Ecology of the City of Sofia

SPECIES AND COMMUNITIES IN AN URBAN ENVIRONMENT

Edited by

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev

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Sofia-Moscow

2004

ECOLOGY OF THE CITY OF SOFIA
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First published 2004
ISBN 954-642-224-X

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www.pensoft.net

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INTRODUCTION

It is expected that in this year (2005), about half of the human population will be urban dwellers, and the proportion is increasing. Thus, urban areas – including green areas – are becoming increasingly important for humankind. In order to manage urban areas for the benefit of people and biodiversity more information is needed about ecological patterns and processes in cities. The present volume is a result of many years of investigations of the environment and biota of the city of Sofia, carried out by researchers from various academic institutions in Bulgaria. The book is intended to fulfill an obvious gap in the knowledge of the biota of Sofia. In spite of the various research projects carried out during the last decades, there is no volume published so far aiming to summarize the accumulated data. Such a gap is especially apparent when comparing Sofia to several other capitals or big European cities, such as Leipzig, Warsaw, Berlin, Prague, Rome and others.

The idea of the book came about from the participants of the Bulgarian team of the GLOBENET project. The GLOBENET project was proposed by Jari Niemelä during a workshop in 1998 in Helsinki. GLOBENET aims at studying landscape changes in urban environment with both standardized sampling and data methods in various cities across the world using ground beetles (Coleoptera, Carabidae) as a model group. The rationale of GLOBENET is based on the "urban-to-rural gradient" concept proposed by Klausnitzer in 1982-83 and consequently by McDonnell and collaborators during the 1990's. The concept assumes the existence, in virtually all big cities of the world, of a gradient, starting from heavily urbanized habitats within the city through suburban areas around the city, to rural habitats (natural or semi-natural) in its vicinities.

Shortly after the meeting in Helsinki, three international teams started sampling by standardized methods in Helsinki, Edmonton and Sofia. Furthermore, similar short-term projects have been carried out in Hiroshima (Japan), Debrecen (Hungary) and Hamburg (Germany). The habitats studied were forests – city parks, semi-natural forests in suburban areas and natural forests in rural areas. In each site, ground beetles were sampled using a standard number of pitfall traps.

The samplings in Sofia resulted in a rich collection of other invertebrate groups. Therefore, the Bulgarian GLOBENET team extended the scope of research by inviting specialists in several groups of soil invertebrates, such as molluscs, millipedes and centipedes, spiders, ants and others to collaborate in the research. The aim was to study how the different organisms and their assemblages react to urbanization. During the course of research, we realized that a useful interpretation of the results is hardly possible without using data from other research projects in urban ecology. Therefore we invited several Bulgarian scientists from different academic institutions – zoologists, botanists, ecologists, climatologists, forest researchers and environmentalists – to summarize their knowledge on the environment and biota of the city of Sofia.

The outcome of this multi-institutional cooperation is summarized in the present volume. The institutions involved are: Central Laboratory of General Ecology of the Bulgarian Academy of Sciences (BAS), Institute of Botany (BAS), Institute of Zoology (BAS), Forest Research

Institute (BAS), Institute of Hydrology and Meteorology (BAS), Sofia University St Kliment Ohridski and the University of Forestry, Sofia.

The book consists of three parts – *Environment, Plants* and *Animals*. The papers in the first part aim to describe the environment of Sofia in order to provide a basis for present-day and future research on the biota. A research team from the Institute of Hydrology and Meteorology of the Bulgarian Academy of Sciences provided an extensive review on the climate, air and water quality of Sofia. An interesting view on the impact of climate on human comfort is discussed in the paper by Andreev *et al.* The Green System of Sofia, its history, development and especially the problems generated by conflicts between land owners and municipality during the period of transition to market economy are briefly presented in the paper by Atanas Kovachev. The Sofia GLOBENET Sites are described in a separate paper by Penev *et al.* in order to provide the environmental background for several papers in this volume dealing with variation in species composition and assemblages of soil invertebrates along urban-to-rural GLOBENET gradients.

The botanical part consists of 9 papers, ranging from inventories (bryophytes, vascular plants) to studies on the soil moisture regime and lead transformation in city parks. Of special interest is the map of air quality produced by using the Lichen Diversity Index discussed in the paper of Ivanov & Kovatchev. The potential dangers to man of using medicinal plants and mushrooms collected within the city are studied in a paper by Yurukova. The tree vegetation of Sofia is of special interest to several academic institutions and three papers are devoted to its dendrological structure (Delkov & Gateva), impact of pollution on trees (Gateva) and pathological and entomological issues of the tree vegetation in urban environment (Rosnev *et al.*).

The third part of the book deals with several animal groups. Eight papers summarize data sampled in the GLOBENET sites – nematodes (Mladenov *et al.*), myriapods (Stoev), terrestrial gastropods (Dedov & Penev), opilionids (Mitev & Stoyanov), spiders (Antov *et al.*), carabid beetles (Stoyanov & Penev; Stoyanov) and ants (Lapeva-Gjonova & Atanasova). Besides, two more papers present inventories of the urban fauna of aphids (Tasheva) and scuttle-flies (Langurov). Compound nests and mixed colonies of ants in city parks are studied by the youngest member of the GLOBENET team – Vera Antonova. Finally, birds as an important element of the biodiversity of the city are discussed in the papers of Stoyanov *et al.* and Kamburova.

This volume aims to summarize present-day knowledge on the environment, ecology and threats to life in the city of Sofia, offered by various academic teams. Therefore, one cannot expect that the present book will offer the final word on the biota and environment of Sofia. The Editors hope that the conclusions drawn in the different studies can be used in urban planning and decision-making processes. We also hope that this first volume will be a solid basis and stimulus for further research on the ecology of Sofia.

The Editors

Environment

The Sofia (Bulgaria) GLOBENET Sites: Description and Spatial Variation of the Landscape Mosaic

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Abstract

The present study summarizes all the main physical and phytological features of the sampling sites, examined during the Sofia GLOBENET Project. Based on these data, an attempt for classifying the structure of the investigated landscape mosaic has been made. As a result, the presence of a strong urban-rural gradient, with no distinct intermediate "suburban" zone, was demonstrated. The gradient also showed a naturally hierarchic sub-structure. The prominent landscape descriptors that determine the described landscape mosaic patterns were identified – some of the most important include: origin of the forest, altitude, patch area, litter humidity, and built-up area.

Key words

Urban habitats, urban-rural gradient, GLOBNET, Sofia, Bulgaria.

INTRODUCTION

The spatial variation of biotic communities in urban environments became recently a field of study that enjoy a prime interest of biologists, landscape ecologists, and specialists in urban planning. The increasing number of papers and monographs treating species' behavior in, and biotic communities' responses to urbanization processes, is evidence for the growing need to investigate how the specific conditions of the big cities affect the environment, and how this environment can be adapted in order to ensure both the protection of biodiversity and improving the living conditions for the people. For an extensive summary on the role of soil ecology (and particular soil zoology) in this process see Whiteley (1994).

Urbanization seems to have quite similar characteristics in different parts of the world. Although this statement appears intuitive, some evidence exists that the landscape structure

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 3-24

affected by urbanization retains its specificity at different places around the globe (Reynaud & Thioulouse, 2000), while globalization leads to a "uniformity" in the look of big cities around the world. At the same time, urbanization exists in virtually all floristic/faunistic regions of the Globe, affecting local flora and fauna of rather different features, such as species composition and diversity, age of association, adaptiveness and so on. Hence, the idea of investigating the impact of "a common factor onto different floras/faunas in different ecological/historical conditions" or "intercontinental community convergence" (Schoener, 1986) finds an appropriate application in times of global urbanization.

One of the first steps in this direction was the establishment of the GLOBENET project, aimed at a survey of the common anthropogenic impacts on biodiversity on a global scale using carabid beetles, launched in 1997 by Jari Niemelä and co-workers at the first GLOBENET Workshop in Helsinki, Finland (Niemelä *et al.*, 2000; Niemelä & Kotze, 2000). The basic concept lies in the presumption that monitoring landscape changes caused by urbanization in similar habitats (forests) over different geographical regions, using one and the same focal taxonomic groups (ground beetles – Carabidae, Coleoptera), and employing the same sampling methodology, would lead to useful conclusions about the reaction of biotic communities anthropogenic pressure (Niemelä & Kotze, 2000).

The idea has quickly found supporters, and the work started the year after the GLOBENET-Workshop in three cities of Europe and North America – Helsinki (Finland), Sofia (Bulgaria), and Edmonton (Canada). The first results were reported at the Second GLOBENET Meeting in Barziya (Bulgaria) in May 1999.

The increased interest in the project encouraged the Sofia team to extend the work towards incorporating studies on soil and floristic components of the GLOBENET sites, as well as inviting specialists in some important soil mesofauna groups, such as gastropods, spiders, myriapods, opiliones, ants, nematodes and others.

The present paper aims at: 1) presenting a detailed physical and floristic description of the Sofia GLOBENET Sites, 2) describing the methods used in measuring these site characteristics, 3) analyzing their joint variation in order to describe, and quantify the hypothesized gradient, and 4) classifying the investigated landscape mosaic.

MATERIALS AND METHODS

General information on the relief, climate, and soils in the investigated area were gathered from the literature (Vaptsarov *et al.*, 1997; Bluskova *et al.*, 1983; Ninov, 1997). The area, distance from the city center, and exposition of the sampling sites were directly estimated from maps of the city and its surroundings (Smilenova *et al.*, 1996). The variable "built-up area", designed to provide an alternative estimate of urbanization, was also estimated from the maps and is expressed as a percentage of the area covered with buildings within a 2 x 2 km square centered at the respective study plot. Altitude was measured with a portative altimeter. Additionally, data on the tilt, origin, age and height of the tree stands, were obtained from the database of the Forest Committee. The canopy cover was estimated visually. Further, the "number of trees" and "diameter of trees" variables were obtained by averaging the count of trees and the tree diameter (measured at breast height) within five 10 x 10 m square samples at each sampling plot. Leaf-litter thickness is an average of 140 randomly placed measurements. The ordinal variables "grass cover", "humidity of leaf-litter", and "humidity of soil" were estimated (140 per site) subjectively on a scale from 0 (absent) to 5 (very strong). To estimate nonparametrically the "location" of each sampling site (based on the latter three variables) for the purposes of further analysis, we calculated the rank-sums of each variable and subsequently ranked these to obtain the values shown in Table 3 and entered into the multivariate analyses. The anthropogenic soils were classified after Gencheva (1995), while for the non-antropogenic soils we used the classification of FAO-UNESCO (1988). The chemical and mechanical properties of soil at the sampling sites were obtained as follows: pH was potentiometrically estimated using a "Practronic MV98"; organic carbon and humus were assessed with the Turin method (e. g. Arinushkina, 1970); nitrogen contents of the soil was estimated as Total Kjeldahl Nitrogen (TKN) (Isaac & Johnson, 1976); and the mechanical composition of the soil was determined following the method of Kachinsky (1958).

In the numerical analyses the data presented in Tables 1-4 (except for the variable "ground" which had some categories of insufficient frequency) were entered into a Principal Component Analysis after centring and normalizing. For identifying of naturally hierarchical clusters of rows (i. e. sampling sites) in the analyzed matrix, a repeated "*K*-means" clustering procedure (based on the algorithm of Hartigan & Wong (1979)) with *K* varying from 2 to 5 clusters was employed on the first two principal components. All the computations were performed in the **R** language environment (Ihaka & Gentlemen, 1996).

RESULTS

One of the main criteria used to select the sampling sites was the prevalence of more or less the same type of forest – in our case broad-leaved forests dominated by oak (*Quercus* L.). One

Table 1. Physical characteristics of the Sofia GLOBENET sites. For abbreviation description and disposition of sites see Fig. 1.

