Spatial Variation in Terrestrial Gastropod Communities (Gastropoda, Pulmonata) along Urban-Rural Gradients in Sofia City, Bulgaria

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Abstract

We examined terrestrial snails as a model group for identification of the urbanisation impact in Sofia city, Bulgaria. A total of 3 519 specimens were collected from 11 sites, situated at various distances from the city center, in the urban, suburban and rural zones. The potential of terrestrial snails as good indicators of environmental changes was confirmed. Existence of malakocoenoses, typical for urban environment, was shown. The existence of individual gastropod assemblages, typical for the suburban zone, was not confirmed. The density of snail populations appeared higher in parks compared to the rural zone. A linear change in the parameters of diversity, evenness and dominance along the urban-rural gradient was not observed.

Key words

Molluscs, urban-rural gradient, gastropod communities, Sofia, Bulgaria.

INTRODUCTION

Snails are a group widely used as bioindicators of heavy metal pollution (Samiulla, 1990). Based on studies of a meadows malakocoenose, Huber *et al.* (1997) also recommended the use of terrestrial snails in bioindication. Sverlova (2001) pointed out the good indicatory role of terrestrial snails for surveys in city parks.

Reports on the species composition and habitat distribution of the terrestrial snails in some cities in Europe can be found in the papers by Kosiñska (1979) for Wroclaw (Poland), Schileyko (1981) for Moscow (Russia), Pfleger (1992) for Prague (Czech Republic), Juričkova (1995, 1998) for Prague and Hrad Hradue (Czech Republic) and Sverlova (1997a, 1998, 1999a,b, 2000 a,d) for Lvov (Ukraine). The anthropogenic impact on the ecology, morphology and population parame-

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ters of various species of terrestrial snails were widely discussed in the papers of Sverlova (1997 b, 2000 b,c). Bajdashnikov (1985, 1992) commented on the impact of human activities on the snail fauna of some areas in the Ukraine.

Dedov & Penev (2000) conducted the only deliberate study of the urban snail fauna in Bulgaria. The authors reported 41 species of terrestrial snails from Sofia and analysed the origin of the urban gastropod fauna.

The purpose of this work is to study the existence of individual urban malakocoenoses by means of comparative analysis, and to ask whether terrestrial snails and the parameters of their communities are suitable indicators for anthropogenic changes in the environment.

The study falls within the framework of the GLOBENET project, studying the impact of urbanisation on the environment on the basis of population characteristics of soil invertebrates. The idea of the project is to create a global network for monitoring of landscape changes (Niemelä *et al.*, 2000).

MATERIAL AND METHODS

Study area and sampling sites

Samples were collected along four gradients starting from the city of Sofia to its vicinities in north-western, western, southern and south-eastern directions.

In each gradient, 3 sampling sites in urban, suburban and rural zones were selected, except for gradient No 3, where no suitable suburban site was found (see Penev *et al.*, this volume). The respective localities were entitled as "U" for urban, "S" for suburban and "R" for rural habitats, which reflected the basic hypothesis of GLOBENET for the existence of three types of zones, determined by the different level of anthropogenic pressure, in direction from the city center through the suburbs to the natural habitats outside the city (see map of the sites in Penev *et al.*, this volume).

The sampling sites were situated in deciduous forests with prevailing of *Querceta* formation, and list of them is given below:

a) Gradient 1, South East

UI - Sofia, Borisova gradina Park (550 m), forest dominated by *Quercus*, *Acer*, *Fraxinus*, and *Carpinus*.

SI - vill. German (700 m), *Quercus rubra* forest.

RI - German Monastery (800 m), forest dominated by *Quercus*, *Carpinus* and single individuals of *Fagus*.

b) Gradient 2, West

UII - Sofia, Western Park (550 m), *Quercus rubra* forest.

SII - Ljulin mountain, (700 m), forest dominated by *Quercus* and *Carpinus,* mixed with *Acer* and *Tilia*.

RII - Ljulin mountain, (800 m), forest dominated by *Quercus* and *Carpinus*.

c) Gradient 3, North

UIII - Sofia, Northern park, (550 m), forest characterized by *Quercus rubra* and *Crataegus*.

