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Patterns of urbanisation in the City of Sofia as shown by carabid beetles (Coleoptera, Carabidae), ants (Hymenoptera, Formicidae), and terrestrial gastropods (Mollusca, Gastropoda Terrestria)

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SUMMARY

The GLOBENET project in Sofia was expanded from studies on carabid beetles to assess how different soil invertebrates reflect urbanisation. Carabid beetles, terrestrial gastropods and ants were chosen for being well-studied, widely distributed and functionally important groups in ecosystems. At the same time, they are characterised by different life strategies, habitat requirements and trophic relationships.

The urban faunas of all three groups were formed by (1) filtering out several native species from the regional species pools of Sofia Kettle, (2) gaining new autochtonous species, and (3) gaining new allochtonous species. The latter is exhibited mainly by gastropods and less by ants (invasive ant species are found only in houses or greeneries). There were also no clearly invasive carabid beetle species. A trend of colonisation by invasive gastropods species from Sofia invading the surroundings was observed.

In all three groups, there were clearly distinguishable "urban" assemblages that differed from those of the rural and suburban zones. Specific suburban assemblages were formed by ants, but not by gastropods or carabid beetles.

The main factors affecting spatial variation of ground-beetle, ant and terrestrial gastropod assemblages respectively were: distance from the city center; perimeter/area ratio of the fragment, area of the homogenous habitat, distance to the nearest fragment; and altitude, area and level of urbanisation of the sampling sites.

The patterns of urbanisation had much in common amongst the three groups studied, but at the same time they displayed group-specific peculiarities. Hence, bioindication and monitoring activities should be carefully planned to include various taxonomic groups with different life-strategies.

Keywords: terrestrial gastropods, ants, ground-beetles, Sofia, Bulgaria, urbanisation, biodiversity, habitat preference, zoogeographical structure

INTRODUCTION

The spatial variation of biotic communities in urban environments enjoys a prime interest of biologists, landscape ecologists, and specialists in urban planning. In virtually all regions of the Globe, urbanisation is easily detectable and affects the local floras and faunas in many ways – e.g. altering their composition and diversity. Hence, the idea of studying the impact of "a common factor onto different floras/faunas in different ecological/historical conditions" or the so called "intercontinental community convergence" (Schoener, 1986) finds its appropriate application in on times of ongoing global urbanisation.

One of the first steps in this direction became the establishment of the GLOBENET project, aimed at surveying the common anthropogenic impacts on biodiversity on a global scale using carabid beetles (Niemelä et al., 2000; Niemelä & Kotze, 2000). The basic concept utilized within the framework of the GLOBENET initiative is the paradigm of urban-rural gradients as primary interfaces between heavy urban development and the relatively less disturbed natural landscapes (Klausnitzer, 1982; McDonnell & Pickett, 1990). The GLOBENET project engendered immediate interest among the carabidologists. Impact of urbanisation on ground beetle assemblages was studied using the GLOBENET unified methodology and sampling protocols in several cities of the world (e.g. Niemelä et al., 2002; Ishitani et al., 2003; Sadler et al., 2006; Elek & Lövei, 2007; Magura et al., 2008) followed by similar studies on other animal groups (Hornung et al., 2007; Vilisics et al., 2007; Magura et al., 2008).

Increased international interest in the project encouraged the Sofia team to extend its work toward a more detailed examination of the soil properties and the floristic components of the landscape, as well as to include some additional soil mesofauna groups, such as gastropods, spiders, harvestmen, myriapods, ants and nematodes among others. The results of the collaboration between several specialists in abiotic and biotic components of the urban environment of Sofia were summarized in a collection of studies (Penev et al., 2004).

The present paper aims at comparing the effect of urbanisation on different soil invertebrates characterized by different life strategies and habitat requirements. We compare here the general patterns of formation of urban ground beetle, ant and terrestrial gastropod faunas. Spatial variations of some assemblage parameters, such as alpha-diversity, zoogeographical and ecological structure, were observed in field sites where these groups co-occurred.

All three animal groups studied are highly diverse and abundant in almost every terrestrial habitat. They have been chosen for being taxonomically well known, locally abundant and easy to collect by various sampling methods, including quantitative ones. All three groups are "key species" in ecosystems as predators, prey, detritivores, mutualists and herbivores. Moreover, their habitat requirements range broadly from higrophily to xerophily. Carabids, in particular, are known as excellent model objects for monitoring purposes mainly because they are widely distributed, abundant, sensitive to landscape alteration and other environmental factors (e.g. Stork, 1990). Ants are appropriate for inventory and monitoring programs because most of the species have stationary, perennial nests with restricted foraging ranges (from less than one meter to few hundred meters). The low mobility of terrestrial gastropods makes them sensitive to environmental changes. Terrestrial gastropods are known to be one of the dominant groups in city parks (Pisarski et al., 1989). Similarly, ground beetles and ants are also abundant at these locations.

MATERIAL AND METHODS

Site description

The investigated area is situated in West Bulgaria and includes the City of Sofia, Sofia Kettle and the adjacent foothills of the surrounding mountains – Stara Planina, Vitosha, Sredna Gora, and Lyulin, ranging up to about 1000 m above sea level.

One of the main criteria, besides distance from the city centre, used to select the sampling sites, was the prevalence of more or less similar forest types – in our case, broad-leaved forests dominated by oak (*Quercus* spp.) (Penev et al., 2004). The ant study sites were also located in open grassy habitats chosen on the basis of prevalence of common dominant grass and herb species (e.g. *Poa* spp., *Festuca* spp., *Phleum pratense* L., *Avena fatua* L., *Setaria viridis* (L.), *Cynodon dactylon* Pers., *Dactylis glomerata* L., *Trifolium* spp., *Taraxacum officinale* Weber., *Bellis perennis* L., *Capsella bursa-pastoris* Med., and *Plantago* spp.), as well as in forested habitats dominated by oak trees (Antonova & Penev, 2006).

Carabid beetles and gastropods were sampled at eleven sites along an urban-rural gradient (with its urban end in the city parks of Sofia, spreading towards the rural surroundings) (Fig. 1). More detailed site descriptions are provided in Penev et al. (2004). Ants were collected at 56 localities situated in the urban greenery – i.e. wooded and open areas in the parks, green yards, along the transport corridors and streets – specifically 10 "forest" and 46 "meadow" sites. A further 8 localities situated in the vicinity of Sofia (at the foothills of Vitosha, Lyulin and Lozen Mountains, not higher than 150 m above the average altitude of the city with distance up to 10 km from the city ring road), were sampled, too. (Fig. 2).