Code	Area [ha]	Exposition	Altitude [m]	Slope [degree]	Distance [km]	Built area [%]
UI	1.9	E-SE	550	4	3.3	71
UII	1.2	W-WS	525	4	3.8	64
UIII	3.7	N-NE	575	4	5.6	35
UIV	1.2	S-SE	570	4	3.7	56
SI	1.9	N	650	17	13.2	13
SII	8.0	N	900	14	12.0	6
SIV	13.7	N, NW-W	950	17	11.3	27
RI	18.0	NE	850	24	14.5	0.2
RII	15.2	NE	920	14	13.5	0
RIII	7.0	N	800	7	29.0	0.3
RIV	15.0	W	1000	18	10.2	0.3

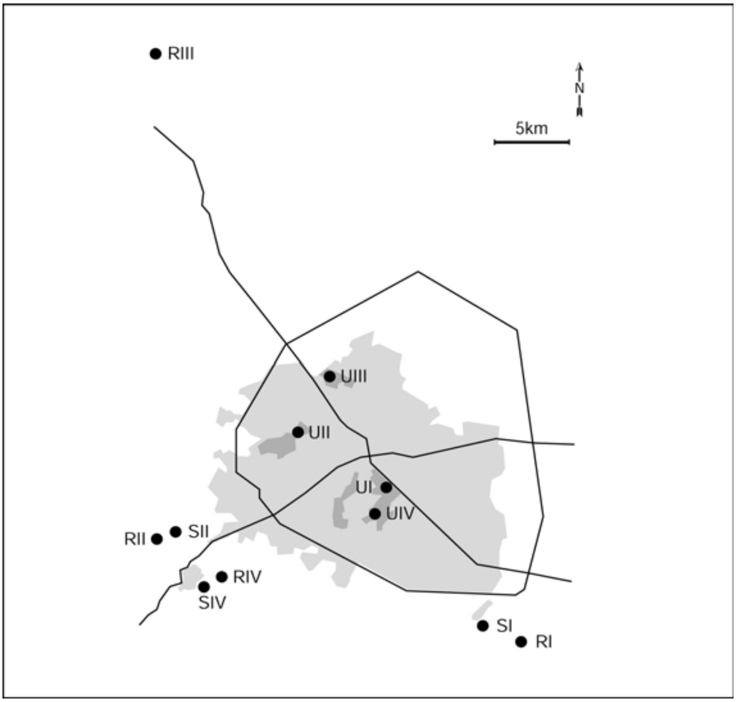

Fig. 1. The Sofia GLOBENET sites: U1 – Knyaz Borissovata Gradina; U2 – Zapaden Park; U3 – Severen Park; U4 – Loven Park; S1 – SE of German Village; S2 – locality "Vilite" (Lyulin Mt.); S4 – SE of Vladaya Village (Vitosha Mt.); R1 – S of Germanski Monastery (Lozenska Mt.); R2 – N of locality "Manastirski Polyani" (Lyulin Mt.); R3 – S of Drenovo Village; R4 – locality "Tikhiya Kat" (Vitosha Mt.)

reason for the choice of similar habitats along the urban-rural gradient was to minimize the additional variation of different habitat types on the soil mesofauna. Another reason that contributed to the elaboration of the mentioned sampling strategy, was the fact that this habitat type have been the most significantly transformed during (at least) the last 300 years, being naturally dominant in the investigated region for centuries (see Stoyanov, 1937).

Eleven sites, situated along the urban-to-rural gradient (having its urban end in the city parks of Sofia, and spreading radially through the suburban zone towards rural areas – respectively in southeastern (1), southwestern (2), northern (3), and southern (4), directions) were selected (Fig. 1). Based upon our convention about the sampling design, and limited by the availability of appropriate forest habitats, each gradient was preliminary stratified into three zones, reflecting the varying degree of urbanization, namely "urban" (U), "suburban" (SU), and "rural" (R). As already mentioned, due to the complete absence of appropriate forest habitats northwards of the city of Sofia, the northern gradient lacks the intermediate (SU) zone (Fig. 1).

Physical description of the sites

Location and relief

The investigated area is situated in West Bulgaria and includes the Sofia Kettle and foothills of the surrounding mountains – Stara Planina, Vitosha, Sredna Gora, and Lyulin, up to 1000 m a. s. l. The association of the mountains is completely tectonic. Geomorphologically all sites belong to the South Bulgarian province of the Trans-Balkan kettle subregion (Vapzarov *et al.*, 1997).

Climate

According to climatic regioning, the investigated region pertains to the temperate-continental climatic region of Bulgaria. This climatic region is characterized by warm summers, cold winters, the annual air temperatures have a significant amplitude, spring-summer maximum and winter minimum of rainfalls, and a relatively steady snow cover with altitude-related duration (Velev, 1997). Generally, the climate of the city of Sofia is comparatively milder than the surrounding regions and is characterized by higher mean temperatures of the coldest month and a cooler summer (Bluskova *et al.*, 1983).

Soils

The leached chromic livisols, present in sites Knyaz Borisova Gradina (U1) and Zapaden Park (U2), are characterized by a rich humus horizon with 5-6 % humus (Tab. 2). Their structure is grainy, turning downwards into a prismatic one, with heavier mechanical composition (31-54% clay content), hence higher hygroscopic moisture. pH varies between 4.6 and 6.5. The color of the soils varies from leached black to dark brown with low differentiation along the soil profile. The water tightness is low and the water-air regime is worsened. In comparison to the above described city parks, the soils in Loven Park (U4) are more acid, with lighter mechanical composition in the upper layer and can be determined as transitional form to the maroon chromic livisols. The soils in Severen Park (U3) possess typical anthropogenic features. Their chemical

Table 2. Soil characteristics of the Sofia GLOBENET sites.

Code	Ground	pH	Humus [%]	Mechanical composition	N [%]
UI	Chromic livisols	6.50	5.83	Medium	0.18
UII	Chromic livisols	5.85	5.06	Heavy	0.16
UIII	Urbogenic anthroposoils	7.05	10.67	Heavy	0.21
UIV	Maroon chromic livisols	5.30	6.38	Medium	0.14
SI	Leached maroon forest soils	6.65	7.73	Light	0.27
SII	Leached maroon forest soils	4.65	3.67	Light	0.15
SIV	Leached maroon forest soils	5.50	9.61	Medium	0.26
RI	Leached maroon forest soils	6.60	6.33	Light	0.19
RII	Maroon soils	4.90	4.97	Light	0.16
RIII	Leached maroon forest soils	5.75	7.95	Heavy	0.21
RIV	Leached maroon forest soils	5.10	8.16	Medium	0.27

reaction is neutral to low-alkaline (pH 6.9-7.05), the humus content is high and weakly differentiated along the profile. The mechanical composition is heavy, and according to Gencheva (1995), these soils can be determined as terri-cumulic, urbogenic anthroposols. The foothills of the surrounding mountains are covered by leached maroon forest soils. The sites at Lozenska Mt. (German Village, S1) and Lyulin Mt. (Vilite, S2) are characterized by a less strong profile (70-80 cm), heavier mechanical composition with stronger differentiation along the profile. The chemical reaction of the soil solution is acid to low-acid (pH approximately between 4 and 6), the humus content is low. The soils in the region of Vladya Village (S4) are deeper (over 90 cm), in comparison to the previously mentioned sites, with a lighter mechanical composition, a more acid reaction (pH 4–5), and rather diverse with respect to the humus content (0.2 to 9 %). With an increase in altitude up to 700–800 m a. s. l., thinner maroon soils become prevailing at sites "R3" and "R4". The site near the German Monastery (R1) differs by the low alkaline reaction (pH 6–8) of its soils, due to the carbonate basic rocks in that area. In the negative forms of the relief, as it is the case at site "R2" (situated on former terraces), a kind of meadow maroon soils are present. They are characterized by a strong (100 cm) and rather differentiated soil profile, with low-acid reaction (pH about 6.5). Besides, these soils are characterized by a low humus content (about 3 %) and are rather influenced by the higher level of underground water.

Biological description of the sites

Plant communities

According to the floristic regioning of Bulgaria (Jordanov, 1966), the study sites are situated in four different floristic regions: 1) Sofia Region – all urban sites (U1-4); 2) Western Sredna Gora Region – "S1" and "R1"; 3) Vitosha Region – "S2", "R2", "S4", "R4"; 4) Western Stara

Table 3. General features of the plant communities of the Sofia GLOBENET sites.

Code	Origin	Age [years]	Canopy [%]	Height [m]	Number of trees [100m^{-2}]	Diameter of trees [cm]	Thickness of leaf-litter [cm]	Grass-cover	Humidity of leaf-litter	Humidity of the soil
UI	Artificial	90	85	22	15,4	18.4	2,2	9	9	3
UII	Artificial	50	90	15	16,6	20.0	3,7	1	6	10
UIII	Artificial	60	70	30	8,4	23.3	2,8	4	10	11
UIV	Artificial	90	90	26	17,6	19.4	3,8	3	11	9
SI	Artificial	40	80	18	16,4	16.0	4,0	2	7	6
SII	Secondary	60	85	18	22,4	14.1	2,8	10	2	5
SIV	Secondary	50	85	15	11,2	18.9	3,3	8	5	7
RI	Secondary	20	60	20	14,6	16.5	3,1	5	1	1
RII	Secondary	50	85	17	25,4	11.5	3,0	7	3	2
RIII	Secondary	50	80	17	16,2	17.0	3,3	6	4	4
RIV	Secondary	70	80	25	10	20.6	2,9	11	8	8

Planina Region – "R2". This reflects local specificity of the floristic composition of the sites (Appendix I) caused by both local physical peculiarities of the site and its geographical position. All sampling sites belong to the zone of hornbeam-oak woods ranging, in Bulgaria, from 600-700 to 1000-1200 m a. s. l. (Bondev, 1991). Sites "S2", "R2", "S4" and "R4" approach the beech-woods belt.

The main criterion for selecting the GLOBENET sampling sites was the presence of broad-leaved forests, dominated by oak-tree species. In the city parks, the introduced mesophilous oak species *Quercus rubra* prevails. In the natural and semi-natural habitats the commonest oak species are *Q. cerris* (S4, R4), *Q. pedunculiflora* (U1) and *Q. polycarpa* (S2, R2) (Appendix I). The herb layer is dominated by *Dactylis glomerata* and *Poa nemoralis*, which seem to be the most common herb species and are recorded from all sites. Some species are present only in urban environment (*Bromus inermis* and *Elymus hispidus*), while other are found only in suburban and rural habitats (all *Carex* spp. and *Danthonia alpina*). Some species occur in most of the suburban and rural habitats but are absent in the urban environment (*Festuca heterophylla* at "S4", "R1", "R2", "R4", and *Melica uniflora* at "S2", "S4", "R1", "R2"). There are also obvious geographical peculiarities in the distribution of certain species, i. e. such characteristic for the Vitosha Floristic Region only (S4, R4 – *Agrostis capillaris*, *Arrenatherum elatius*, *Briza media*, *Bromus ramosus*, *Calamagrostis arundinacea*, *Elymus caninus*, and *Luzula luzuloides*). The floristic specificity of the rural habitats of the Western Stara Planina Region are marked by the presence of *Festuca valesiaca* and *Luzula campestris*, the Western Sredna Gora Region – by *Luzula forsteri* and *Poa pratensis*. The sampling plot "U1" is a mixed deciduous-coniferous forest, dominated by *Quercus pedunculiflora* (the plant formation is Querceta pedunculiflorae). The forest-habitat "U2" is dominated by *Quercus rubra* (the plant formation is Querceta rubrae). The forest at sampling-site "U3" may be subdivided into two homogeneous sub-sites: the first one is a deciduous forest dominated by *Quercus rubra* (formation Querceta rubrae), the second one is a mixed deciduous-coniferous forest, dominated by *Populus nigra* (formation Populeta nigrae). At "U4" the mixed deciduous forest is dominated by *Quercus rubra* (formation Querceta rubrae). Sampling site "S1" is a plantation almost entirely consisting of *Quercus rubra* (formation Querceta rubrae). The next suburban sampling plot (S2) is a mixed deciduous forest dominated by *Quercus polycarpa*, the other common tree species is *Carpinus betula* (formation Querceta polycarpae). The dominating tree at study site "S4" is *Quercus cerris* (Querceta cerris). The rural sampling site "R1" is a mixed deciduous forest with *Quercus sessiliflora* and *Carpinus betulus* (formation Querceta sessiliflorae). Site "R2" is a mixed deciduous forest dominated by *Carpinus betulus* and *Quercus polycarpus* (formation Querceta ploycarpae). The highly isolated forest, where sampling site "R3" is located, is dominanted by *Quercus cerris*. Finally, site "R4" is a *Quercus cerris* forest (Querceta cerris). For a full plant species composition of the sampling sites, refer to Appendix I.

DISCUSSION

Looking at the overall data structure that emerged from the multivariate analyses of our datasets (Figs. 2-10), the main landscape gradient is clearly visible in most of the cases. When analyzing the plant cover of the sampled landscape, the clearest support of our initial working

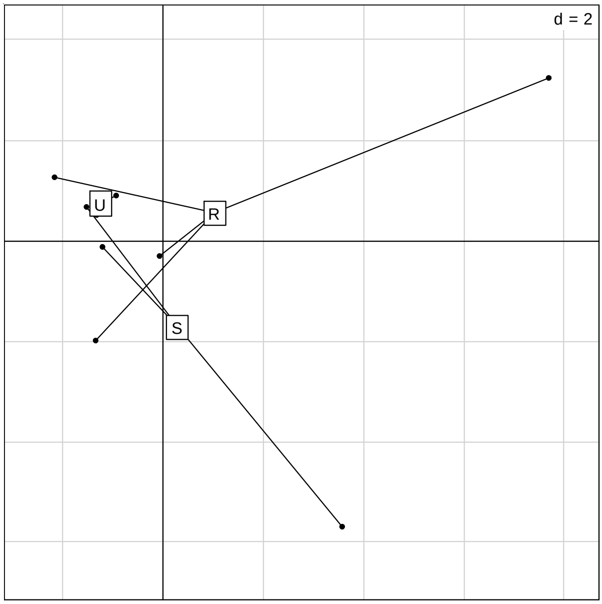

Fig. 2. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of grasses.

