygynous ant species disperses exclusively in an antropochorous way throughout Europe by colony fragments (Espadaler et al. 2007). The isopod is a commensalist in the ant's nest and appears accompanying it first in botanic gardens and plant nurseries (Hornung et al. 2005). Soil ballast and ornamental plants often serve as transmitters for small soil animals including isopods (Lindroth 1957; Hornung and Szlávecz 2003). *P. coeculum* was introduced by local citizens with ornamental plants (*Nerium oleander* L.) brought from Mediterranean area (M. Székely, pers. comm.). Presently the species has a small, isolated population in a garden of Buda.

Habitat heterogeneity is related to the size, structure and age of a city providing different levels of biotope diversity and shelter sites which affect species richness (Mabelis 2005). The occurrence of native species in the urban environment proves that a city can provide suitable conditions for their survival. The fragmented and diverse habitat network of a great city like Budapest harbours species of different character. The species pool consists of native and introduced, steno- and polytopic, habitat specialist and generalist species alike.

In general, species appearing in only one habitat type can be taken as habitat specialist or stenotopic. Such classification of isopod species occuring in Hungary was based on a comprehensive, country-wide survey (Hornung et al. 2008). E.g. *T. nodulosus* is a characteristic isopod of grasslands on the Great Hungarian Plains (Hornung 1989), while *T. ratzeburgii, O. planum* and *H. montivagus* are common in deciduous forests (Hornung et al. 2008). *Platyarthrus* spp. are myrmecophilous, *P. spinicornis* is bound to stony surfaces, *Haplophthalmus* and *Hyloniscus* species need extra wet conditions. *P. major* is qualified as domicol (sensu stricto Csuzdi et al. 2008) appearing regularly in cellars; *A. nasatum* occurs in and around greenhouses. The last record of *P. dilatatus* was is 1879 (cited in Forró and Farkas 1998) prior to our study.

As a direct negative effect of urbanisation, a high proportion of cosmopolitan, established introduced and alien species indicate a high degree of biotic homogenization. Particularly, private gardens and especially botanical gardens serve as introduction hot-spots for alien species, and as a possible threat to the native fauna. Beyond the detected negative effects of high anthropogenic pressures on potential habitats' structure, we recorded isopods in practically all less disturbed urban habitats, regardless in which part of the city they were located. To promote the survival of native soil fauna in urban environments, we suggest a decrease in disturbance and avoiding the strict regular removal of all organic matter (e.g. to leave fallen trees, litter).

As the highly fragmented landscape in the human influenced environment is a global phenomenon, the trend experienced—cohabitation of native, cosmopolitan, introduced species in an urban matrix—is expected to be a general feature of great cities.

Acknowledgements The Hungarian National Research Fund (OTKA T 43508) supported our research. We appreciate the serious and detailed comments, suggestions and the linguistic help of our referees and of Mr. Justin Goldberg that highly improved the manuscript.

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