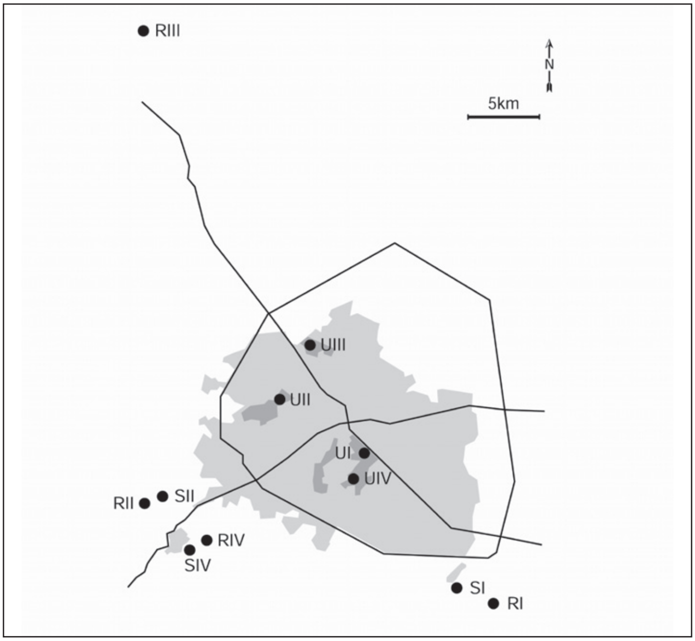

Fig. 1. The GLOBENET sampling sites for carabid beetles and gastropods (UI-UIV – urban sites; SI-SIII – suburban sites; RI-RIV – rural sites).

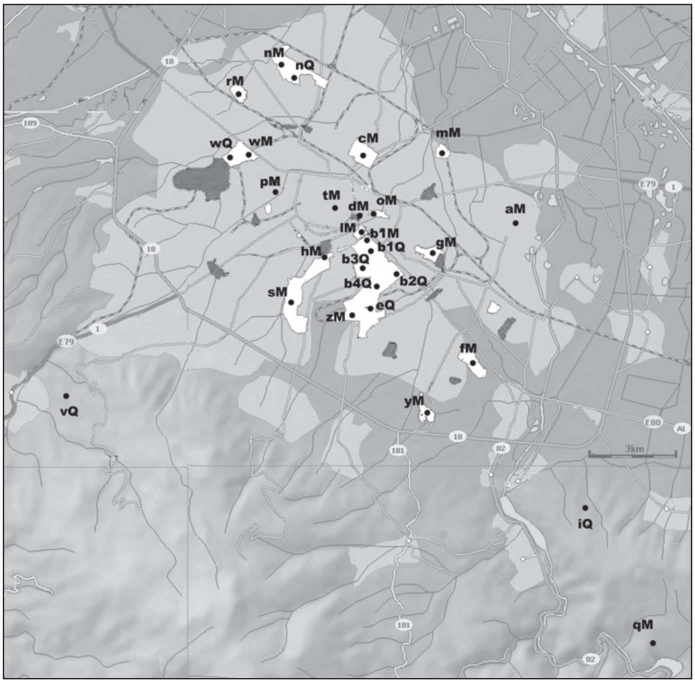

Fig. 2. The sampling sites for ants in Sofia and its surroundings.

Sampling methods

Ground beetles

At each site we collected carabid beetles using pitfall traps which were active during the vegetation seasons of 1998 (May 07-October 22) and 1999 (April 01-October 26) and were emptied monthly (for details of sites and sampling design see Niemelä et al., 2002, Penev et al., 2004). All carabid beetles caught in the pitfall traps were identified to species using standard keys (Freude et al., 1976; Hůrka, 1996). The Balkan and Bulgarian endemic species were identified using an unpublished manuscript by the late O. L. Kryzhanovskij. The systematic nomenclature follows Kryzhanovskij et al. (1995).

Ants

Quantitative quadrate samples were taken: ten 3 m x 3 m (9 m^2) plots in forest habitats and ten 1 m x 1 m (1m^2) plots in meadow sites (Czechowski et al., 1995). Additionally, a "direct sampling" method (Bestelmeyer et al., 2000) was used in the urban green areas of Sofia. In the forest sites the colonies were sampled from the litter, the ground (up to 25 cm depth), under bark and stones, in logs and nuts. In the meadow sites samples were taken from the ground, grass clumps, and under stones. Ants were identified to species after Atanassov & Dlussky (1992), Seifert (1996) and Czechowski et al. (2002). The ant material for the present study was collected in 2003-2005 and is kept in the collection of V. Antonova at CLGE-BAS.

Gastropods

Terrestrial gastropods were sampled quantitatively by a quadrat method (50 x 50 cm) proposed by Oekland (1930). Ten samples were taken at each site from April to October in 1999 and 2000. Leaf litter and underlying soil horizon of each sample were sifted at depth of 10 cm. Hand collecting from the soil surface, under tree bark and stones, in rotten wood and on plants supplemented these plots.

Species characteristics

Ground beetles

The Siberian, Holomediterranean (expansive), and the Ponto-Mediterranean (expansive) species were considered being widely distributed (WD in Table 1), while the Balkan (sub)endemics, the Holomediterranean, and the Ponto-Mediterranean elements (sensu DeLattin, 1967) were classified as species with a more restricted (local) distribution (RD in Table 1). The polytopic/stenotopic dichotomy was defined in the following way:

Table 1. Species list, distribution, and ecological characteristics of the ground beetles.

No	Species	Zone	Zoog.	Ecol.
1	*Ophonus melleti* (Heer, 1837)	U	RD	P
2	*Ophonus diffinis* (Dejean, 1829)	U	RD	P
3	*Harpalus caspius* (Steven, 1806)	U	RD	P
4	*Ophonus rufibarbis* (Fabricius, 1792)	U	WD	P
5	*Panagaeus bipustulatus* (Fabricius, 1775)	U	RD	P
6	*Loricera pilicornis* (Fabricius, 1775)	U	WD	S
7	*Pterostichus anthracinus* (Illiger, 1798)	U	WD	S
8	*Lebia humeralis* Dejean, 1825	U	RD	P
9	*Patrobus atrorufus* (Ström, 1768)	U	WD	S
10	*Leistus ferrugineus* (Linnaeus, 1758)	U	WD	P
11	*Scybalicus oblongiusculus* (Dejean, 1829)	U	RD	P
12	*Badister bullatus* (Schrank, 1798)	U	WD	P
13	*Asaphidion flavipes* (Linnaeus, 1761)	U	WD	P
14	*Brachinus explodens* Duftschmid, 1812	U	WD	P
15	*Amara familiaris* (Duftschmid, 1812)	U	WD	P
16	*Agonum viduum* (Panzer, 1797)	U	WD	P
17	*Syntomus obscuroguttatus* (Duftschmid, 1812)	U	RD	P
18	*Acupalpus flavicollis* (Sturm, 1825)	U	WD	P
19	*Amara majuscula* (Chaudoir, 1850)	U	WD	P
20	*Clivina fossor* (Linnaeus, 1758)	U	WD	P
21	*Pterostichus ovoideus* (Sturm, 1824)	U	WD	S
22	*Dromius linearis* (Olivier, 1795)	U	RD	S
23	*Zabrus tenebrioides* (Goeze, 1777)	UR	WD	P
24	*Pterostichus niger* (Schaller, 1783)	UR	WD	S
25	*Pterostichus oblongopunctatus* (Fabricius, 1787)	UR	WD	S
26	*Ophonus nitidulus* Stephens, 1828	UR	WD	P
27	*Pterostichus melanarius* (Illiger, 1798)	UR	RD	P
28	*Trechus quadristriatus* (Schrank, 1781)	UR	WD	P
29	*Stomis pumicatus* (Panzer, 1796)	UR	RD	P
30	*Platynus assimilis* (Paykull, 1790)	UR	WD	S
31	*Pterostichus strenuus* (Panzer, 1797)	UR	WD	S
32	*Trechus obtusus* (Erichson, 1837)	UR	RD	P
33	*Pterostichus nigrita* (Paykull, 1790)	UR	WD	S
34	*Poecilus cupreus* (Linnaeus, 1758)	UR	WD	P
35	*Synuchus vivalis* (Illiger, 1798)	UR	WD	P
36	*Carabus coriaceus* Linnaeus, 1758	UR	WD	S
37	*Calathus fuscipes* (Goeze, 1777)	UR	RD	P