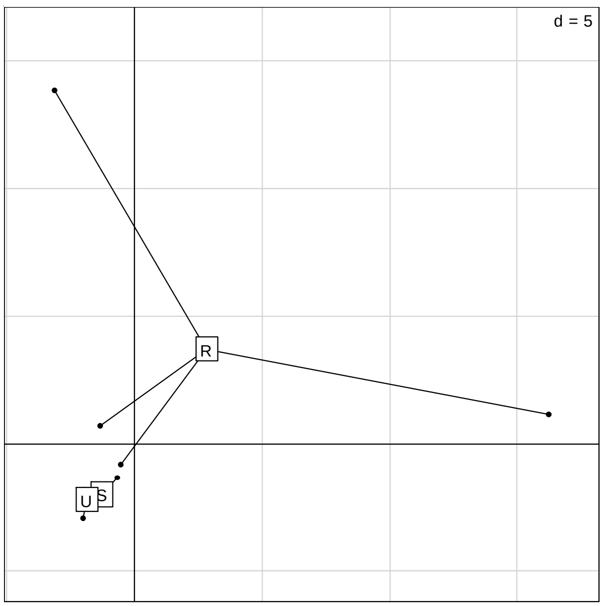

Fig. 3. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of herbs.

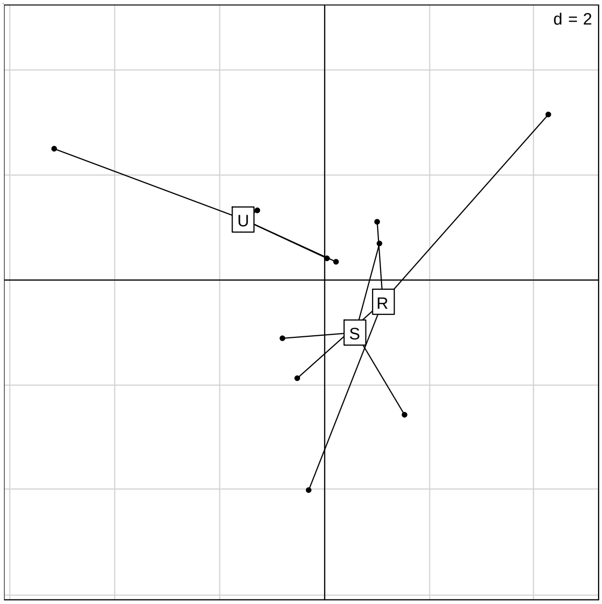

Fig. 4. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of shrubs.

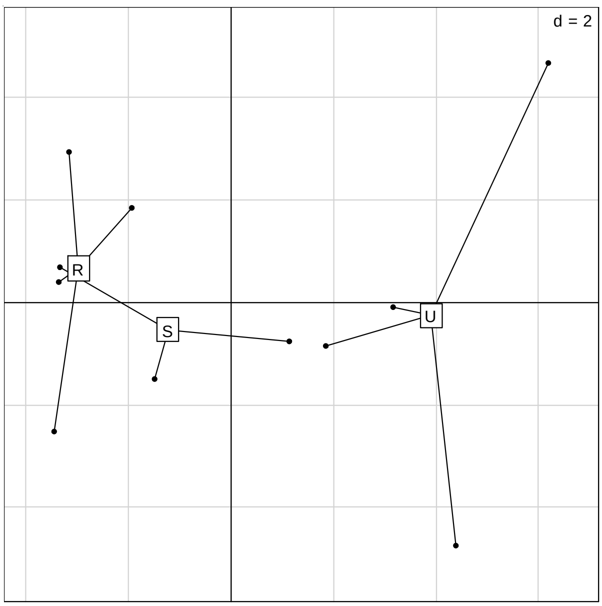

Fig. 5. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of trees.

hypothesis (i. e. the urban-to-rural gradient) is the tree stratum of the vegetation communities (Fig. 5). As plant size decrease (respectively its edification role), through the series trees-shrubs-herbs-grasses (Figs. 5, 4, 3, 2) the presumed urban-to-rural-gradient becomes less prominent. When including all the vegetation layers in the analysis (Fig. 6), the urban zone becomes most distinct and clearly separates from the non-urban zones. Here we are speaking of "non-urban" zone mainly to translate our findings to the framework of the implemented urban-suburban-rural sampling design, and to refer to the strongly overlapping "rural" and "suburban" sites. When including all the measured environmental variables (with the vegetation data), the picture of the urban-to-rural gradient becomes even clearer (Fig. 7). The urban zone is again clearly different form the other two, which in turn are more or less intergrading. When considering the relationships between the measured environmental properties of the sampling plots, a not so complex structure, although of strongly intercorrelated variables, in the investigated landscape becomes evident (Fig. 8). The principal component analysis reveals the existence of one prominent factor summarizing about 41% of the total variation within the landscape. The environmental variables that are most strongly correlated with this first principal component of the data are: forest origin, altitude, and area (positively correlated), and litter humidity, built-up area, tree diameter (negatively correlated). The second principal component summarizes about half the variation of the data, and is most strongly correlated with tree number/100 m, canopy, and vegetation PCA axis 1 (positively), and with humus contents, nitrogen contents, and tree diameter (negatively). Finally, our attempt to classify the observed structures revealed a strong and (most important) hierarchical organization (Fig. 10) of the sampled landscape

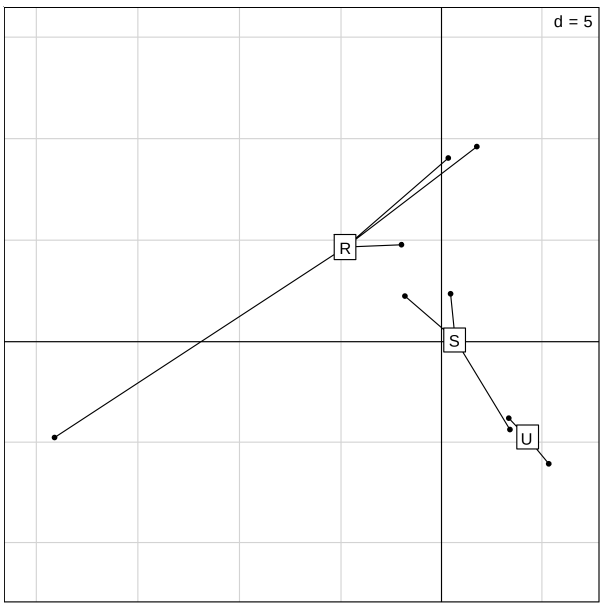

Fig. 6. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on all plant species.

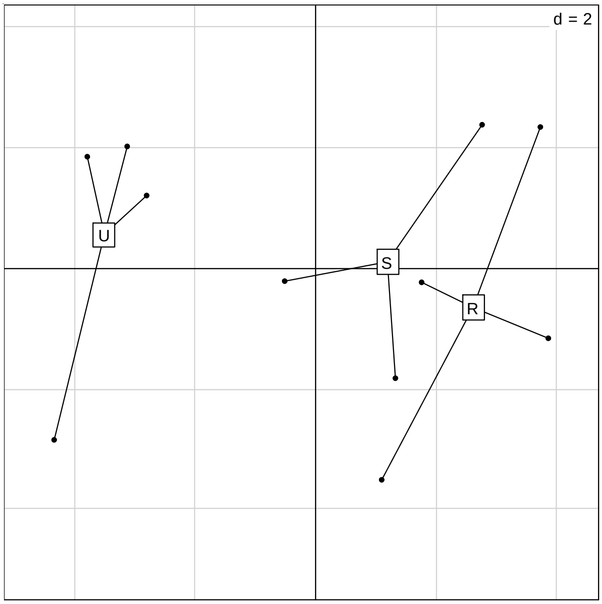

Fig. 7. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on environmental variables.

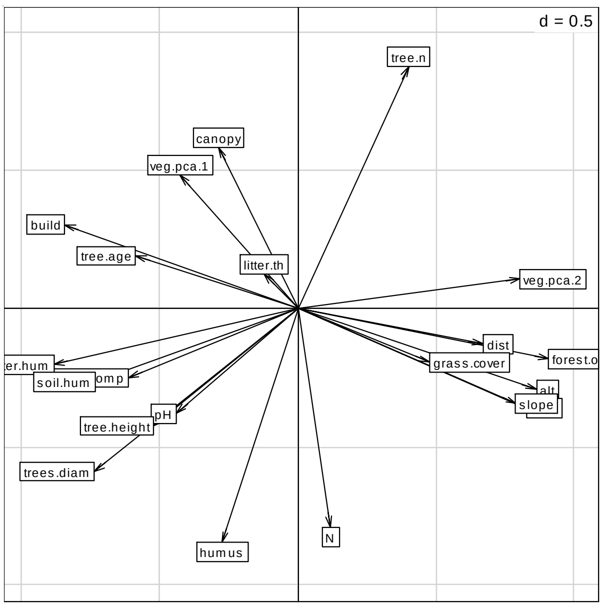

Fig. 8. PCA ordination of the environmental variables measured at the Sofia GLOBENET sites (F1=40.5%, F2=19.6%).

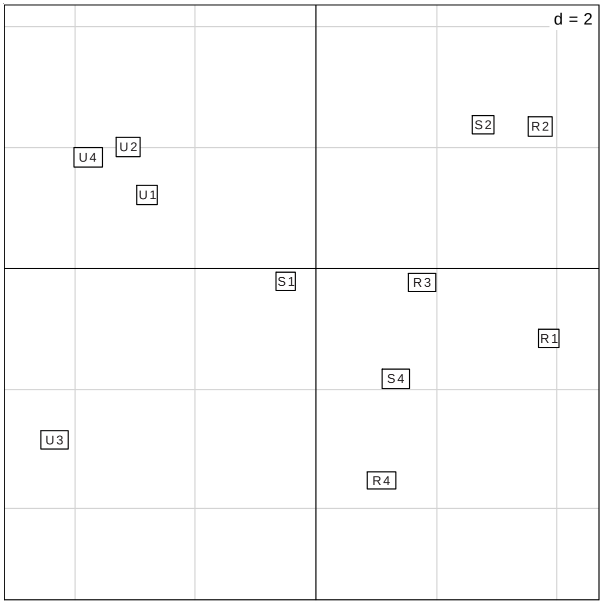

Fig. 9. PCA ordination of the Sofia GLOBENET sampling sites, based on environmental data (the factorial plane summarizes 60.1% of the total dataset variability).

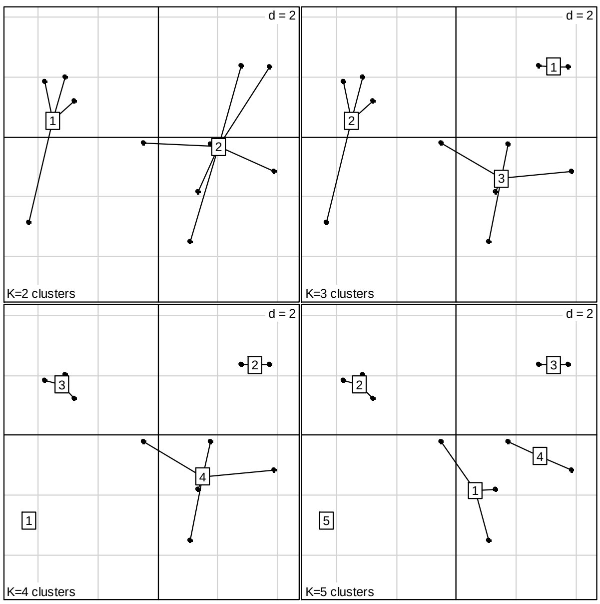

Fig. 10. Sequential "K-means" (starting from K=2 to K=5) clustering of the PCA ordination of the Sofia GLOBENET sites, based on environmental data.

structures (Fig. 9). The sequential "*K*-means" partitioning procedure yielded homogeneous clusters with virtually no interchangeable cluster-members. For example at the 2-cluster level of the procedure, the urban zone clearly opposites the non-urban one. At the subsequent 3-cluster level, the urban zone remains compact, while the non-urban splits in two (mainly due to the isolated position of sites at Lyulin Mt. – S2 and R2). The urban cluster parted when we have repeated the clustering with *K*=4. The most peculiar site within this group appears to be Severen Park (U3). The remaining partitioning subdivided the greater non-urban cluster, hinting that at least partially the site-group containing "S1", "S4" and "R4" may be considered a transitional zone in the sense of our working hypothesis (Fig. 10).