RIII - Lom Road (700 m), forest characterized by *Quercus cerris*, *Crataegus*, *Cornus*, *Prunus spinosa*, and *Corylus avellana*.

d) Gradient 4, South

UIV - Sofia, Hunting Park (550 m), forest dominated by *Quercus*, *Tilia*, *Fraxinus*, *Acer*, and *Crataegus*.

SIV - Vitosha Mountain, vill. Vladaya (900 m), forest characteized by *Quercus*, *Carpinus, Crataegus*, *Corylus avelana*, and *Rosa* sp.

RIV - Vitosha Mountain, Tihiya kat (900 m), *Quercus dalechampii* forest.

Sampling method

Ten samples from each site were collected per month, using the 50x50 cm^2 square method (Ökland, 1929, 1930). Samples were taken with a sifter with 1,5 cm diameter net openings. The depth of collecting activities was defined by the exhaustion of live snails, but in all cases it was not less than 5 cm.

Statistical methods

Data were processed with the BIODIV software (Baev & Penev, 1995) for cluster analysis of malakocoenoses and for the calculation of indices of α-diversity (Table 2). For the purposes of classification of localities and species, TWISNPAN was used (Hill, 1979). Techniques available in CANOCO (Ter Braak, 1988) were used for direct and indirect gradient analyses (Jongman *et al*., 1987).

The species data set

All the analyses conducted were based on the matrix presented in Table 1, consisting of data collected from April to October 1999. The bulk of the samples were collected during spring months (April–May). Only live snails were registered and included in the data matrix.

Environmental data set

An initial data set of several environmental factors (see Penev *et al*., this volume) was tested with the option "Forward Selection of Environmental Variable" of CANOCO in order to select those variables with the best explanatory value. The variables used for the purpose of the analyses were: level from built up area (build) and surface (S) of the investigated locality, distance from the city center (dist), altitude (alt) and tilt (tilt), origin of forest (orig_a – artificial, orig_n – natural), density (treeN), coverage (treeC), height (treeH) and diameter (treeD) of trees, age of forest (treeage), thickness (leafH) and moisture (leafhm) of the litter, grass cover (grass), soil type (soil_a - Chromic livisols, b - Maroon chromic livisols, c - Urbogenic anthroposoils, d - Leached maroon forest soils, e - Maroon soils), moisture (soilhm), mechanical composition (mech), pH, humus composition (humus) and nitrogen (N) of the soil.

RESULTS

During the study a total of 3 519 specimens belonging to 33 species of terrestrial snails were collected. With regard to the value of the diversity indices, two localities were identified as most

Table 1. Species composition and numbers of specimens at the sampling sites. For abbreviations of site names see **Material and methods**.

	UI	UII	UIII	UIV	SI	SII	SIV	RI	RII	RIII	RIV
Ena obscura (Müll.)		2			3						1
Chondrula tridens (Müll.)	1		1								
Cochlicopa lubrica (Müll.)											17
Cochlodina laminata (Mont.)											7
Balea biplicata (Mont.)	1	77									
Arion lusitanicus Mabille		14	16	30							
Arion fasciatus (Nilsson)	8	114	353	141	105						
Arion distinctus Ferussac	72	139		544							
Arion subfuscus (Drap.)				7	36	14	8	11	11	3	6
Arion silvaticus Lohmander						94	90	61	29		113
Euconulus fulvus (Müll.)											5
Vitrina pellucida (Müll.)		3	1								
Aegopinella nitens (Michaud)	113	10									
Aegopinella minor (Stabile)	14			14			10	74	25	60	11
Vitrea contracta (West.)					2					1	
Oxychilus translucidus (Morttillet)			2								
Oxychilus glaber (West.)					3						
Oxychilus draparnaldi (Beck)			7								
Daudebardia rufa (Drap.)	14	8		1	18	14	17	30	22		11
Daudebardia brevipes (Drap.)	29	6	3	4	7	9	4	5	2		4
Carpathica stussineryi (Wagner)						18	21	3	54		22
Limax maximus L.		1		5	12		1	4	2	3	5
Limax cinereoniger Wolf								1			
Deroceras turcicum (Simroth)	35	37	44	69	13	7		3	6	1	3
Deroceras reticulatum (Müll.)			12								
Deroceras agreste (L.)			38								
Deroceras bureshi (Wagner)						3	1		4		9
Tandonia budapestensis (Hazay)		52	165								
Tandonia cristata (Kaleniczenko)		13	19			10	2				2
Lindholmiola corcyrensis (Deshayes)										39	
Euomphlaia strigella mehadiae (Bourg.)		1						1		4	3
Perforatella incarnata (Müll.)		16	18	3		1		1			10
Helix lucorum L.	15	2	8	1	1					2	1
live species in site	**10**	**16**	**14**	**11**	**10**	**9**	**9**	**11**	**9**	**8**	**17**
live specimens in site	**302**	**495**	**687**	**819**	**200**	**170**	**154**	**194**	**155**	**113**	**230**