38	*Brachinus crepitans* (Linnaeus, 1758)	UR	WD	P
39	*Bembidion subcostatum javurkovae* Fassati, 1943	UR	RD	P
40	*Carabus convexus* Fabricius, 1775	UR	WD	P
41	*Calosoma inquisitor* (Linnaeus, 1758)	UR	WD	S
42	*Calathus melanocephalus* (Linnaeus, 1758)	UR	WD	P
43	*Amara convexior* Stephens, 1828	UR	WD	P
44	*Amara aenea* (DeGeer, 1774)	UR	WD	P
45	*Abax carinatus* (Duftschmid, 1812)	UR	RD	S
46	*Bembidion lampros* (Herbst, 1784)	UR	WD	P
47	*Anchomenus dorsalis* (Pontoppidan, 1763)	UR	WD	P
48	*Amara ovata* (Fabricius, 1792)	UR	WD	P
49	*Notiophilus rufipes* Curtis, 1829	UR	WD	P
50	*Laemostenus terricola* (Herbst, 1783)	UR	RD	P
51	*Harpalus rufipes* (DeGeer, 1774)	UR	WD	P
52	*Harpalus rubripes* (Duftschmid, 1812)	UR	WD	P
53	*Notiophilus palustris* (Duftshmid, 1812)	UR	WD	P
54	*Nebria brevicollis* (Fabricius, 1792)	UR	WD	P
55	*Leistus rufomarginatus* (Duftshmid, 1812)	UR	WD	S
56	*Harpalus atratus* Latreille, 1804	UR	RD	P
57	*Diachromus germanus* (Linnaeus, 1758)	UR	RD	P
58	Carabus violaceus Linnaeus, 1758	UR	RD	P
59	*Harpalus luteicornis* (Duftschmid, 1812)	UR	WD	P
60	*Harpalus latus* (Linnaeus, 1758)	UR	WD	P
61	*Harpalus cupreus* fastuosus Faldermann, 1836	UR	RD	P
62	*Calosoma sycophanta* (Linnaeus, 1758)	R	WD	S
63	*Harpalus quadripunctatus* Dejean, 1829	R	WD	S
64	*Carabus hortensis* Linnaeus, 1758	R	WD	S
65	*Cicindela campestris* Linnaeus, 1758	R	WD	P
66	*Molops dilatatus dilatatus* Chaudoir, 1868	R	RD	S
67	*Molops alpestris centralis* Mlynar, 1977	R	RD	S
68	*Platyderus rufus* (Duftschmid, 1812)	R	WD	S
69	*Platynus scrobiculatus* (Fabricius, 1801)	R	RD	S
70	*Cychrus semigranosus* Pallairdi, 1825	R	RD	S
71	*Pterostichus melas* (Creutzer, 1799)	R	WD	P
72	*Gynandromorphus etruscus* (Quensel, 1806)	R	RD	P
73	*Carabus intricatus* Linnaeus, 1761	R	WD	S
74	*Carabus montivagus* Pallairdi, 1825	R	RD	S
75	*Carabus ullrichi* Germar, 1824	R	RD	P
76	*Molops robustus parallelus* Mlynar, 1976	R	RD	S

77	*Amara saphyrea* Dejean, 1828	R	RD	P
78	*Amara similata* Gyllenhal, 1810	R	WD	P
79	*Tapinopterus kaufmanni* (Ganglbauer, 1896)	R	RD	S
80	*Xenion ignitum* (Kraatz, 1875)	R	RD	S
81	*Amara eurynota* (Panzer, 1797)	R	WD	P
82	*Myas chalybaeus* (Palliardi, 1825)	R	RD	S
83	*Pterostichus brucki* Schaum, 1859	R	RD	S
84	*Molops piceus bulgaricus* Maran, 1938	R	RD	S
85	*Aptinus bombarda* (Illiger, 1800)	R	RD	S
86	*Molops rufipes golobardensis* Mlynar, 1976	R	RD	S

Abbreviations: P – polytopic, S – stenotopic; RD – species with a restricted distribution, WD – species with a wide distribution; U – found collected in the urban zone, UR – found collected in both urban and rural (=non-urban) zones, R – found collected in the rural zone.

polytopic species are defined as ecologically tolerant species that occur in both forested and open habitats, while the forest specialist species were classified as stenotopic.

Ants

Stenotopic species were considered those that occurred exclusively in one habitat, while the polytopic ones occurred in multiple habitats. The Holarctic, Palearctic, European and Euro-Siberian species were considered widely distributed (WD), while Euro-Caucasian, Central-European, South-Transpalaearctic, Eurasian steppe, Pontic, Mediterranean, and Boreo-Montane were classified as species with restricted distribution (RD) (Table 2).

Table 2. Species list, distribution, and ecological characteristics of the ants.

No	Species	Zone	Zoog.	Ecol.
1	*Camponotus truncates* (Spinola, 1808)	U	RD	P
2	*Lasius balcanicus* Seifert, 1988	U	RD	P
3	*Lasius psammophilus* Seifert, 1992	U	WD	P
4	*Myrmica rugulososcabrinodis* Karawajew, 1929	U	RD	P
5	*Myrmica salina* Finzi, 1926	U	WD	P
6	*Myrmica rubra* (Linnaeus, 1758)	U	WD	P
7	*Ponera coarctata* (Latreille, 1802)	U	RD	P
8	*Prenolepis nitens* (Mayr, 1852)	U	RD	P
9	*Stenamma debile* (Förster, 1850)	U	RD	P
10	*Temnothorax affinis* Mayr, 1855	U	RD	P
11	*Tetramorium hungaricum* Röszler, 1935	U	RD	P
12	*Camponotus fallax* (Nylander, 1856)	UR	WD	P