CONCLUSIONS

Based on the above considerations, the following conclusions may be drawn:

1) A clear urban-to-rural gradient was demonstrated.
2) Our working hypothesis about the presence of a sharply delimited and self-contained "sub-urban" zone was not supported by the analyses.
3) The classification of the observed gradient structure showed the existence of a natural and hierarchic sub-structure.
4) We revealed the prominent environmental factors determining the investigated landscape structure. These are: origin of forest, altitude, patch area, litter humidity, built-up area, tree diameter, tree number, canopy, general vegetation variability (as expressed by the first PCA axis of a separate analysis), humus and nitrogen content of the soil, tree diameter.

ACKNOWLEDGEMENTS

This work was partly supported by the National Scientific Fund (grant B-808/1998). We thank Dr. D. J. Kotze for final editing the English text.

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Appendix I. Species composition of the plant communities of the Sofia GLOBENET sites.

	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4
Trees											
Acer campestre L.	+	+			+	+	+		+		+
Acer hyrcanum Fisch. et C.A. Mey.								+			
Acer platanoides L.	+		+						+		
Acer pseudoplatanus L.				+				+	+		
Acer tataricum L.		+		+							
Betula pendula Roth			+	+							
Carpinus betulus L.						+	+	+	+	+	+
Cornus mas L.					+			+		+	
Cornus sanguinea L.									+		+
Coryllus avellana L.							+	+		+	+
Fagus sylvatica L.						+	+		+		+
Fraxinus excelsior L.	+	+	+	+		+					
Fraxinus ornus L.				+	+				+		
Juglans regia L.			+								
Larix decidua Mill.				+							
Quercus cerris L.							+	+		+	+
Quercus pedunculiflora C. Koch	+			+							
Quercus polycarpa Schur						+			+		
Quercus rubra L.		+	+	+	+						
Quercus sessiliflora Salisb.								+			
Pinus nigra Arn.	+	+		+	+						
Pinus strobus L.				+							
Populus nigra L.			+								
Populus tremula L.							+	+	+		
Prunus avium L.				+		+			+		+
Prunus cerasifera Ehrh.	+	+	+					+		+	+
Pseudotsuga glauca Mayr			+								
Pyrus pyraster Burgsd.	+			+		+	+	+	+	+	+
Robinia pseudoacacia L.		+	+	+				+			
Sambucus nigra L.		+	+								
Sophora japonica L.			+								
Sorbus aucuparia L.									+		
Sorbus torminalis (L.)							+	+	+		+
Tilia cordata Mill.		+				+					
Tilia tomentosa Moench	+		+	+							
Ulmus minor Mill.	+	+	+	+	+						
Shrubs											
Chamaecytisus hirsutus (L.)							+	+			
Clematis vitalba L.	+		+	+	+						
Crataegus monogyna Jacop.		+	+	+	+	+	+	+		+	+
Euonymus europaeus L.											+
Euonymus verrucosus Scop						+		+			

Appendix I. Continued.

	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4
Hedera helix L.	+	+		+	+		+		+		+
Juniperus communis L.							+				
Ligustrum vulgare L.	+	+	+	+	+				+		+
Lonicera tatarica L.			+								
Mahonia aquiflora (Pursh.)				+							
Philadelphus coronarius L.			+								
Prunus spinosa L.					+		+				+
Rosa canina L.	+				+		+	+			
Rosa dumalis Bechst.											+
Rosa jundzillii Besser			+								
Rubus caesius L.			+	+		+					
Rubus idaeus L.									+		
Rubus macrophyllus Weihe et Nees											+
Symphoricarpos racemosus Mich.		+									
Viburnum lantana Hemsl.								+		+	
Viburnum opulus L.					+	+			+		+
Grasses											
Agrostia capillaris L.											+
Arrenatherum elatius (L.)											+
Artemisia vulgaris L.											+
Atriplex patula L.			+								
Brachypodium sylvaticum (Huds.)		+							+		+
Briza media L.							+				+
Bromus inermis Leyss.	+										
Bromus ramosus Huds.											+
Calamagrostis arundinacea (L.)							+				+
Carex cuprina					+						
Carex divisa Huds.							+				
Carex silvatica L.							+				
Dactylis glomerata L.	+	+	+	+	+		+	+	+		+
Danthonia alpina Vest.							+				
Elymus caninus (L.)											+
Elymus hispidus (Opiz.)	+										
Festuca heterophylla Lam.							+	+	+		+
Festuca valesiaca Schleich.										+	
Galium odoratum (L.)								+			
Lapsana communis L.			+								
Luzula campestris (L.)										+	
Luzula forsteri (Sm.)								+			
Luzula luzuloides (Lam.)							+				+
Melica uniflora Retz.						+	+	+	+		
Poa nemoralis L.	+		+			+	+		+		+
Poa pratensis L.								+			

Appendix I. Continued.

	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4
Herbs											
Achillea millefolium L.	+										
Agrimonia eupatoria L.					+						
Ajuga genevensis L.						+		+		+	
Alliaria petiolata (Bieb.)								+		+	+
Anthriscus cerefolium (L.)											+
Arabis recta Vill.										+	
Arabis turrita L.											+
Arctium lappa L.											+
Aremonia agrimonoides (L.)						+		+		+	+
Arum maculatum L.										+	
Ballota nigra L.	+										
Betonica officinalis L.						+					+
Buglossoides purpurocoeruleus (L.)									+		+
Campanula bononiensis L.			+								
Campanula persicifolia L.					+						
Cardamine bulbifera (L.)						+			+		
Centaurea jacea L.											+
Centaurea phrygia L.											+
Centaurea rutifolia S.S.							+				
Cerastium caespitosum (L.)								+			
Cichorium intybus L.		+									+
Clinopodium vulgare L.					+		+				+
Convallaria majalis L.						+			+		
Corydalis slivenensis Vel.										+	
Cruciata glabra (L.)						+	+	+	+		+
Cruciata laevipes (L.)										+	
Dianthus armeria L.											+
Digitalis viridiflora Lindl.											+
Echinops sphaerocephalus L.										+	
Epilobium hirsutum L.									+		
Epipactis helleborine (L.)						+					
Erithronium dens canis L.										+	
Euphorbia amygdaloides L.						+	+		+		+
Euphorbia cyparissias L.										+	+
Filipendula vulgaris Moech.											+
Fragaria vesca L.					+			+	+	+	+
Galim schultesii Vest.											+
Geranium robertianum L.						+					+
Geranium sanguineum L.							+		+		+
Geum urbanum L.	+		+	+		+		+			+
Glechoma hederacea L.						+					
Helleborus odorus Waldst et Kit.						+	+	+	+	+	+

Appendix I. Continued.

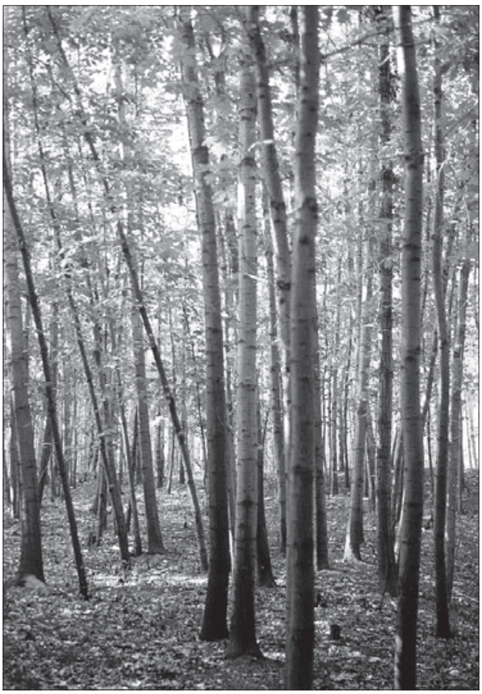
	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4
Hieracium laevigatum Willd.											+
Hieracium umbellatum L.											+
Hypericum perforatum L.	+										+
Knautia drymeja Henff.					+				+	+	+
Lamium purpureum L.						+					
Lapsana communis L.											+
Lathyrus laxiflorus (Desf.)							+	+	+		
Lathyrus niger L.							+	+	+	+	+
Lathyrus vernus L.						+		+	+		
Lentodon asper (W.K.)					+						
Lilium martagon L.						+			+		
Limodorum abortivum (L.)									+		
Lysimachia vulgaris L.											+
Melissa officinalis L.					+						
Mellitis mellisophyllum L.								+	+		
Mercurialis annua L.										+	
Muscari botryoides (L.)										+	
Mycelis muralis (L.)					+				+	+	+
Myosotis sparsiflora Mikan								+			
Neottia nidus-avis (L.)								+	+		+
Nonnea pulla (L.)										+	
Ornithogalum montanum Cyr.										+	
Ornithogalum umbellatum L.	+										
Peucedanum alsaticum L.											+
Physospermum cornubiense (L.)								+			+
Picris echioides L.					+						
Plantago media L.					+						
Polygonatum odoratum (Mill.)								+	+		
Potentilla alba L.										+	
Potentilla micranta Ramond.			+				+	+	+		
Potentilla neglecta Baumg.										+	
Primula veris L.								+	+	+	
Prunella vulgaris L.	+	+			+	+		+			+
Pteridium aquillinum (L.)							+				
Pulmonaria officinalis								+	+		
Pulmonaria rubra Schott										+	
Ranunculus auricomus L.						+		+		+	
Ranunculus fallax (Wimm. et Grab.)										+	
Ranunculus millefoliatus Vahl.										+	
Rumex crispus L.											+
Rumex dentatus L.				+							
Rumex sanguineus L.		+									
Sanguisorba minor Scop.					+						

Appendix I. Continued.

	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4
Sanicula europaea L.	+					+		+			
Silene alba (Mill.)							+				
Sonchus asper (L.)	+										
Stachys germanica L.					+						
Stachys recta L.					+						
Stellaria holostea L.						+	+	+	+		
Stellaria media (L.)	+										
Stellaria nemorum L.							+				
Symphytum tuberosum L.						+		+	+	+	
Tanacetum corymbosum (L.)						+					+
Tanacetum vulgare L.											+
Taraxacum officinale Web.								+		+	
Teucrium chamaedrys L.					+						
Thalictrum minus L.											+
Torilis japonica (Houtt.)			+								+
Trifolium medium L.									+		
Valeriana officinalis L.											+
Veratrum lobelianum Benh.									+		
Verbascum phoeniceum L.											+
Veronica chamaedrys L.							+		+		+
Veronica serpyllifoli L.								+			
Vincetoxicum hirundinaria Medic.									+		
Viola reichenbachiana Jod.						+	+	+			
Viola riviniana Reichenb.	+										
Viola suavis M.B.			+								
Viola sieheana Becker										+	
Viscaria vulgaris Röhl.									+		

Appendix II A. Appearance of the Sofia GLOBENET sites (gradient 1) – Knyaz Borissovata Gradina (U1).

Appendix II B. Appearance of the Sofia GLOBENET sites (gradient 1) – SE of German Village (S1).



Appendix II C. Appearance of the Sofia GLOBENET sites (gradient 1) – S of Germanski Monastery (R1).

Climate and Human Comfort of Sofia

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SUMMARY

Urban climate is a result of both the city's geographical location and its structure, i.e. of regional meteorology, and its interaction with the fabrics. The continental background climate of the Sofia valley is described. Experimental investigations concerning the radiative inversion destruction in Sofia are also objects of consideration. The Sofia heat island effect is characterized by air temperature differences in urban and rural areas. Microclimatic regions of Sofia are also given. The lidar measurements of the spatial distribution of aerosol particles and the vertical profiles of temperature, humidity and wind are noted. They were used to investigate the diurnal evolution of the atmospheric boundary layer. Local wind deformations are investigated using laboratory and numerical models. Human comfort conditions in Sofia's urban and suburban districts are given, analyzing the cooling index "K" distribution. As a result of a lack of correspondence with the climate peculiarities of the different parts of Sofia some defects of town-planning are noted.

KEY WORDS

Sofia city; Sofia valley; local meteorology; microclimate; urban climate; radiative temperature inversions; inversion destruction; urban heat island; Sofia microclimatic regions; lidar measurements; local wind field; laboratory modelling; numerical modelling; human comfort; cooling index.