diverse – Tihiya Kut (RIV) and the Western Park (UII). The lowest diversity was recorded at the village of Drenovo (RIII) and in the Hunting Park (UIV). Evenness was highest at Lyulin, above the Bonsovi livadi (RII) and lowest at the Tihiya Kut (RIV). Dominance was highest in the Hunting Park (RII) and lowest in the Western Park (UII) (Table 2).

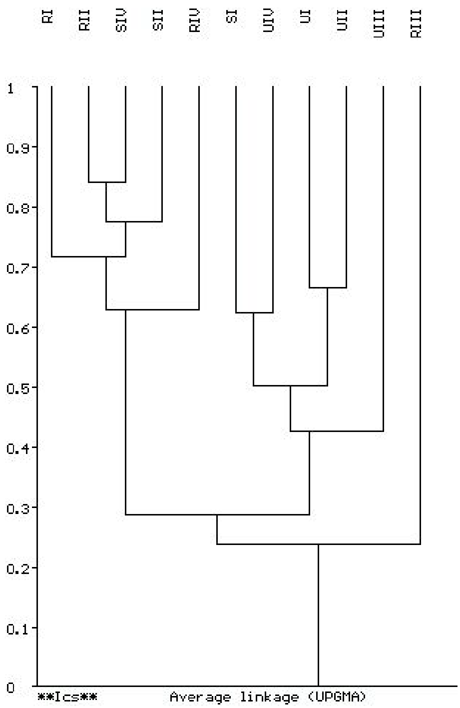

Fig. 1. Group average clustering dendrogram of the terrestrial snail assemblages based on the Czekanowski-Sörensen similarity index for presence-absence data. For abbreviations of site names see **Material and methods**.

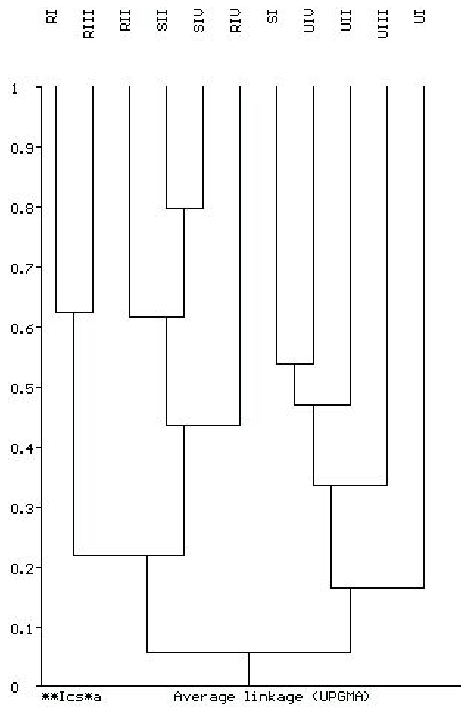

Fig. 2. Group average clustering dendrogram of the terrestrial snail assemblages based on the Czekanowski-Sörensen similarity index for abundance data. For abbreviations of site names see **Material and methods**.

Table 2. Species diversity, evenness and dominance at the sampling sites. For abbreviations of site names see **Material and methods**.