13	*Camponotus piceus* (Leach, 1825)	UR	RD	P
14	*Camponotus vagus* (Scopoli, 1763)	UR	WD	P
15	*Dolichoderus quadripunctatus* (Linnaeus, 1771)	UR	WD	P
16	*Formica cinerea* Mayr, 1853	UR	RD	P
17	*Formica cunicularia* Latreille, 1798	UR	RD	P
18	*Formica pratensis* Retzius, 1783	UR	RD	P
19	*Formica rufibarbis* Fabricius, 1793	UR	WD	P
20	*Formica sanguinea* Latreille, 1798	UR	RD	P
21	*Formica fusca* Linnaeus, 1758	UR	WD	P
22	*Lasius alienus* (Förster, 1850)	UR	WD	P
23	*Lasius brunneus* (Latreille, 1798)	UR	RD	P
24	*Lasius citrinus* Emery, 1922	UR	RD	P
25	*Lasius flavus* (Fabricius, 1781)	UR	WD	P
26	*Lasius fuliginosus* (Latreille, 1798)	UR	WD	P
27	*Lasius paralienus* Seifert, 1992	UR	WD	P
28	*Lasius platythorax* Seifert, 1991	UR	WD	P
29	*Lasius niger* (Linnaeus, 1758)	UR	WD	P
30	*Myrmica lonae* Finzi, 1926	UR	WD	S
31	*Myrmica ruginodis* Nylander, 1846	UR	WD	P
32	*Myrmica rugulosa* Nylander, 1846	UR	WD	P
33	*Myrmica sabuleti* Meinert, 1860	UR	WD	P
34	*Myrmica scabrinodis* Nylander, 1846	UR	WD	P
35	*Myrmica schencki* Emery, 1894	UR	WD	P
36	*Myrmica specioides* Bondroit, 1918	UR	RD	P
37	*Myrmecina graminicola* (Latreille, 1802)	UR	WD	P
38	*Plagiolepis pygmaea* (Latreille, 1798)	UR	WD	S
39	*Polyergus rufescens* Latreille, 1798	UR	RD	P
40	*Solenopsis fugax* (Linnaeus, 1758)	UR	RD	P
41	*Tetramorium forte* Forel, 1903	UR	RD	P
42	*Temnothorax tuberum* (Fabricius, 1775)	UR	WD	P
43	*Temnothorax unifasciatus* (Latreille, 1798)	UR	RD	P
44	*Tapinoma erraticum* (Latreille, 1798)	UR	WD	P
45	*Temnothorax nylanderi* (Förster, 1850)	UR	RD	P
46	*Tetramorium caespitum* (Linnaeus, 1758)	UR	WD	P
47	*Camponotus ligniperda* (Latreille, 1802)	R	WD	P
48	*Camponotus aethiops* (Latreille, 1798)	R	RD	P
49	*Cataglyphis nodus* (Brullé, 1832)	R	RD	S
50	*Formica gagates* Latreille, 1798	R	RD	P
51	*Formica rufa* Linnaeus, 1761	R	WD	P

52	*Myrmica sulcinodis* Nylander, 1846	R	RD	P
53	*Messor structor* (Latreille, 1798)	R	RD	P
54	*Plagiolepis taurica* Santschi, 1920	R	RD	S

Abbreviations: P – polytopic, S – stenotopic; RD – species with a restricted distribution, WD – species with a wide distribution; U – found collected in the urban zone, UR – found collected in both urban and rural (=non-urban) zones, R – found collected in the rural zone.

Gastropods

Locally abundant snail species, strongly dependent on one environmental factor (e.g. hygrophilous, calciphilous species) were considered stenotopic (S), while the more globally abundant in Sofia mesophilous and xerophilous gastropod species were classified as polytopic (P). The geographically widely distributed (WD) species included Latomediterranean, European, Palaearctic and Holarctic species. The Bulgarian endemics, Balkan endemics, Ponto-Mediterranean and Holo-Mediterranean gastropods were classified as species having a restricted distribution (RD) (Table 3).

Table 3. Species list, distribution, and ecological characteristics of the terrestrial gastropods.

No	Species	Zone	Zoog.	Ecol.
1	*Lehmania* sp.	U	?	P
2	*Chondrula microtraga* (Rossmässler, 1839)	U	RD	P
3	*Oxychilus translucidus* (Mortillet, 1854)	U	RD	P
4	*Oxyloma elegans* (Risso, 1826)	U	WD	S
5	*Succinea oblonga* Draparnaud, 1801	U	WD	S
6	*Vallonia excentica* Sterki, 1892	U	WD	P
7	*Arion distinctus* Mabille, 1868	U	WD	P
8	*Aegopinella nitens* (Michaud, 1831)	U	WD	P
9	*Oxychilus draparnaudi* (Beck, 1837)	U	WD	P
10	*Tandonia kusceri* (Wagner, 1931)	UR	RD	P
11	*Tandonia cristata* (Kaleniczenko, 1851)	UR	RD	P
12	*Limax conemenosi* Boettger, 1882	UR	RD	P
13	*Lindholmiola girva* (Frivaldsky, 1835)	UR	RD	P
14	*Euomphalia strigella* (Draparnaud, 1801)	UR	RD	P
15	*Helix lucorum* Linnaeus, 1758	UR	RD	P
16	*Vallonia pulchella* (Müller, 1774)	UR	WD	P
17	*Cochlicopa lubrica* (Müller, 1774)	UR	WD	P
18	*Cochlicopa lubricella* (Porro, 1838)	UR	WD	P
19	*Pupilla muscorum* (Linnaeus, 1758)	UR	WD	P

20	*Ena obcura* (Müller, 1774)	UR	WD	P
21	*Chondrula tridens* (Müller, 1774)	UR	WD	P
22	*Zebrina detrita* (Müller, 1774)	UR	WD	P
23	*Arion lusitanicus* Mabille 1868	UR	WD	P
24	*Arion fasciatus* (Nilsson 1823)	UR	WD	P
25	*Arion subfuscus* (Draparnaud, 1801)	UR	WD	P
26	*Arion silvaticus* Lohmander, 1937	UR	WD	P
27	*Vitrina pellucida* (Müller, 1774)	UR	WD	P
28	*Aegopinella minor* (Stabile, 1864)	UR	WD	P
29	*Oxychilus glaber* (Rossmässler, 1835)	UR	WD	P
30	*Daudebardia rufa* (Draparnaud, 1805)	UR	WD	P
31	*Daudebardia brevipes* (Draparnaud, 1805)	UR	WD	P
32	*Tandonia budapestensis* (Hazay, 1881)	UR	WD	P
33	*Laciniaria plicata* (Draparnaud, 1801)	UR	WD	P
34	*Balea biplicata* (Montagu, 1803)	UR	WD	P
35	*Limax maximus* Linnaeus, 1758	UR	WD	P
36	*Limax flavus* Linnaeus, 1758	UR	WD	P
37	*Deroceras reticulatum* (Müller, 1774)	UR	WD	P
38	*Deroceras turcicum* (Simroth, 1894)	UR	WD	P
39	*Deroceras sturanyi* (Simroth, 1894)	UR	WD	P
40	*Deroceras agreste* (Linnaeus, 1758)	UR	WD	P
41	*Perforatella incarnata* (Müller, 1774)	UR	WD	P
42	*Monacha cartusiana* (Müller, 1774)	UR	WD	P
43	*Xerolenta obvia* (Menke, 1828)	UR	WD	P
44	*Cttania balcanica* (Kobelt, 1876)	UR	RD	S
45	*Argna truncatella* (Pfeiffer, 1841)	UR	WD	S
46	*Carychium tridentatum* (Risso, 1826)	R	WD	P
47	*Merdigera obscura* (Müller, 1774)	R	WD	P
48	*Cochlodina laminata* (Montagu, 1803)	R	WD	P
49	*Oxychilus hydatinus* (Rossmässler, 1838)	R	RD	P
50	*Milax parvulus* Wiktor, 1868	R	RD	P
51	*Tandonia serbica* Wagner, 1931	R	RD	P
52	*Deroceras bureshi* (Wagner, 1934)	R	RD	P
53	*Vestia ranojevici* (Pavlović, 1912)	R	RD	P
54	*Candidula rhabdotoides* (Wagner, 1927)	R	RD	P
55	*Sphyradium doliolum* (Draparnaud, 1801)	R	WD	P
56	*Punctum pygmaeum* (Draparnaud, 1801)	R	WD	P
57	*Discus perspectivus* (Mühlfeld, 1818)	R	WD	P
58	*Eucobresia diaphana* (Draparnaud, 1805)	R	WD	P