INTRODUCTION

The actual urban climate is strongly dependent on both the city geographical location and its structure, i.e. on the regional meteorology and its interaction with the human-made fabrics. That is why only a few micrometeorological rules are general enough to be exported from one city to another.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 25-54

The most characteristic phenomenon of the urban climate is the *urban heat island* i.e. the systematic higher temperature of the atmosphere over the city compared to that of the upwind neighbouring rural area. It is known that the temperature differences DT_{u-r} between typical urban and rural stations increase with time and are dependent on the city size, from 2°C for small towns up to 12°C for very large ones. Temperature is also quite variable during the diurnal cycle and dependent on the meteorological conditions with, for example, maximums at the end of the afternoon or the beginning of the night in conditions of weak winds and clear air, and in winter. A more detailed description of the recent knowledge about this urban climate peculiarity and, in particular, the physical processes that take part in the heat island generation can be found in the paper by V. Andreev in this book. Heat island parameters depend on the city size, structure, density, energy consumption and degree of pollution (see Mestayer & Anquetin, 1995; Oke, 1990; Oke *et al.*, 1991). Where pollution is low, the impact of solar radiation on the urban surfaces seems to be the main factor. Where pollution is high, energy consumption is also usually quite high and the anthropogenic energy flux seems to be the determinant factor. Of course it is always a combination of various factors. At least 6 causes of heat build-up can be listed: the increase of long wave radiation from the sky; the decrease of solar radiation reflection due to radiative trapping; the increase of solar radiation absorption by urban materials due to their lower albedo; the increase of heat storage by urban wall and ground materials; the anthropogenic sources of heat and energy; and the decrease of latent heat consumption due to reduced vegetation and to the water collection networks. The role and importance of these various factors appear to be much dependent on the solar cycle and the season; e.g., the alteration of the water budget is a dominant factor in summer, while the dominant factor in winter seems to be the anthropogenic heat flux. Measurements over large urban areas show that the internal patterns of the heat islands are both rather complicated in space and changing quite rapidly in time during the diurnal cycle, as a result of the 3-dimensional influence of the terrain heterogeneity. It must be noted that while a negative temperature difference DT_{u-r} is rarely observed in city centers, it happens quite often in suburban areas due to the presence of artificial ground surfaces and the absence of strong heat sources and heat storages (Myrup *et al.*, 1993). This increases the actual complexity of the local flows over the city and the urban "ground" description for dispersion modeling.

Observations show that the heat island appears to be a characteristic feature of the urban atmosphere and occurs over built-up areas of all sizes, even over small villages or isolated large districts, shopping centers etc.

Experimental studies have demonstrated that the heat island effect is important not only close to the ground but also higher in the atmospheric boundary layer and that it generates either "heat bubbles" or "heat plumes" (Fig. 1). Due to the city-induced thermal and dynamic convection, the frequency and the intensity of the inversion layers tend to decrease over urban areas and the "urban boundary layer" therefore tends to be more often close to neutral. In conditions as in scheme Fig. 1a, the development of an "internal boundary layer" over a flat plate is characteristic due either to a change in roughness (dynamic internal layer) or to a change in the surface heat flux (thermal internal layer). These model flows have been extensively studied in wind tunnels. The scheme (a) sees the urban boundary layer as one (or a series of) internal layer(s) in development in the atmospheric boundary layer. Therefore the city constructions appear as a carpet of roughness elements and the city landscape as a rough terrain. Actually all meteorological conditions produce some combination of the two situations in Fig. 1 and the picture is much more complicated: the structure of the "urban boundary layer" is 3-D, depending largely on the local orography and on the heterogeneity of the different districts inside the city. In calm or weak wind conditions, the specific atmospheric circulation is formed over the city in complex terrain. Its characteristic components are "slope wind" and "urban breeze" (see review by V. Andreev in this book). The models of the boundary layer structure and air circulation over a city are classical but crude approximations. Most of the studies over the last 25-30 years however have been developed in the framework of these conceptual models.

The urban ground is covered with natural and artificial materials, buildings and other obstacles. The heat budget as well as the flow structure close to the ground depend largely on the height and density of the constructions. The flow structure varies from a series of turbulent wakes due to isolated obstacles to strongly interacting turbulent streaks and even to turbulent flows having some similarities with flows in semi-porous media. The atmospheric layer below the roof level is called the *urban sub-layer or urban canopy* by analogy with the atmospheric layer between ground and the trees of dense forests. Kondo & Yamazawa (1986) proposed to define its height by the integral of the building heights: $h=1/S(\Sigma H_i.S_i)$, where S is the total area under consideration, H_i and S_i are the height and area of the individual obstacles (buildings).

Urban areas can induce some meso-scale perturbations in the atmosphere. One of them is demonstrated by the urban "plume" model of Fig. 1a showing that the climatic perturbations generated by the city are transported by wind, like a mesoscale "plume" of anthropogenically-modified and polluted air as large as the city itself. This plume can generate a series of perturbations over the downwind regions at distances of several hundreds of kilometers (e.g., the "Ozone plumes"during photo-oxydant episodes).

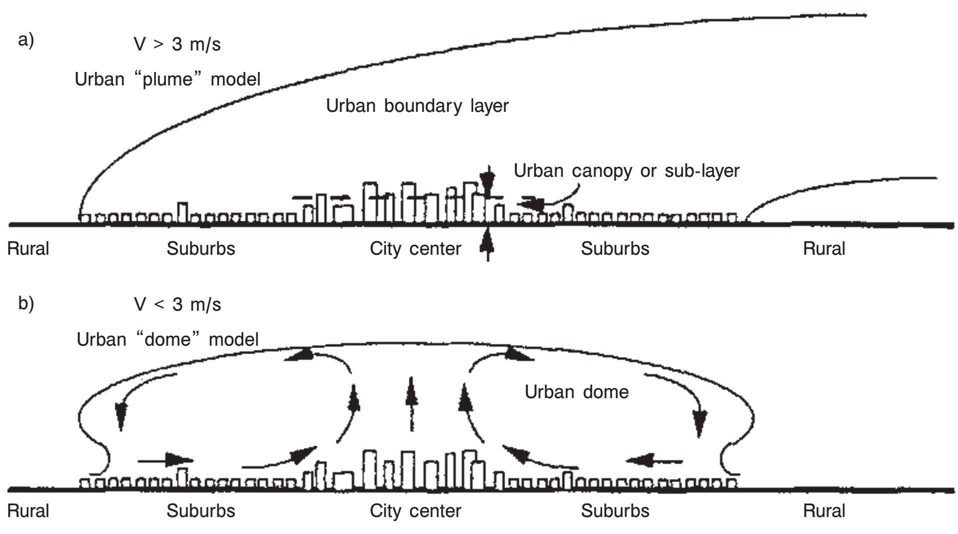

Fig. 1. Models of the urban heat island in conditions of (a) moderate to strong wind and (b) weak wind.

Humans are constantly being exposed to the simultaneous influence of meteorological (temperature, air humidity, wind speed, etc.) and geophysical (solar radiation, Earth magnetism) impacts. In addition, their mutual action is not equivalent to the sum of their separate actions.

There is a complex connection between every element of urbanization (a building, a street, a plant, a park, a parking lot, etc.) and the environment in which it exists. As a result, each element or a complex of elements form their own, specific microclimate.

The alteration of one of the basic abiotic factors of the city ecosystem - the climate, because of city development, leads to a change in the degree of *comfortableness of the climatic conditions for the city population.* A range of indices and bioclimatic parameters have been introduced through which attempts have been made for the assessment of the impact of the climatic conditions on humans.

Most essential for humans are thermal conditions. Their effects are revealed in the process of heat and mass exchange with the environment. Humans represent a complex thermodynamic system, supporting a high stability of its inner isotherm, in spite of substantial variations of external conditions.

During conditions of comfort, the heat balance is not disturbed, the energetic balance of a human is reached most easily and the vitality of the human being is at a normal level. In other words, heat comfort is present at a combination of the meteorological conditions when the thermoregulation of the organism is minimally burdened, i.e. the organism is at physiological rest.

There are different approaches and a multitude of methods, indices and complex indicators that have been developed for rendering an account of the influence of weather on humans. The conditions of comfortableness for the human organism are evaluated by using these methods or a bioclimatic regionalization of a certain territory is performed.

The oldest method used for a complex assessment of the thermal conditions of the environment is the method of effective temperatures. Effective temperature, suggested by Houghten & Yaglou (1923), represents the temperature of static air with saturated water vapour, in which a human being experiences the subjectively same sense of comfort as in the real environment for which the effective temperature is calculated.

Another similar parameter is the effectively-equivalent temperature. It is determined by the simultaneously measured values of the basic meteorological elements – temperature, air humidity, and wind speed.

Analysing the existing indices for assessment of the climate comfort conditions during summer months, Davis (1968) suggested an index based on data for the average diurnal maximum temperature (in deg F) for the three summer months (June, July, August), on the average diurnal sun radiation (in hours for these months) and the total precipitation (in inches).

Attempts have been made for the completion of maps of physiological comfort. Gregorczuk & Cena (1967) calculated the effective temperatures for the territory of the entire Earth for January and July. Maunder in 1962 (see Temnikova, 1975) used thirteen climate indicators for determining the favourable and unfavourable conditions for living regions. Terjung (1966, 1968) and Terjung & Louie 1971 introduced the term “index of comfort” for the USA, later applied to the entire Earth. The combination of temperature and relative air humidity form its foundation.

B.A. Eisenstaedt in 1973 (see Temnikova, 1975) developed a method taking into account the body heat balance through the quantity of released perspiration per a unit time, i.e. through an objective criterion for reflecting the degree of tension of thermo-regulation.

The method of I.A. Arnoldi (see Temnikova, 1975) can be applied for determining the cooling action of the wind by the so-called "conditional temperature". It is accepted by the method that an increase of wind speed by 1m/s is equivalent to a decrease in air temperature of 2°C.

For a description of the heat balance of the human body, Rusanov (1973) united the various existing meteorological complexes into classes of weather, composing different types of weather in relation to their influence on the human heat state.

Evaporation, especially perspiration, is a strong body cooling process and can be determined by the temperature-humidity index THI of Thom (1959).

There exists a method classifying weather in relation to its effect on the psychic state of man (Besancenot, 1978). This method, based on the duration of sun radiation and the quantity of precipitation, evaluates the dominant climatic influences on the human psyche.

The climatic-physiological approach, suggested by Kandor *et al.* (1974) is applicable for the examination of the climatic influence on the human organism for the purposes of summer recreation and tourism.

In the method of vapour pressure of Marinov (1971), an important role is played by the so-called normal physiological boundary of heat adaptation. By means of this method, the following energetic states of the organism are determined: *cooling* – the pressure of water vapour on the body surface is equal to air pressure; *subcomfortable* – the pressure of water vapour on the body surface is between air pressure and 31 hPa; *comfortable* – the pressure of the water vapour on the body surface is between 32 and 44 hPa; *over-comfortable* – the pressure of the water vapour on the surface of the body is from 45 to 62.5 hPa; *overheating* – the pressure of the water vapour is over 62.5 hPa.

The conditions of comfortableness in the urban environment, situated in a complex relief with a different degree of urbanization, changing with the development of the city, should be characterised by a method based on these meteorological elements which are greatly influenced by urbanization and relief. For some regions, as, for example, Sofia, the most appropriate index appears to be "the coefficient of cooling" K, suggested and used by Siple & Passel (1945) (see also Kyle, 1994):

$$K=1.163(10.45+10\sqrt{v}-v)(33-t), \quad [W/m^2] \qquad (1)$$

where v is wind speed in m/s, t is the air temperature in *deg C*. This index characterizes the degree of body cooling due to the influence of wind at a certain air temperature in the shade and average skin temperature of 33°C, without taking into account evaporation.

The sizeable changes in local, urban and regional climates due to anthropogenic activities have produced many changes in the biosphere and a mixture of winners and losers in the socio-economic context (see Mestayer & Anquetin, 1995). In the lee side of St. Louis, where the climate had been altered, 25% increase in average summer precipitation and a reduction in visibility due to pollutants have led to more automobile accidents, less leisure time, increased storm damages, more suburban and farm land flooding, and more soil erosion, but a net increase in crop production and increased cropland values. The migration away from urban centers leading to suburban development over the last 100 years was partly due to the less-than-pleasant climate, including poor air quality and worse human comfort in the urban center. Study of the relocation process of wealthier urban residents and the stay-in-place decisions of affected farmers located beyond the cities is important. These findings are important for those concerned with the environmental impacts and socio-economic adjustments to large-scale changed climatic conditions.

MATERIAL AND METHODS

Our present knowledge of urban climatology is based mainly on three types of data and methods: *site measurements*; *wind tunnel and water tank simulations* and *numerical model studies*. It must be noted that a large part of our knowledge comes from field campaigns. Useful measurements of the urban atmospheric phenomena that can add to these three types of data are the measurements by lidars, sodars, radar profilers and satellites.

For characterizing the general climatic conditions and the comfortableness of the air environment in the city of Sofia and the Sofia valley region, perennial data, received from climatic stations in the region performing measurements at 7, 14 and 21 hrs local time, was used. The microclimatic studies are substantially more expensive for they require a climatic network with an increased density. In Sofia, a similar network with a comparatively good density exists. Nevertheless, the number of stations of this network decreased considerably in the last 10-15 years due to shortage in financing. This fact substantially limits the possibilities for scientific studies and especially for those concerned with the microclimate of the city.