	RI	RII	RIII	RIV	SI	SII	SIV	UI	UII	UIII	UIV
Number of species (S)	11	9	8	17	10	9	9	10	16	14	11
Number of specimens (N)	194	155	113	230	200	170	154	302	495	687	819
Shannon's diversity (H')	1.53	1.79	1.14	1.96	1.52	1.48	1.38	1.69	2.02	1.53	1.13
Hill's diversity (N1)	4.63	5.99	3.14	7.13	4.57	4.37	3.98	5.4	7.56	4.64	3.09
Alatalo's evennenss (F)	0.72	0.79	0.69	0.44	0.58	0.56	0.56	0.72	0.72	0.56	0.56
Molinari's evennenss (G)	0.37	0.46	0.32	0.09	0.2	0.17	0.18	0.36	0.37	0.17	0.17
Berger-Parker's dominance (d)	0.38	0.34	0.53	0.49	0.52	0.56	0.58	0.39	0.28	0.52	0.65

Similarity between the gastropod assemblages is presented in Fig. 1 (for presence/absence data) and Fig. 2 (for quantitative data). The analysis of the dendrogram for presence/absence data (Fig. 1) shows that three main groups of assemblages can be distinguished at 35 % similarity – 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 urban type malakocoenoses (UI, UII, UIII, UIV and SI). At the same time, these snail communities demonstrate greater differences among each other compared to the rural ones. A clearly distinct suburban zone could not be observed, and the suburban SII and SIV sites were grouped with the rural, and SI with the urban localities, respectively.

When entering a quantitative component in the data (Fig. 2), the dendrogram of similarity became more comprehensive. At a rather low level of similarity (about 10 %), two main groups of localities were identified – urban and rural. The low similarity showed the specificity of the urban malakocoenoses. The suburban locality at the village of German, (SI) falls under this group.

Calculations conducted using TWINSPAN (Fig. 3) gave similar and even more explicit results. The first grouping sharply distinguished the urban biotopes from the rest. The second grouping isolated the RIII and SI sites. The rest of the non-urban biotopes were grouped together with this method, regardless of whether they are suburban or rural. Indicator species for urban environment are *A. lusitanicus*, *A. distinctus*, *A. fasciatus* and *T. budapestensis.* Species which are relatively independent of the anthropogenic factor and were found to occur in similar numbers in almost all biotopes include *A. minor*, *D. rufa*, *L. maximus*, *D. brevipes* and *D. tucicum*.

		R,R, R,S, S, R, S,U,U,U,U IV,I,II,II,IV,III,I,I,II,III,IV	
3	C_lub	4 – – – – – – – – – –	00000
4	C_lam	3 – – – – – – – – – –	00000
11	E_ful	3 – – – – – – – – – –	00000
10	A_sil	5 5 5 5 5 – – – – – –	00001
21	C_stu	5 2 5 4 5 – – – – – –	00001
23	L_cin	– 1 – – – – – – – – –	00001
27	D_bur	3 – 2 2 1 – – – – – –	00001
9	A_sub	3 4 4 4 3 2 5 – – – 3	0001
14	A_min	4 5 5 – 4 5 – 4 – – 4	0010
19	D_ruf	4 5 5 4 4 – 4 4 3 – 1	0010
22	L_max	3 2 2 – 1 2 4 – 1 – 3	0010
31	E_str	2 1 – – – 2 – – 1 – –	0010
15	V_con	– – – – – 1 2 – – – –	0011
17	O_gla	– – – – – – 2 – – – –	0011
30	L_cor	– – – – – 5 – – – – –	0011
1	E_obs	1 – – – – – 2 – 2 – –	01
20	D_bre	2 3 2 3 2 – 3 5 3 2 2	01
24	D_tur	2 2 3 3 – 1 4 5 5 5 5	10
29	T_cri	2 – – 4 2 – – – 4 4 –	10
7	A_fas	– – – – – – 5 3 5 5 5	110
32	P_inc	4 1 – 1 – – – – 4 4 2	110
33	H_luc	1 – – – – 2 1 4 2 3 1	110
2	Ch_tri	– – – – – – – 1 – 1 –	111
5	B_bip	– – – – – – – 1 5 – –	111
6	A_lus	– – – – – – – – 4 4 5	111
8	A_dis	– – – – – – – 5 5 – 5	111
12	V_pel	– – – – – – – – 2 1 –	111
13	A_nit	– – – – – – – 5 4 – –	111
16	O_tra	– – – – – – – – – 2 –	111
18	O_dra	– – – – – – – – – 3 –	111
25	D_ret	– – – – – – – – – 4 –	111
26	D_agr	– – – – – – – – – 5 –	111
28	T_bud	– – – – – – – – 5 5 –	111
		0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 1 1 01111	

Fig. 3. TWINSPAN table of the terrestrial gastropod assemblages based on species abundance.