59	*Vitrea diaphana* (Studer, 1820)	R	WD	P
60	*Vitrea subrimata* (Reinhardt, 1871)	R	WD	P
61	*Vitrea contracta* (Westerlund, 1871)	R	WD	P
62	*Aegopinella pura* (Alder, 1830)	R	WD	P
63	*Oxychilus inopinatus* (Uličny, 1887)	R	WD	P
64	*Oxychilus depressus* (Sterki, 1880)	R	WD	P
65	*Carpathica stussineri* (Wagner, 1805)	R	WD	P
66	*Nesovitrea hammonis* (Ström, 1765)	R	WD	P
67	*Limax cinereoniger* Wolf, 1803	R	WD	P
68	*Lehmania nyctelia* Bourguignat, 1861	R	WD	P
69	*Deroceras laeve* (Müller, 1774)	R	WD	P
70	*Euconulus fulvus* (Müller, 1774)	R	WD	P
71	*Bradybaena fruticum* (Müller, 1774)	R	WD	P
72	*Soosia diodonta* (Ferussac, 1821)	R	WD	P
73	*Pseudotrichia rubiginosa* (Schmidt, 1853)	R	WD	P
74	*Cepaea vindobonensis* (Ferussac, 1821)	R	WD	P
75	*Helix pomatia* Linnaeus, 1758	R	WD	P
76	*Orcula bulgarica* Hesse, 1915	R	RD	S
77	*Macedonica frauenfeldi* (Rossmässler, 1856)	R	RD	S
78	*Arianta pelia* (Hesse, 1912)	R	RD	S
79	*Truncatellina claustralis* (Gredler, 1856)	R	WD	S
80	*Truncatellina cylindrica* (Ferussac, 1807)	R	WD	S
81	*Vertigo antivertigo* (Draparnaud, 1801)	R	WD	S
82	*Vertigo alpestris* Alder, 1838	R	WD	S
83	*Acanthinula aculeata* (Müller, 1774)	R	WD	S
84	*Balea perversa* (Linnaeus, 1758)	R	WD	S
85	*Bulgarica vetusta* (Rossmässler, 1836)	R	WD	S

Abbreviations: P – polytopic, S – stenotopic; RD – species with a restricted distribution, WD – species with a wide distribution; U – collected in the urban zone, UR – collected in both urban and rural (=non-urban) zones, R – collected in the rural zone.

RESULTS AND DISCUSSION

Composition and origin of urban faunas

Ground beetles

The total carabid species diversity recorded from the territory of the City of Sofia and its vicinity (255 species) represents about 35% of the 720 ground-beetle species in the Bulgarian fauna (Stoyanov, 2004). Of them, 237 species were recorded in the city itself (33% of the Bulgarian list). The fauna of the City of Sofia is an almost full subset (222 species, or 94%, shared) of the fauna of the West Bulgarian region (sensu Gueorguiev & Gueorguiev, 1995) and shows the highest similarity with that of the Vitosha Mt. Both regions (Sofia+West Bulgaria and Vitosha Mt.) share 114 carabid species – about 59% of the total 192 species recorded from both regions so far.

Altogether, 86 carabid species (12% of the Bulgarian fauna) were collected at the GLOBENET sites, 63 (73%) of them were recorded at the non-urban sites and 61 (71%) at the urban sites. While there was a considerable overlap between the faunas, 39 (45%) shared species, 25 (40% of the species collected from non-urban sites, or 29% of total species richness) of these were lost in the urban compared to the non-urban zone. However, 22 (36% of species collected from urban sites, or 25% of total species richness) ground-beetle species not found in non-urban sites were recorded in the urban zone (see Table 4).

Table 4. General urbanisation patterns in soil mesofauna groups, studied in the framework of Sofia GLOBENET project.

	Carabidae (12% of the Bulgarian fauna)			Formicidae (41% of the Bulgarian fauna)			Gastropoda (35% of the Bulgarian fauna)		
	U	**trend**	**Non-U**	**U**	**trend**	**Non-U**	**U**	**trend**	**Non-U**
Species richness (% of zone total)	71	↑	73	85	↓	80	53	↑	89
Unique species (% of species richness)	36	↑	40	24	↓	19	20	↑	53
Widely distributed species (% of zone total)	69	↓	57	52	↓	48	80	↑	79
Species of restricted distribution (% of zone total)	31	↑	43	54	↓	46	20	↑	21
Polytopic species (% of zone total)	77	↓	57	96	↓	91	91	↓	84
Stenotopic species (% of zone total)	23	↑	43	4	↑	9	9	↑	16

When taking into account the zoogeographical characteristics of the carabid beetles in both contrasting zones of the landscape, it becomes clear that the widely distributed species are more common in the urban zone (42 species, or 69%) than in the non-urban one (36 species, 57%). On the other hand, species of a more restricted geographical distribution (i.e. Balkan (sub)endemics + Holomediterranean + Ponto-Mediterranean) are more numerous in the non-urban zone – 27 species (43%) vs. 19 (31%) in the urbanised area of the city of Sofia.

According to the habitat preferences of the ground-beetle species recorded from each investigated region, the number of polytopic species (i.e., ecologically tolerant species that occur in both forested and open habitats) is quite similar across both of them – 47 species (77%) in the urban and 36 (57%) in the non-urban zone. The situation is more contrasting when considering the stenotopic (forest specialist) species – the non-urban region is inhabited by nearly 2 times more forest-specialist species (27 spp., 43%) than the urban one (14 spp., 23%) (see Table 4).

Ants

Fifty-four species, belonging to 17 genera, of ants were recorded in the studied region, representing 41% of the list of all species known from Bulgaria (131) (see Table 4). Within the City of Sofia, 46 species, comprising 85% of all species in the Sofia region and 35% of the Bulgarian list, were recorded.

All outdoor ant species found during the current study were autochthonous. Three allochthonous species were of tropical origin and occurred in greenhouses and buildings (*Monomorium pharaonis*, *Linepithema humile* and *Hypoponera punctatissima*). Until now, the invasive species *Lasius neglectus* has not been found in Sofia, although it was recorded in other Bulgarian cities – i.e. Varna (Seifert, 2000) and Silistra (unpublished data).

Some of the common, locally dominant species in the vicinity of Sofia and the Sofia region (i.e., *Formica pratensis*, *F. rufa* and *F. sanguinea*), exist in low numbers within the city of Sofia. On the contrary, the sub-dominant species in non-urban communities (i.e. *Lasius platythorax* and several *Myrmica* species) represented a larger component of the ant community in the urban areas. These species occupy the ecological niches vacated by the species that dominate in the native assemblages (Klausnitzer, 1987). Analogously, in urban and semi-urban grasslands, the sub-dominant *Lasius niger*, *Tetramorium caespitum*, *Formica rufibarbis* and *F. cunicularia* take over the leading role in ant assemblages, because the true dominant species of the neighbouring natural communities (i.e., *Formica pratensis*) are rare in the city.