For some of the studies, as, for example, for receiving the climatic characteristics of the temperature inversions in the Sofia valley, data from 1953-1963 from aerological sounding and hourly data from the thermographs, situated at 2 and 40 m (on the meteorological tower of NIMH - in Mladost 1), as well as synoptic maps for a 5-year period were used (see Blaskova *et al.* 1968).

The high price of regular microclimatic observations necessitates the implementation of other types of observations and most of all of short-term "field (natural) experiments", frequently called "field campaigns". For these, temporary networks of an increased number of stations over short periods of time, but with more frequent observations, are used. Due to the substantial influence of microclimatic conditions on air quality in local regions, these experiments are usually complex, i.e. the meteorological measurements (in surface layer and in height) are combined with measurements of the concentrations of air pollutants (see Palmgren, 1996). The experiments are usually conducted during the representative periods (from 15 days to one or more months) of the cold and warm half-year. The number of stations in the examined region as well as the frequency and variety of measurements are increased. In this publication, altogether with results from studies from perennial regular climatic observations, data obtained from short-term experiments is also presented. Some of these observations were implemented through the entire city (e.g. "Sofia'76" – see Andreev, 1980 or "Sofia'82" – see Andreev, 1984) while in others – only in separate regions (Sofia-Drujba'93 – see Syrakov, 1992, 1993), and still in others – only at separate points (see Branzov *et al.*, 1992). The last type – an experiment at a discrete point – was conducted in 1988-1991 in the NIMH region (Mladost 1) within the project "Experimental study of the structure and dynamics of temperature inversions and the convective boundary layer for the Sofia region". The project was performed in two observational periods per year – spring and autumn, during around 20 selected days with ground radiative temperature inversion. The measurements began before sunrise, when the inversion reaches maximum thickness, and continued to its destruction in the examined layer. Thus, for the separate experimental days, from 7 to 12 vertical profiles of temperature, relative air humidity and wind speed were obtained. For the layer from 2 to 600 m, pilot-balloon and a specially constructed radiosonde were used (Branzov *et al.*, 1992). The measurements were made every 50 m as the entire measurement with the observation balloon in the 2-600 m layer continued for 40 min on average. That is why interpolative methods were used for measuring the values of temperature, humidity and wind speed at the same moment in time. For the 600-1500 m layer, data from the routine NIMH soundings in 2:00, 8:00 and 14:00 hrs local time were used.

Computer experiments with numerical models were used to replace the absence of direct observations in the natural atmosphere. The oldest model simulations of the perturbations induced by large cities on the meso-scale climatology were realized with meso-scale models. The stationary versions of these models did not have the features allowing to simulate or predict the climatology of the cities in detail. But, the recent development of non-hydrostatic meso-scale models allowed us to perform such studies. Such experiments for the Sofia region were made by quasi-hydrostatic meso-scale model developed by Ganev *et al.* (see Ganev, 1993). This model was adapted for the Sofia valley (Dimitrova & Ganev, 2000) and used for determining the meteorological fields, having a significant role for the meso-scale distribution of air pollution in the valley at stationary conditions.

RESULTS AND DISCUSSION

The city of Sofia is situated in the central and southern parts of the Sofia hollow valley at a mean altitude of about 550 m. The Sofia hollow valley itself consists of two parts: hollow's bottom (often called "field") and the surrounding mountain slopes. Climate in this region of Bulgaria has a continental character. What are the most characteristic features of the climate of the Sofia valley?

The quantity of radiative energy reaching the ground surface depends on many factors – the geographical latitude and ground exposition, the cloud cover regime, composition of air and in particular the aerosol particles. The main part of the income of radiative energy on the ground surface is due to direct solar radiation. The quantity and the type of its diurnal and annual changes depend mostly on the height of the sun. The maximum is during noon. The intensity of direct solar radiation on a horizontal surface in the region of Sofia at noon changes from 0.24 kW/m^2 in winter to 0.70 kW/m^2 in summer. The total solar radiation has a well expressed annual change. Its annual value on average is 136 MJ/m^2. These values are lowest in December-January – around 3.5-4.5 MJ/m^2, while in a sunny January they can reach 6-7 MJ/m^2. Because of the proximity of the mountain, the sun sets in winter 1-2 hours earlier than in other seasons and this influences incoming solar radiation. Solar radiation reaches its maximum in July when on average it is 19.3 MJ/m^2. In separate years it can reach up to 27 MJ/m^2. Spring is sunnier than autumn; in April the solar radiation is around 14 MJ/m^2, while in October it is 9 MJ/m^2. Local factors greatly influence the values of solar radiation. As an example, solar radiation on many steep, southern slopes is almost always at a maximum. A tendency exists for a decrease in the total incoming solar radiation during the 1950-1990 period. In the last 10 years an increase of this radiation is observed (Fig. 2).

The duration of sunshine is different through the seasons and depends on the length of the day and the cloud cover regime. The average duration is 2040 hours annually. In separate years

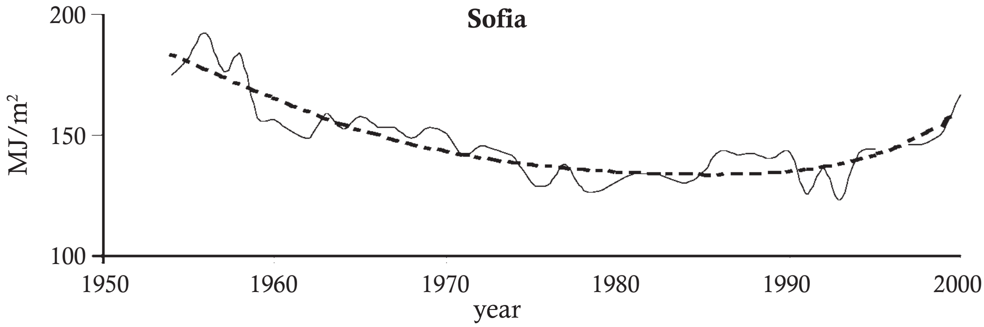

Fig. 2. Change of annual total radiation.

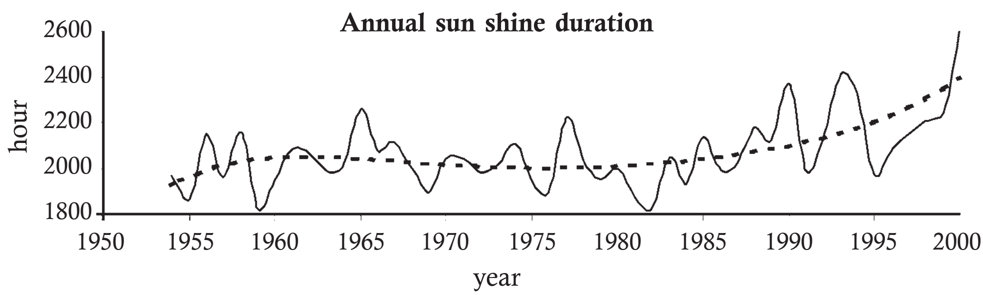

Fig. 3. Change of annual duration of radiation.

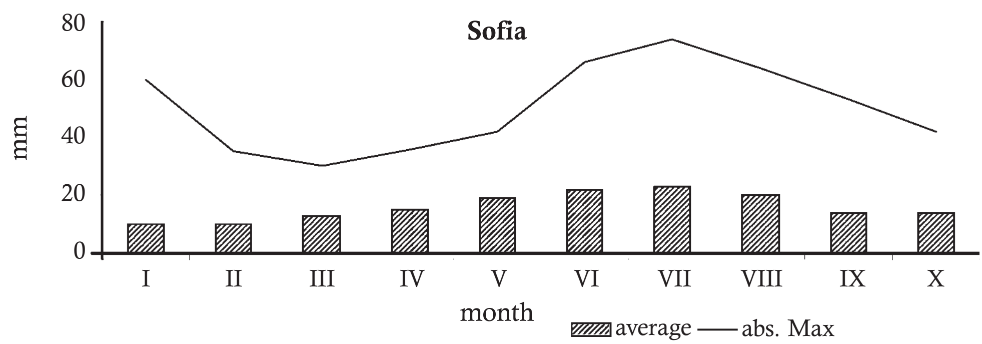

Fig. 4. Annual distribution of maximal precipitation.

the annual duration reaches 2600 hours. It is sunniest in July and August when the duration of sunshine is 280-300 hours and it may reach up to 360 hours monthly. The duration is shortest in December and January – around 75-90 hours and in separate years as low as 25-35 hours.

On Fig. 3 a well expressed tendency of increasing yearly sunshine duration over the last years can be seen, as well as for total solar radiation.

Annual change in precipitation in this part of the country has a well expressed continental character – the quantity of winter precipitation is substantially lower than in summer (Fig. 4); the difference is around 16% from the annual total precipitation. Winter precipitation in the region is lowest – 100-120 mm (or 18% on average of the annual total precipitation). Winter precipitation decreases from December to February (in February – 30-40 mm), but the difference between the two months does not exceed 10-15 mm. In the winter months, though rarely, greater precipitation may occurs, reaching 60-70 mm in 24 hours. In winter, around 50-60% of the precipitation is from snow. In spring, precipitation increases in comparison with winter. In March it is still low and close to that in February due to the humidity-scarce continental air masses. At the beginning of spring snowy precipitation prevail. In the second half of spring and in summer the transport of air mass from the Atlantic ocean is more frequent, appearing as cold fronts. The Atlantic air is rich in moisture and its intense warming over the fastly heating mainland leads to a strong increase in instability. That is why there is generally shower-type precipitation, frequently accompanied by thunderstorms. Frontless-type precipitation is also more frequent. The increase in precipitation is especially greater on the northern slopes of the surrounding mountains due to the strengthening of the vertical component of the air flux from forced lifting. The increase in precipitation in April (still a part of it is snow) is relatively low, but in May it increases sharply by 25-30 mm, reaching 70-90 mm. The summer precipitation is generally frontless and the monthly precipitation sums are greatest – around 170-190 mm (28-30% of the annual total precipitation) with highest values in June (75-85 mm).

A gradual transition to winter circulation occurs in the autumn. The influxes of Atlantic air, decreasing already in August, continue to diminish in September. The sum of precipitation in the region in September is lower than in August but is still relatively high (35-75 mm). In October and especially in November, the cyclonic activity in the Mediterranian basin is intensified and the periods with lasting and heavy precipitation in the country are more frequent. The autumn increase of precipitation is not well expressed in the region. More, precipitation in October is almost equal to that in September and on locations even lower. In November precipitation is 10-20 mm lower than in September, and 40-60% of it consists of snow.

Monthly precipitation varies widely in different years and ranges between 0 and 100 mm, and sometimes more. The frequency of a given quantity of precipitation in separate months is different. In January the probability for the monthly sum to be below 20 mm is around 20%, while in May and in June – only 5%. In May-June the probability is greatest for sums over 100 mm; it is 30-40%. The number of days with precipitation has a weakly expressed annual change. In January there are around 10 days with precipitation, rising to 15 days in May and June and then it decreases again. On average there are 120 days with precipitation within the year – this number has decreased slightly in recent years.

Over a 24 hour period, different quantities of precipitation are observed. Of the 120 days with precipitation, for 5-6 days it is over 15 mm, and in only 2-3 days it exceeds 25 mm. In separate years the diurnal precipitation can surpass the monthly norm. Greater diurnal precipitation falls during the warm parts of the year because it is mostly of the convective type. The diurnal maximum of precipitation and particularly its extremes are generally the result of accidental processes, frequently of local character.

Climate dryness is determined by the distribution of meteorological elements, in particular temperature and precipitation. To follow the perennial change of precipitation in the region, the average precipitation for this region is usually calculated, as well as an index of anomaly (Koleva, 1988):

$$V_j = \frac{1}{n}\sum_{i=1}^{n}\frac{x_i}{\overline{\overline{x_i}}}$$

where j = 1,..., N; $\mathbf{x_i}$ – the annual precipitation at the ith-station, $\overline{\mathbf{x}}_\mathbf{i}$ – the average annual precipitation for the same station, and **n** – the number of stations.

In Fig. 5, the change of the annual index of anomaly is given, calculated at 9 stations. The chart shows a tendency for a decrease in precipitation in recent years. The last few years in Bulgaria have been drier and warmer than normal (Koleva *et al.*, 1996). According to the World Meteorological Organisation, the averages of the 1961-1990 period are used to describe the contemporary climate. Precipitation is around 80-90% bellow normal. Winters and summers are warmer than usual.

The perennial change of precipitation sub-periods can be defined, characterised by different precipitation conditions. During the last hundred years, there were two periods at longer-lasting and strong droughts – 1942-1953 and 1982-1994. During the first period, the dry years are 26% while in the second they increased to 32%. The dry years for the 1961-1990 period are only 10%. The average total annual precipitation for the 1961-1990 period is 543 mm, while for the 1982-1994 – 473 mm. Analysis of the annual distribution of precipitation during these periods shows that during the 1942-1953 period drought was observed at the end of summer and the beginning of autumn when precipitation was 10 mm bellow normal. In the 1982-1994 period, the precipitation is particularly low also in winter. In all three periods, precipitation maintained its moderate-continental distribution.