According to the CCA ordination analysis performed with CANOCO, a rural – urban gradient is observed along the first axes (engenvalue 0.821) (Fig. 4). UI, UII, UIII, UIV and SI were isolated as localities of the urban type. RI, RII, RIII, RIV, SII and SIV were distinguished as localities of non-urban type. The locality at the village of Drenovo (RIII) is clearly distinguished

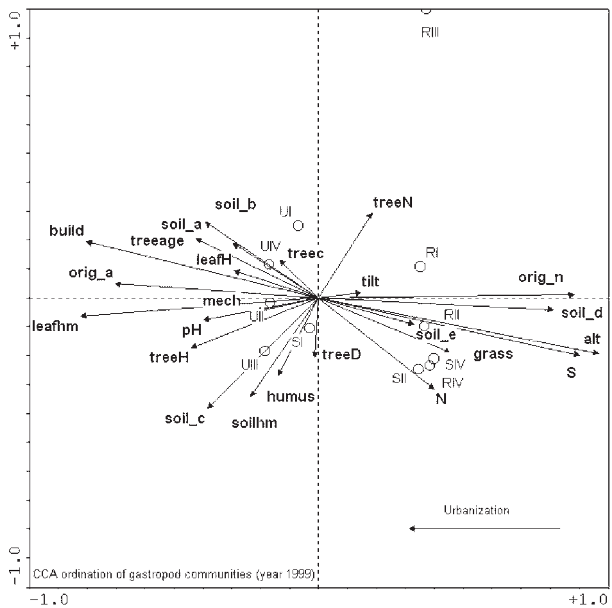

Fig. 4. Correspondence analysis (CCA) ordination diagram of the species and localities. (Forward selection of environmental variables was used to select the factors with best possible explanatory value). For abbreviations of environmental variables see **Environmental data set**.

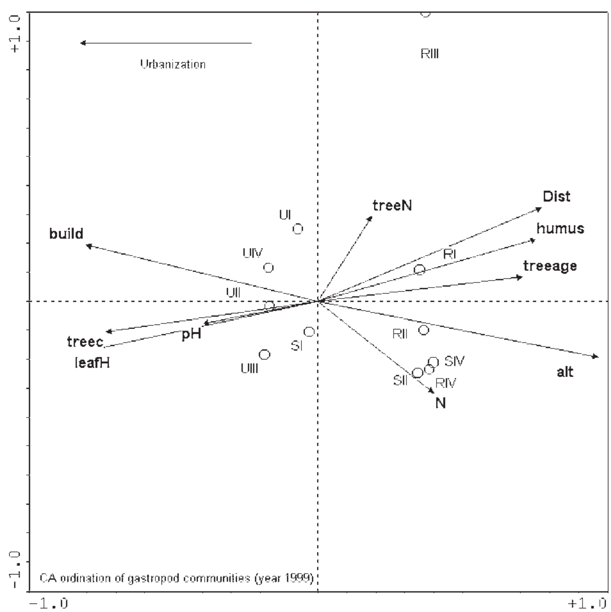

Fig. 5. Correspondence analysis (CA) ordination diagram of the localities and environmental factors. For abbreviations of environmental variables see **Environmental data set**.

along the second axis (engenvalue 0.489). Factors partly explaining the spatial variation in gastropod assemblages appeared to be altitude, surface and level of built up areas of the sampling sites. The first two factors increase in the localities of non-urban type, while the percentage of built up areas is higher in the urban biotopes. A major factor proved to be the "origin of forest" – natural for the localities of non-urban type and artificial for urban localities. Other important factors related to those described above are soil type, inclination of the sampling site, level of development of grass vegetation, pH and nitrogen in the soil, thickness and moisture of the leaf litter and the mechanical composition of the soil.

The CA ordination analysis (Fig. 5) along the first axis (engenvalue 0.821) indicates similar variation of gastropod assemblages distinguishing them as groupings of urban and non-urban type. Along the second axis (engenvalue 0.530), the RIII locality was distinguished. At the non-urban localities (RI, RII, RIII, RIV, SII, SIV) the altitude is higher, the age of forests increases, as well as the humus contents of the soil and the distance of the respective sampling site from the center. At the localities of urban type (UI, UII, UIII, UIV, SI) the level of built up area of the respective sampling site increases as well as the coverage of forest, soil pH and the thickness of the leaf cover.