Most of the species were polytopic and occured in more than one habitat – 50 species (93 % of the urban and rural fauna). These are either forest species (i.e., *Myrmica rubra*, *M. ruginodis*, *Temnothorax nylanderi*, *Myrmecina graminicola* and *Lasius platythorax*), or meadow species (*Solenopsis fugax*, *Tetramorium caespitum*, *Lasius niger* and *Formica cinerea*). There were also polytopic species with narrow ecological tolerance, such as *Ponera coarctata*, *Myrmica rugulosa*, *M. scabrinodis*, *M. schenki*, *M. specioides*. There were two stenotopic species in the urban zone (*Plagiolepis pygmaea* and *Myrmica lonae*) (4%) and two in the rural zones (*Plagiolepis taurica* and *Cataglyphis nodus*) (9%) (see Table 4).

Within the Euro-Siberian complex, the highest percentage (by number of species) is represented by the Euro-Siberian s. str. (16%), Euro-Caucasian (14%) and Holarctic (13%) elements in the studied region (Antonova & Penev, 2006). The other categories of the same complex are represented by less than four species (7%). The percentage of Mediterranean species (sensu stricto) is remarkably low (eight species, 15 %). Hence, the percentage of widely distributed (Holarctic, Palearctic, Euro-Siberian and European) species is around 54 % of the whole urban fauna (Table 4).

Thus, the urban ant fauna of Sofia can be regarded as a slightly impoverished version of the native fauna of the Sofia Kettle. There were no truly invasive ant species in the natural and semi-natural habitats of Sofia, because the three alien ant species recorded were entirely synanthropic.

Gastropods

The total number of terrestrial gastropod species recorded in Sofia and its vicinity was 85, that is 35% of all species known from Bulgaria (Table 4). The species richness within the city was almost half (45 species – 53% of the sampled species, or 19% of the Bulgarian list that holds 240 species so far) of the 76 species (89% of the sampled gastropod species) occurring in the areas surrounding Sofia. Thirty-six of the species known from the vicinity of Sofia (80% of all species in Sofia) have been found in the urban environment as well.

There were 10 species of synanthropic and/or introduced gastropod species, alien to the local fauna (24% of the fauna of the city). These can be divided into 2 sub-groups: species established as synanthropic in Sofia, but occurring either in natural or anthropogenic habitats in other regions of Bulgaria (five species), and species introduced by man into the urban fauna of Sofia (five species). In most cases, these were invasive species (except for *Aegopinella nitens*) that were well adapted to urban conditions and often capable of penetrating from their suburban and rural habitats into the City of Sofia (i.e. *Arion lusitanicus*, *Arion fasciatus*).

Polytopic species dominated the urban assemblages (41 species, 91% of all urban fauna). There are a few exceptions of abundant stenotopic species – the hygrophilous *Oxyloma elegans* and S*uccinea oblonga*, and the calciphilous species *Helicigona balcanica* and *Argna truncatella* (altogether totalling 9%). The proportion of stenotopic species decreased in the urban environment – four species (9% of all species found in Sofia) versus non-urban environment – 12 stenotopic species (16% of all species in the non-urban zone).

From a zoogeographic point of view, widely distributed gastropod species were the most prevalent element of the fauna of Sofia (80%). These were from the Lato-Mediterranean – eight species (23%), European – 18 (51%), Palaearctic – 3 (9%) and Holarctic – 6 (17%) ranges. Species of restricted distribution (20%) were the Bulgarian endemics – 1 (11%), Balkan endemics – 3 (33%), Ponto-Mediterranean – 4 (44%), Holomediterranean – 1 (11%); 1 species is currently of unclear zoogeographical status.

The origin of the terrestrial gastropod fauna of Sofia can be considered as a result of several parallel processes: (a) fragmentation of the natural ranges of the autochthonous species that occurred in the region prior to urbanisation, (b) introduction of allochthonous species, (c) expansion of xerophilic snails from the environs of Sofia into free ecological spaces "opened" due to the fragmentation of forested habitats, and (d) immigration of mesophillous species from the broad-leaved forests situated around Sofia into the city parks. These processes cannot be distinguished clearly from each other and their action goes on at present with varying intensity. Moreover, not only does immigration of species from the vicinity of Sofia into the urban environment occur, but also the opposite process of invaders (*Arion lusitanicus*, *Arion fasciatus*, and *Deroceras reticulatum*) expanding from the city to the suburbs seems to take place. The resulting patterns are both complex and dynamic (Dedov & Penev, 2000).

Do "urban" assemblages exist?

Ground beetles

As pointed out by Niemelä et al. (2002), the sites in the urban zone are clearly clustered together and separately from the non-urban sites that also form a compact group. Spatially adjacent sites in the city are faunistically more similar to each other than the sites in the non-urban zone (see also Stoyanov & Penev, 2004). The most isolated and heavily transformed sites on the Sofia plain (i.e. sites SI and RIII; Fig. 1) exhibit some weak similarity, while the more or less rural sites at the foothills around Sofia form a distinct group. The observed pattern clearly confirms the "urbanisation" of the carabid fauna of Sofia.

Ants

The cluster analysis of the assemblages based on presence/absence data resulted in grouping into two main clusters: woody and open habitats (Antonova & Penev, in press). The assemblages of the open areas were further subdivided into two groups: grassy habitats and artificial biotopes (asphalt coverings and agricultural land). Most of the assemblages of open areas clearly demonstrated the impact of urbanisation by grouping into three main zones depending on the distance from the city centre: central, peripheral and rural. The central urban zone encompasses sites situated concentrically at about 3,5 km distance from the city centre ("St. Nedelja" square) (Antonova & Penev, in press). The peripheral zone looks like a stripe of fragments within the city, situated between the central urban zone and the ring road.

Gastropods

Due to the low mobility of the terrestrial gastropods (Sverlova, 1998), it could be expected that the urban environment will provoke quick changes and degradation of the urban malacocoenoses. Dedov & Penev (2004) found that in the parks of Sofia distinguishable "urban" malacocoenoses existed. The analysis of the presence/absence data showed that three main groups of assemblages can be distinguished at 35 % similarity level – locality

RIII, all urban sites together with the SI locality and the rest of the rural localities. It can be concluded that there are clearly distinctive malacocoenoses of urban type (UI, UII, UIII, UIV and SI). At the same time, the urban snail communities demonstrate greater differences among each other than the rural ones do. A clearly distinct suburban zone could not be observed, and the suburban sites SII and SIV were grouped to the rural and SI to the urban localities, respectively.

Which are the main factors in spatial variation of assemblages in urban environment?