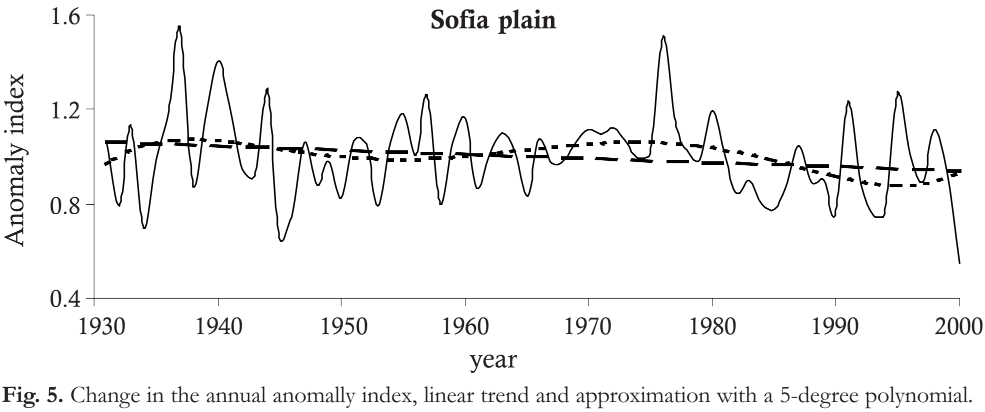

Fig. 5. Change in the annual anomally index, linear trend and approximation with a 5-degree polynomial.

The driest year during the 20th century for the Sofia valley is 2000. Among the driest years are also 1945, 1934, 1946, 1990, 1993, 1994, 1985. After each dry period, there usually follows a comparatively moist period. During the last decade, 1991 and 1995 were substantially humid.

For determining the frequency and intensity of droughts, different criteria are used such as the following:

a) Ped Index: $P_{ed} = \frac{\Delta T}{\sigma_T} - \frac{\Delta P}{\sigma_P}$, where **DT** and **DP** are the deviations of the air temperature and the precipitation from their average values for a given period of time; $\mathbf{s_T}$, $\mathbf{s_P}$ – the standart deviations of these elements. Values for the index between 1 and 2 show a weak drought, at $2<\mathbf{P_{ed}}<3$ – a moderate drought, and at $\mathbf{P_{ed}}>3$ the drought is severe. Negative values for the index point to a moist period. During the last decade, the dry years were 1989, 1990, 1993, 1994, 2000. The years 1990, 1994 & 2000 were considerably dry, and the values for the dryness index were greater than 4. During the last years, a tendency exists for an increase in the Ped Index (Fig. 6).

b) De Marton index: $J = \frac{12P}{T+10}$, where **P** and **T** are the monthly precipitation and air temperature. At values for the index **J** lower than 30, there is a drought, and at values below 20 – a severe drought. The average annual value of this index in the region of Sofia for the 1961-1990 was 28-29, while during 1982-1994 it decreased to 23-25. On Fig. 7, the change of the Marton index is given per month. The driest months for 1982-1994 were July-October, when the index **J** reached values between 2 and 17.

Air temperature for the region increased over time. This tendency is well expressed both for the average temperature and the minimal and maximal temperatures (Fig. 8 and Fig. 9). The same is observed with other temperature characteristics. Thus, for example, the number of days with a maximal temperature above 30°C also grows in the recent years (Fig. 8).

Temperature inversions are the background of a range of phenomena and processes such as the convective boundary layer (CBL); gravitational waves; accumulation of polluting substances in the atmosphere; minimal night temperatures accompanied by ground frost, etc. The mutual connection and interdependence among these phenomena as well as the role of the ground surface is a matter of interest for every region. Climatic characteristics of the temperature inversions in a particular region are of independent interest in connection with some

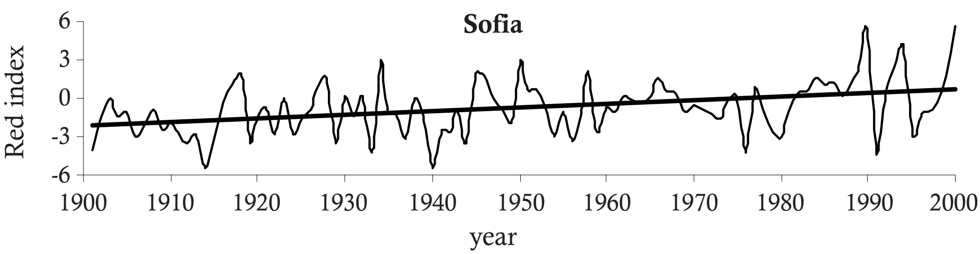

Fig. 6. Perennial change of the Red index.

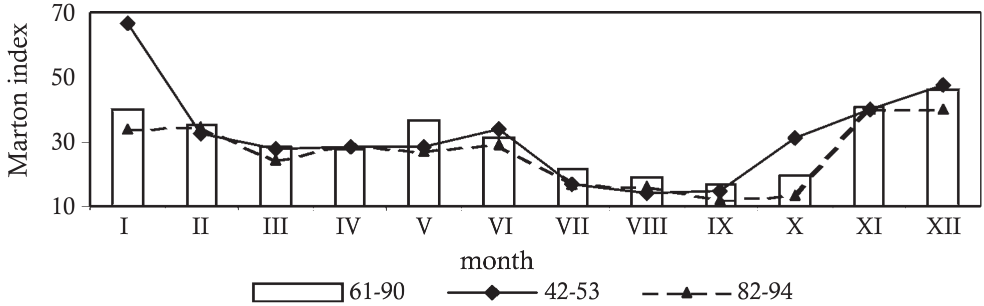

Fig. 7. Annual distribution of the de Marton index for different periods.

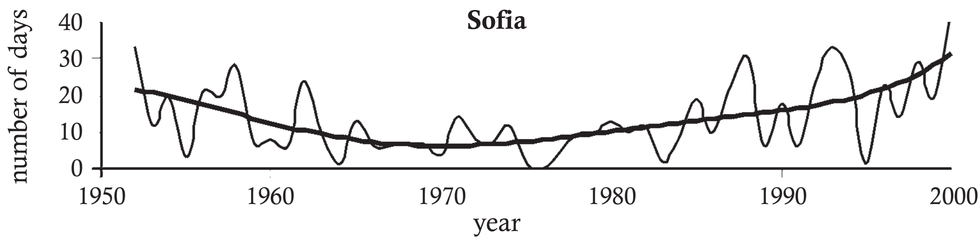

Fig. 8. Perennial change in number of days with maximum temperatures over 30°C and smoothing with a 5-degree polynomial.

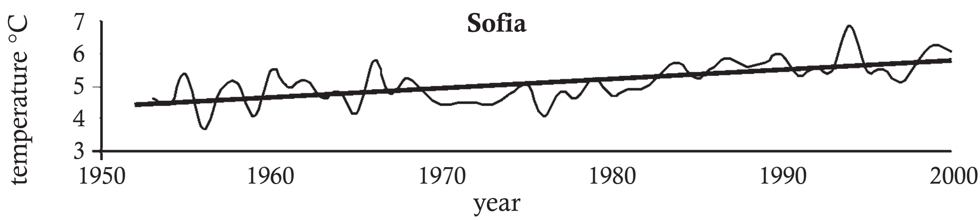

Fig. 9. Perennial change of the average minimum temperature and linear trend.

tasks and particularly for the control of air pollution. Such characteristics for the Sofia valley were obtained by Bluskova *et al.* (1968) from 10-years' observations of the ground air (at 2 and 40 m above ground level) and by aerological observations. It was found that around 90% of all inversions are situated at heights up to 2500 m. Within a year, the greatest frequency (around 45% of all inversions) is for those starting from the ground surface or the first 100 m; around 30% of the inversions are in the 200 to 1400 m layer, and 25% – in the layers above 1400 m. The most frequent ground inversions are those having a thickness of 200-400 m (35%), and with thickness over 1000 m – only 8%. The average duration of the inversions reaching 40 m in height is around 19-20 hours in winter and 10-11 hours in summer. The average duration is greatest in January and December – around 23 hours for inversions up to 40m and around 25 hours for up to 1400 m. On separate occasions, the duration of continuous inversions may reach 10-12 days in winter. Inversions in the ground layer (40 m) in winter lasting over 6 hours were present in 80% of all days in a year, while in the layer up to 1400 m with the same duration – in around 60% of all days. The number of positive air temperature gradients in the layer up to 300 m was almost 7 times greater than the negative ones and the most frequently measured values were 0.6-0.8 deg/100 m. With an increase in altitude (in the 300-600 m and 600-900 m layers) the most frequently measured gradients were 0.5-0.6 deg/100 m. Inversions in the layer up to 40m for all months of the year, are formed during the period beginning from 10° Sun's altitude to sunset. The destruction of the inversions in this layer happens usually when the Sun rises to 15°. Inversions are formed at all forms of the surface pressure field but most frequently at anticyclonic fields (about 60% of all days). At cyclonic field conditions they are present in around 30%, and at transitional pressure fields – in around 10% of all days.

In the publication by Bluskova *et al.* (1968), research was conducted for the disease rate based on data for the districts Hadji Dimitar and Dragalevci at the presence of inversions when an increase of air pollution is usually observed. It was found that, for example, the number of sick children and adults with rhinopharyngitis, tonsilitis and bronchitis increases on average by 20-30% in winter.

The study of Teneva *et al.* (1989) complemented our knowledge of the temperature inversions in the region of Sofia, reporting some supplementary characteristics separately for each of three radiosoundings at 02, 08 and 14 hrs local time for the 1970-1979 period. Thus, for instance, ground inversions according to the 02 hrs sounding have their greatest frequency in August (around 56%) and lowest - in February (around 34%). At 08 hrs, though, these inversions are most frequent in December (around 38%) and least frequent in July (only 3%). The ground inversions at 14 hrs during all months are rare (frequency bellow 1%) with the exclusion of December when the frequency is around 12%. The average thickness of the ground inversions is correspondingly: 200-300 m at 02 hrs, 320-450 m at 08 hrs, while at 14 hrs there are separate events with thicknesses from 100 to 480 m. Their mean intesity varies from 1.7 to 2.6°C at 02 hrs and from 0.7 to 3.1°C at 08 hrs. The ground inversions in Sofia at 02 and 08 hrs during the whole year are most frequently observed during calm weather at ground layer (61%). Their frequency is not that low at a weak southern wind (around 19.5%) which is explained by mountain-valley wind from the Vitosha mountains at small-gradient pressure fields.

The upper inversions (with a lower boundary of 2000 m) at 02 hrs are most frequent in February (around 43%) and less frequent in August (around 14.5%). Their frequency increases at 08 hrs with a maximum in summer months due to the elevation of part of the ground inversions observed at 02 hrs. The upper inversions are a very frequent phenomenon at 14 hrs in autumn and winter (in around 76% of all days with inversions). Their average thickness is between 290 and 520m and their average intensity reaches up to 4.3°C with a maximum in winter.

The altitude of the lower boundary of the upper inversions has great importance for ground air pollution. The inversions with a lower boundary below 1 km at 02 hrs are around 73% of all upper inversions. They are observed most frequently in winter (32% at 02 hrs, 30.5% at 08 hrs, and 38.5% at 14 hrs), and are less frequent in summer (13.5% at 02 hrs, 4% at 08 hrs) and spring (around 27% at 14 hrs).

Some tasks, connected mainly with the diffusion and transformation of admixtures in air as, for example, the prognosis for the level of air pollution in a certain region, demand knowledge concerning the structure and mechanisms of destruction of the radiative temperature inversions. During the 1988-1991 period, a project was realized for studies in this field, named "Experimental study of the structure and dynamics of temperature inversions and the convective boundary layer for the Sofia region" (see Branzov *et al.*, 1992). In Fig. 10, an example of the transformation with time of a radiative temperature inversion at the time of that project is shown. The vertical profile of temperature is in hours towards sunrise (time SR).