DISCUSSION

Diversity, evenness and dominance (Table 2) did not change linearly along the urban-rural gradient. Just as the two most diverse localities (UIV, RIV), the two localities with lowest diversity (UIV, RIII) belong to the two different main zones - urban and non-urban (rural). On the other hand, the highest and lowest values of evenness were observed at two of the non-urban (rural) communities (RII, RIV). Table 2 shows that the possible reason for the high diversity at the sampling site in the Western Park is not only the high number of identified species (16) and specimens (495), but the lack of a clear dominant species, thus a low level of dominance (0.28). In the Northern Park with a similar number of species (14) and a much higher abundance (687), but relatively high dominance (0.52), the diversity indices have lower values. The reasons for the high diversity at the sampling site at Tihiya Kut (RIV), however, need to be sought mainly in the greatest number of species identified for the investigated locality (17), as well as their relatively high density in the rural zone (230). The low evenness at RIV corresponds to its high diversity and is probably due to the same reasons. Here the index of dominance has a medium value (0.49).

A similar pattern is observed at the localities with lowest diversity. In this way, the low diversity of the urban locality in the Hunting Park is mainly due to the superdominance of the species *A. distinctus* (544 from 819 or 66% from all specimens collected in the park). The reasons for the low diversity at the locality at the village of Drenovo, have to be sought in the low number of species registered (8) with a low number of specimens (113). Consequently, despite the well differentiated urban malakocoenoses, the parameters of diversity, evenness and dominance of the investigated 11 communities were not influenced by the anthropogenisation of the environment. The effect of superdominance, characteristic of urban ecosystems (Klausnitzer, 1990) is not observed clearly at the species level for terrestrial snails in urban parks. This shows the role of parks as oases in cities, which are not only habitats of rural species preserved there (Dedov & Penev, 2000), but they also support a stable population structure of synanthropic species. Thus, the parks and forested zones are centers of biodiversity for the terrestrial snails in the urban environment (Sverlova, 1997 b, 2000 a; Bajdashnikov, 1992). The effect of superdominance, characteristic of pressured environments, needs to be sought at the genus level, where the specimens of the genus *Arion* represent approximately 62% of all the species, registered in the parks in Sofia (or 1438 specimens from a total number of 2303 for Sofia). At the same time, for all the other localities, this percentage is 48% (581 specimens from a total of 216). According to Sverlova (2001), in urban conditions, the share of slugs increases in comparison to rural biotopes. Our results confirm this conclusion. So in an urban environment, the total number of slugs was 1928 specimens or 84% from the entire collection of 2303 specimens, for the suburban - 396 specimens from a total number of 524 or 76% and for rural - 277 specimens from a total number of 692 or 40%. Besides the reasons indicated by Sverlova (2001) (a greater number of eggs deposited by slugs, the lower environmental requirements, polyphagy), in our opinion this result can also be explained by the fact that the bulk of the species introduced to Sofia are slugs (*T. budapestensis*, *D. reticulatum*, *D. agreste*, *A. lusitanicus*, *A. fasciatus*, *A. distinctus*). Usually, these are flexible, widely distributed species, living as synanthrops in many European cities, wherefrom they penetrate to neighbouring natural and semi-natural biotopes. Most of these snails live in the cities in high numbers and their very presence is an indication of anthropogenic influence (Bajdashnikov, 1985).

The classification of gastropod assemblages performed with both BIODIV and TWINSPAN revealed, at first, a clear distinction of the urban zone. The inclusion of quantitative data to the same type of analyses reinforces this pattern. Therefore, we can conclude that the anthropogenic factor influences not only the species composition and taxonomic structure of malakocoenoses but also their species abundances. Thus, in urban parks, the numbers of terrestrial snails specimens increases in comparison to other biotopes. The average number of specimens collected per locality was 576 for urban environment, 174 for suburban, and 173 for rural. These numbers show not only the gradual reduction of the number of specimens along the urban-suburban-rural gradient, but also confirm the higher similarity of the suburban biotopes with the rural ones.