Ground beetles

The multivariate analysis of the carabid-beetle assemblages performed by Stoyanov & Penev (2004) clearly demonstrated the presence of one prominent ordination axis that summarizes the essential part of the dataset variation. The urban sites form a relatively compact cluster that clearly stands apart from the non-urban sites. Some of the non-urban sites (RIV) separate from an adjacent group of sites mainly on a geographical basis, while others (RIII, SI) cluster together on basis of their very depauperated ground-beetle fauna, probably resulting from the strong isolation of the respective forest patches within the landscape. The rest of the non-urban sites, while being widely scattered along the second ordination axis, still form a cluster on a geographical proximity basis (RII, SII, SIV) leaving the more geographically distant site (RI) relatively isolated from that cluster. The observed pattern allows us to confidently identify a major "latent" urbanisation gradient that explains most of the observed variation in the carabid beetle data, and a second one illustrating the influence of geographical isolation and landscape configuration of the sampling sites.

Ants

According to a preliminary DCA analysis (Antonova & Penev, in press), the ant assemblages were separated along two hypothetical gradients. One of the gradients explained the variation in ant assemblages from forest to open areas. The second one reflected the effect of the distance from the city centre. The factors of urbanisation most significant for the meadow dwelling ant assemblages appeared to be distance from the city center, area of the homogenous habitat, and distance of the fragment to the nearest one.

Gastropods

According to a CCA ordination analysis performed by Dedov & Penev (2004), a rural-urban gradient was observed along the first axis. Sites UI, UII, UIII, UIV and SI (Fig. 1) were isolated as localities of the urban type, while sites RI, RII, RIII, RIV, SII and SIV were distinguished as localities of non-urban type. The locality near the village of

Drenovo (RIII) is clearly distinguished along the second axis. Factors partly explaining the spatial variation in gastropod assemblages appeared to be altitude, area, and level of urban development (measured as a percentage of built-up area of the sampling sites). The first two factors seem to have a stronger effect in the localities of non-urban type, while the percentage of built-up areas was correlated with assemblages from the urban biotopes. Another major factor was the "origin of forest" – semi-natural for the localities of non-urban type and anthropogenic for urban localities. Other important factors related to those described above were soil type, slope, level of development of grasses, soil pH, soil nitrogen, leaf litter thickness, moisture of the leaf litter and the mechanical composition of the soil (Dedov & Penev, 2004).

GENERAL DISCUSSION

The fauna of a city results from an interaction of several complex factors, such as geographical position, relief in and around the city, the number, area size and quality of the parks, presence/absence of connections with natural habitats around the city, distribution patterns of pollution in the city, stage of fragmentation of the landscape and the ability of a certain animal group to adapt to urban conditions. Also of primary importance seems to be the present-day intensity of construction, de- and aforestation trends and other town-planning activities. All these factors act together in great complexity. This makes any attempt to reconstruct the pathways of urban faunas formation largely speculative (Dedov & Penev, 2000).

The increase of the anthropogenic pressure towards the city centre leads to reduction and extinction of stenotopic species and results in impoverishment of invertebrate faunas (Vepsäläinen & Wuorenrinne, 1978; Klausnitzer, 1987; Chudzicka & Skibinska, 1994, 1998a,b; Sverlova, 1997; Vepsäläinen et al., 2008). In many invertebrate groups, biodiversity is lost in urban habitats (Vepsäläinen & Wuorenrinne, 1978; Czechowski, 1982; Kasprzak, 1981; Niedbala et al., 1982; Pisarski, 1982; Skibinska, 1978, 1982, 1986c; Sawoniewicz, 1982, 1986; Winiarska, 1986). Therefore, the ecological conditions in cities could be considered a hostile barrier for many invertebrate animal groups. This is valid to a great extent for terrestrial gastropods in Sofia, where the diversity loss was nearly 40% (76 species in non-urban versus 45 species in the urban area). A similar abrupt decrease in terrestrial gastropod species number has also been reported in Lvov, Ukraine (Sverlova, 1999). This might be a result of the lower mobility and the corresponding higher sensitivity of snails to deforestation and habitat fragmentation. It may also be a result of anthropogenic pressure of visitors in the city parks, loss of unique habitats, (micro) climatic changes, and pollution of air, waters and soil (Klausnitzer, 1987; Whiteley, 1994). In ground-beetles, the decrease in species richness is negligible – about 8 %, while in ants we observe even the opposite tendency (Table 4) which, is most probably due to the incomplete sampling in the non-urban zone.

In similar studies carried out in Helsinki, it was found that species diversity decreased towards the urban zone (Niemelä et al., 2002; Venn et al., 2003; but see also Alaruikka et al., 2002, who established no trend in species richness along urban-rural gradient). The same decrease of carabid species richness in the urban areas was observed by Niemelä et al. (2002) and Hartley et al. (2007) in the city of Edmonton (Canada) and by Ishitani et al. (2003) in the city if Hiroshima (Japan). In the city of Debrecen (Hungary), however, Magura et al. (2004) demonstrated that the ground beetle species richness was higher in the rural and urban areas, as compared to the suburban one. In ants, changes in species diversity and abundance towards the city centre have been recorded by Kondoh (1978), Pisarski & Czechowski (1978), Vepsäläinen & Wuorenrinne (1978), Pisarski (1982), Czechowski (1991), Behr et al. (1996), Dauber (1997), Dauber & Eisenbeis, (1997), Schlick-Steiner & Steiner (1999), and Vepsäläinen et al. (2008). The low rates of biodiversity loss in ants and ground beetles in our study may be explained by the great mobility of these two groups on one hand, and by the large-sized and relatively well preserved city parks of Sofia that resemble natural and semi-natural forests, on the other.

Despite the general tendency of impoverishment of the fauna in the urban zone, under certain conditions (micro-habitats with slight anthropological influence) an increase of species diversity may be observed. For example, in some parks of Sofia (West Park, North Park, Loven Park), the diversity of snails is increased mainly at the expense of introduced and/or synanthropic species (as *A. nitens*, *Ar. subfuscus*, *Ar. hortensis*, etc.). According to some authors (see Trojan, 1981), the low anthropogenic pressure can increase the species richness of some social insects, including Formicidae. The reason for this may be the establishment of new habitats, their mosaic patterns and the great number of ecotones created by urbanisation (Frankie & Ehler, 1978), as well as the organic refuse (Trojan et al., 1982). Twenty-two species of carabids were gained in the urban sites, compensating for the loss of other species towards the city centre, which leads to a more or less balanced diversity of urban and non-urban carabid assemblages.

It may be considered as a rule that in urban habitats widely distributed species prevail over those with restricted distributions (Klausnitzer, 1987). This holds for a number of taxa studied in urban conditions (for example Vepsäläinen & Wuorenrinne, 1978; Vepsäläinen et al., 2008 – Formicidae; Burakowski & Nowakowski, 1981a,b – Cerambycidae and Elateridae; Cholewicka, 1981 – Curculiondae; Czechowski, 1981 – Carabidae; Czechowski et al., 1981 – Opiliones; Jedryczkowski, 1981 – Isopoda; Kasprzak, 1981 – Oligochaeta; Krzyzanowska et al., 1981 – Aranei; Kubicka, 1981 – Scarabaeidae; Pilipiuk, 1981 – Lumbricidae; Czechowski, 1982 – Carabidae; Jedryczkowski, 1982 – Diplopoda; Pisarski, 1982 – Formicoidea; Sterzynska, 1982 – Collembola; Langourov, 2004 – Phoridae).

In the City of Sofia the same trend of increased percentage of widely distributed species was confirmed for carabid beetles and ants (Stoyanov, 2004; Antonova & Penev, 2006). The share of Holarctic ant species was twice as large in Sofia than in the vicinity. The percentage of widespread Euro-Siberian species also increases in the city. In general, the bulk of the myrmecofauna of Sofia and its suburbs is composed by widespread species. Similar trends have been reported for other urban myrmecofaunas (Pisarski & Czechowski, 1987; Vepsäläinen & Pisarski, 1982; Pisarski & Kuĺesza, 1982). For the carabid beetles, a similar trend has been previously observed by Magura et al. (2004), who found that in urban areas opportunistic species dominated.

The terrestrial gastropods exhibited a trend that seemed to be opposite to the ants and carabid beetles, although the percentage of widely and locally distributed species were very close to each other. This slight difference between most soil mesofauna groups and terrestrial gastropods might be a result of the low mobility of gastropods on one hand, and the specific microhabitat requirements and the peculiarities in their biology (Barker, 2001), on the other. As slowly moving organisms, their distribution across wide areas is also relatively slow and hence, many species adapt to local conditions and manifest narrower ecological tolerance. This can be seen in the formation of many endemic species with different taxonomic lineages (multiple genera and families). This leads to a relatively lower number of terrestrial gastropod species with wide ranges in comparison to more mobile invertebrate taxa. Consequently, in the cities, the share of widely distributed species is lower while several stenotopic species co-occur in the relatively undisturbed parts of city parks (Bajdashnikov, 1992). Another common pattern observed along urbanisation gradients in most invertebrate groups is that the percentage of ecologically tolerant species increases with anthropogenic pressure (see Klausnither, 1987 and references therein). The higher percentage of polytopic species may also be an indicator for anthropogenic influence (Chudzicka & Skibinska, 1998a). According to Whiteley (1994), in urban environment, the specialist species disappear, while the number of generalist species increases. It is also known that higher levels of anthropogenic pressure result in depauperation of faunas (Vepsäläinen & Wuorenrinne, 1978; Bankowska et al., 1984; Pisarski et al., 1989; Chudzicka & Skibinska, 1998a,b), and eventually numerous extinctions (Skibinska, 1986b; Chudzicka & Skibinska, 1998a). The effect of faunal homogenization in the big cities (Whiteley, 1994) brought some researchers to the pessimistic conclusion that most of the species in urban parks do not have a conservation value and thus do not need to be protected (Bankowska et al., 1984). Considering cities as a whole, Luniak (1996) notes that the biodiversity they hold is clearly lower in comparison to the adjacent territories, but points out that urbanocoenoses in many cases are richer in species and more abundant than anticipated – the same isn't valid for the most heavily influenced assemblages. If the multitude of urban habitats is compared, the view of Whiteley (1994), that diversity is dramatically influenced in different urban habitats, finds its logical extension in the view of Trojan (1994), that urbanisation leads in some cases to an increase in biological diversity and a decrease in others.

The analysis of gastropod assemblages showed that in the city of Sofia the percentage of stenotopic species decreased (9% of all species found in the area of Sofia) in comparison to the non-urban territories (16% of all species found in the non-urban zone). The carabids and ants shared a similar trend: carabids (23% and 42% respectively) and ants (4% and 9% respectively) (Table 4). This may be interpreted as a result of the degradation of habitats within the city, as well as a result of destruction and disappearance of some habitats and the rare species inhabiting them (Vepsäläinen & Wuorenrinne, 1978; Chudzicka & Skibinska, 1994, 1998a,b; Sverlova, 1997; Vepsäläinen et al., 2008).

The city parks (including those in Sofia) are among the relatively less influenced urban habitats, and as such function as refuges for many animal groups (Czechowska & Bielawski, 1981; Czechowski, 1982; Czechowska, 1986; Skibinska, 1986a,b; Sterzynska, 1987). They are also the biggest green "islands" within cities that maintaining a higher diversity through their greater area, as found by numerous studies (see e.g. Klausnitzer, 1987; Whiteley, 1994).

Our results confirmed the thesis of Klausnitzer (1987) that the number of animal species in the city increases proportionally with the age and area of a homogeneous park biotope. The pattern observed in the ants was similar to those described by Suarez et al. (1998) and Yamaguchi (2004), who used a multiple regression to find that the fragment area and time of its isolation from the rural habitat (age) were the best predictors for the number of native ants that will be found in that fragment. A significant positive correlation was also found between the area of the habitat and ant species richness as well as between area and nest density in humid habitats in Belgium (Maes et al., 2003). According to these authors, this is due to higher plant diversity and presence of proper nesting places, respectively. Similar correlations between age and size of the parks and diversity of snails have been observed in Lvov, Ukraine by Sverlova (1997, 2000) and Bajdashnikov (1985). The bigger and older the forested areas are, the higher is the diversity of snails. Moreover, several rare stenotopic species may occur in the oldest parts of the parks (Bajdashnikov, 1992).

It has been shown that the urban assemblages are quite distinct (Czechowski, 1982; Nowakowski, 1986; Winiarska, 1986; Pisarski et al., 1989; Chudzicka & Skibinska, 1994, 1998a), and may even be termed "urbanocoenoses" (Luniak, 1996). Our results clearly support the specificity of the urban assemblages which differ from those in suburban and rural areas. However, although being clearly distinguished in species composition and abundancies, urban assemblages of the different animal groups also appear quite different in structure and diversity (Whiteley, 1994). This reinforces the need to use various taxonomic groups when designing bioindication and monitoring schemes in cities.

CONCLUSIONS

1. In all three groups, the urban faunas can generally be regarded as impoverished variants of the regional species pools. For gastropods, however, the urban fauna is enriched by invasive species and may even serve as a source of distribution of such species into the neighbouring suburban and rural territories. For ants, such an enrichment is not recorded, with the exception of three fully synanthropic species, not occurring in natural or semi-natural habitats. There are no invasive species of ground beetles and the urban fauna can be described as a modified, "urbanised" version of the native fauna. Both faunas of ground beetles – the native and the urban one – are of comparable diversity but of slightly different species composition.
2. The diversity of urban faunas decreased relative to neighbouring territories. The degree of decrease differed with taxa and ranged from 2% (ground beetles) to 36%

(gastropods). Species composition was also observed to have changed between these two zones.

3. Urbanisation leads to an increase in the proportion of widely distributed and eurytopic species. This trend was quite prominent in gastropods, but less so in ants and ground beetles. In both latter groups, the proportion of eurytopic and stenotopic species in the city was relatively equal.
4. "Urban" assemblages could be delimited in all three groups. As compared to the native assemblages from the surroundings of the city, they can be characterised by changes in species composition, dominant structure, and the presence of alien species (gastropods). Suburban assemblages were not clearly distinguished in all three groups.
5. The main influence on the spatial variation in assemblages seemed to be a complex urbanisation factor that led to a clear separation of "urban" assemblages from suburban and rural ones. Some peculiar factors revealed by ordination analyses in the different groups were altitude, type of habitat (woody/open), distance from the city centre, area and percentage of built-up area of the sampling sites.
6. Patterns of urbanisation shown by the different groups were similar in many respects, but their qualitative and quantitative assessment differed. This reinforces the necessity of a broad approach, based on different taxonomic groups, when planning bioindication and monitoring activities in cities.

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