We have to seek the reasons for the higher total abundance of snail assemblages in urban parks in their role as shelters for both rural species (i.e. *E. obscura*, *A. subfuscus*, *A. minor*, *D. rufa*, *D. brevipes*, *T. cristata*, *Perforatella incarnata*) and for the introduced forest and park species (Sverlova, 1997 b, 2000 a; Bajdashnikov, 1992). The species *A. nitens* and *A. distinctus* belong to the second group. These species are not typical for the Bulgarian fauna and are only registered in the urban parks in Sofia (Dedov & Penev, 2000). Parks offer better living conditions for some synanthropic species compared to the open biotopes where they also live but in smaller numbers (*A. fasciatus*, *A. lusitanicus*). In addition, species, characteristic of open habitats, but possessing high ecological flexibility, penetrate parks (i.e. *Ch. tridens*, *O. draparnaldi*, *D. reticulatum*). Therefore parks appear to be islands, forming comparatively rich communities of terrestrial snails, aiming at maximum efficient use of the existing space and resources. These anthropogenically influenced biotopes appear to have higher density (in U - 16 spec/m^2 average monthly density) compared to the non-urban habitats, where snails occur at lower density, are more evenly distributed and live at bigger, non-fragmented spaces (in S and R - 5 spec/m^2 average monthly density).

Species living in comparatively high numbers in more than one locality within the urban zone can be considered indicator species of urban communities. According to the TWINSPAN analysis, indicator species for communities of urban areas are (arranged by order of significance): *A. fasciatus*, *A. distinctus* and *A. lusitanicus*.

We can consider species living in comparatively high numbers in more than one locality, in or outside the capital as relatively independent of human influence. These include: *A. minor*, *D. rufa*, *D. brevipes*, *L. maximus*, *D. turcicum*.

The ordination by CCA analysis also confirmed the existence of distinctive urban malakocoenoses and the unclear distinction of the suburban zone. According to Begon *et. al.* (1989), if there is a gradient of a certain key environmental factor, there should be a point where the relative competitive power of species changes radically. The result usually is that one dominant species is replaced by another one. As far as the anthropogenic changes influence the complex of factors and each of them would have such a sharp limit in a different part of the space concerned, the picture in the previous zone would have diverse parameters. This specific example can probably explain why two of the suburban localities (SII, SIV) are grouped together with the rural ones, while SI is closer to the urban biotopes. Hence, the S zone is not strictly distinct and it lacks an autonomous complex of species. For instance, on the first axis the locality at the village German (SI) is grouped closer to the urban, than to the rural localities. This fact may be explained by the close disposition of this suburban biotope to a human settlement (village German), as well in the artificial nature of the forest (a formation of the introduced Red Oak *Quercus rubra*). The locality distinguished along the second axes is the one at Drenovo (RIII). This biotope is distinct at a relatively high level in all analyses, which is mainly due to the isolation of the forest.

The ordination (CA) analysis indicates that, in urban parks, the increase of the forest coverage and the thickness of leaf coverage provide better shelter for terrestrial snails during unfavorable conditions. In cases of extreme conditions in the city (Klausnitzer, 1990), the two factors become important by influencing the water balance in the respective park – an especially important factor for terrestrial snails. The role of moisture for snails in urban biotopes is emphasised also by Sverlova (2000 c). The distance from the center and altitude seem to be the major factors influencing both directly and indirectly the living conditions of snails. The higher density of forest and the thicker humus composition of soil contribute to better living conditions for terrestrial snails outside the capital.

CONCLUSIONS

1. The parks in the city of Sofia host clearly distinctive assemblages of terrestrial snails, typical for the urban environment.
2. There is no individually distinctive suburban zone. Two zones are formed - non-urban (rural) (RI, RII, RIII, RIV, SII, SIV) and urban (SI, UI, UII, UIII, UIV).
3. The density of snails in the parks of Sofia is higher in comparison to those of the rural zone.
4. The parameters diversity, evenness and dominance do not change lineary along the urban-rural gradient.
5. Indicator species for urban type assemblages are *A. fasciatus*, *A. distinctus* and *A. lusitanicus*.
6. Main factors influencing the spatial distribution of species and assemblages are (1) urbanization, (2) altitude and (3) forest origin.

7. Environmental factors with highest correlation to main trends in the species distribution and spatial variation of the assemblages are: pH, mechanical structure and type of soil, moisture and thickness of litter; origin, coverage, density and age of forest.
8. Terrestrial snails are a good model group for studying the changes in the environment caused by anthropogenic factors.

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