The measurements were made with an observation balloon and a special meteorological sounding device. Because the time for a vertical section is around 30 min., the momental expression of the vertical temperature profiles in Fig. 10 is received with an interpolation on time with a cubic spline. The project shows (see Branzov & Panchev, 1991) that a ground radiative temperature inversion in Sofia is not observed at wind speeds over 3 m/s at 10 m. The altitude of the upper boundary of the ground radiative inversion, at unchanged conditions, becomes greater with every following day of the period, when it exists incessantly. Also the speed of formation of the layer with temperature inversion in autumn is greater than in spring. The dependence of altitude of the upper boundary of the temperature inversion on the sequence of the day in the series of days with temperature inversions, was used for the creation of a semi-empirical model for determining the altitude of the unstable convective boundary layer and the time for destruction of a ground radiative inversion over Sofia. It is applicable to wind speeds up to 6 m/s. The physical model for the development of a ground radiative temperature inversion (Branzov *et al.*, 1991) suggests: radiation transfer of heat, determined by the thermo-conductivity equation in a one-dimensional case, at a constant thermo-conductivity coefficient; zero heat flux of the upper boundary level of the temperature inversion; and a linear profile of temperature at the initial

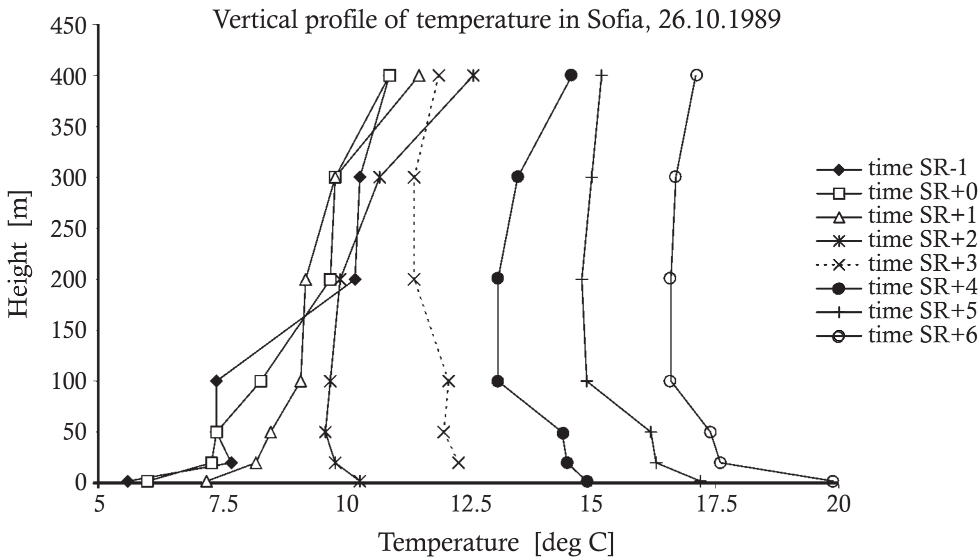

Fig. 10. Experimental results from the transformation of the vertical temperature profile depending on timing after sunrise in a day with a temperature inversion.

moment. Input parameters are: thermo-conductivity coefficient, the surface air temperature (at a height of 2 m) at the initial moment and in separate moments of the inversion development and for the altitude of its upper boundary. The input data for determining the night development of a ground radiative inversion are the initial moment of development; the temperature at 2 m at the initial moment and after that at random time intervals; the time of sunrise and the temperature at 2 m at the moment of sunrise.

It is interesting to note that anticyclonic weather occurs during two thirds of days in the year. In this type of weather, the microclimatic differences, as a result of the relief's peculiarities and city complex influence, can be most clearly distinguished. Hollow forms of the terrain, the relatively high altitude above sea-level and city complexes enhance continental features of the city's climate. Let us now review in short the changes of the basic climate-forming factors and the characteristics of the background continental climate due to these peculiarities of the region, i.e. to give a notion for the microclimate over Sofia. This was done from data of the basic meteorological elements from the functioning (until a few years ago) climatic stations in Sofia and the Sofia valley, as well as from the complex experiments performed in the region.

The heat island is most frequently characterized by a temperature difference "city-surroundings" or "urban-rural" stations – ΔT_{u-r}. Blaskova *et al.* (1983) found, from data from climatic stations functioning temporarily for 12 years (1954-1965), that the average annual temperature in Sofia is 0.7-0.8°C higher than outside the city. The differences are more substantial in the average monthly temperatures for observation at 21 hrs when it is 0.5-1.4°C. Zlatkova and Tzenkova (see Andreev, 1980 or Blaskova *et al.*, 1983) found from expedition data in June and December 1976 that the heat island in summer is most intensive during 03-04 hrs at night when ΔT_{u-r} = 6.3°C was registered. It fades away during the hours around the temperature maximum-14 hrs. In winter the greatest differences on average are found at 22 hrs. The maximal intensity of the heat island registered during the winter experiment was ΔT_{u-r} = 4.3°C.

In the studies by Syrakova and Zaharieva (1998, 1999) the diurnal and annual changes of ΔT for a ten-year period (1981-1990) were studied on hourly data from the stations in Sofia - the Botanic garden (Levski sq. – urban station), NIMH (suburban station) and Lozen (rural station). It was found that an intensive heat island appeared most frequently at night in the summer period July-September where in more than 20% of time the average value of the difference among the three stations ΔT exceeded 3°C, reaching 3.2°C. The largest values of ΔT reach almost 10°C. In some occasions not only a heat island is observed but, contrary, a "cold island" ($\Delta T < 0°$). The average frequency of a negative temperature difference is 20% most frequently appearing in July-September.

The local weather conditions (wind speed and cloud cover) greatly influence the urban heat island. When there are fewer clouds and a low wind, ΔT_{u-r} in summer nights reach values greater than 4°C. An increase in wind speeds leads to a significant decreasing of the heat island intensity, and combined with an increase in cloud cover results in an almost complete loss of the temporal pattern features.

With the expedition data it is possible to determine the form and structure of the heat island for Sofia. It is prolonged in the N-NE sector in direct dependence of the positioning of industrial sites and the "Kremikovtzi" plants. The main nucleus, i.e. the area of most intensive heating, is observed over the central city parts that are densely built-up, with intensive public transport and high dust concentrations. For Sofia, a second nucleus is characteristic over the Iskar railway station – a city district with industrial sites, living areas and a recreational zone (Fig. 11).

ΔT only gives a general view of the intensity of the heat island, but not of its structure. In most cities, with a million people there exists a constantly functioning network of meteorological observation sites and from these data one can obtain adequate information on the microclimatic conditions in a city. In Sofia, unfortunately, most meteorological stations were closed, including the first Bulgarian station (at the Levski monument). The field experiments conducted in 1992 and 1993 give an idea of the thermal regime in the eastern part of the city (Batchvarova *et al.*, 1996). The intensity and configuration of the zones with higher temperatures (here the heat island is not mentioned because the research is conducted only in the eastern part of the city, where a second heat nucleus is formed) depend on the meteorological conditions. The intensity of these zones is greater at night and it decreases two fold at noon. The horizontal gradients are maximal at the boundary between urban and rural environments, and decrease within the urbanized territory. The maximal registered difference "city-surroundings" $\Delta T_{u\text{-}r}$ is 4.8°C during summer and 4.0°C during winter observation periods.

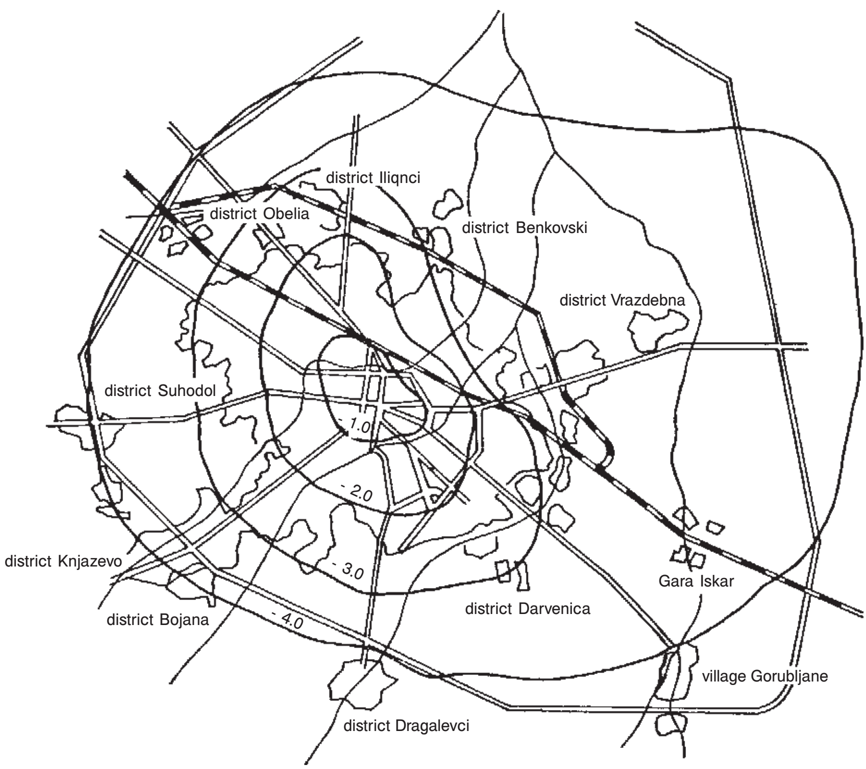

Fig. 11. Air temperature distribution in Sofia on the morning (8 h a.m.) of 30.11.1976.

The wind regime in Sofia was mainly studied from data received through complex experiments and mobile measurements. According to Zlatkova and Tzenkova (see Tzenkova & Ivancheva, 1999), wind speed in different regions of the city is, on average, 1.3-2.0 m/s lower than outside the city. This difference has a maximum during afternoon hours (14-16 hrs) and at a minimum in the morning.

As a quantitative indicator for the change of wind in different parts of the city, the change in wind coefficient was used – $Kv = V_i/V_0$, where V_i is wind speed at a random city point and V_0 – the wind speed in the selected rural point. The change in wind coefficient provides a possibility to choose such building forms allowing for the creation of a more favorable wind regime in a certain location. Zones, where Kv is from 0.0 to 0.5, are considered having weak ventilation. In places, where Kv is from 0.6 to 1.0, there is optimal ventilation for the city environment, and where Kv>1.0, the region is characterized by strong winds.

The mobile measurements conducted in 1983, 1987 and 1989 for the distribution of wind speed for Sofia show, that in most parts of the city Kv<1, as there are a number of locations where Kv=0. These results confirm the decreasing influence of the city on wind speed. In conditions of anticyclonic weather in summer, for the southern districts of Sofia, situated at the foot of the northern slope of Vitosha, the appearance of "slope wind", also called "mountain breeze", is characteristic. During daytime, close to the earth surface, it should blow from the city upwards on the mountain slope (anabatic wind), but this event is almost non-occurent. The night slope wind, which is a katabatic type wind, is well expressed especially in July and August, beginning after 19 hrs and calming down around 07 hrs. During calm and clearly anticyclonic weather at night, this wind brings clean air, rich in negative ions, from the mountain slope towards the polluted city parts. Because its vertical growth (up to 30-40 m) and speed (1-3 m/s) are small, the high buildings situated crosswise can stop the clean air at the periphery of the city. A sound example of this is the mobile measurements conducted on 22 July 1987. The values of Kv obtained by these measurements of wind speed in different city points, showed that while at 20 hrs in the region of Dragalevci the slope wind was clearly expressed with speeds over 2 m/s and Kv=1.2, in the Hladilnika and Krusta region Kv was already bellow 1. This appeared even though the points were situated in close proximity to a boulevard, coinciding with the direction of the wind, and only a few meters away in the side-streets there was no wind. The same experiment illustrated the role of the mountain, the green zones and the aeration conditions for the thermal regime. From 35.4°C at the National Palace of Culture, the temperature gradually fell to 35°C at Krusta, 34.3°C at the ring-road to 29.6°C over Dragalevci, while in the center of the city at the crossroad of Ekzarch Josiph str. and Rakovska str., it maintained a value of around 38.5°C.

Western and northwestern winds usually prevail in the city of Sofia. Therefore, in 1988 and 1989 mobile measurements of the distribution of the wind flux were conducted in some parts of the city during a northwestern wind. Inside the relatively densely urbanized windward part of the city (the Vitosha municipality) a process of blowing-through was observed, and in open areas (the National Library and the Levski monument) the wind maintained its speed. In the southeastern periphery of the city (the background NIMH station in Mladost1 district), the wind completely died away. The situation is rather different in streets having an orientation close to that of the wind flux. Here, the wind maintained its speed or, in some cases as on the ring-road, an effect close to tunneling appeared and the wind speeds increased.

Relative humidity in the densely urbanized center of the city at the time of all field studies in Sofia is lower than in the suburban areas. According to data from experimental researches in the summer and winter of 1976, the difference (Df) in relative humidity between Vazrazdane sq. and different observation points at the periphery of the city has an almost identical diurnal variation. Differences were greatest in the hours before noon and after sunset, when Df reached up to 15% in both seasons. The mobile measurements in October 1989 showed, that, on separate occasions the difference in relative humidity between locations within the city, characterized by different ground surfaces, can reach up to 50%.

Microclimatic regions of Sofia. The relief's peculiarities and city complex influence enhanced continental features of the city's climate, and the mountain surroundings create possibilities for fast spatial changes (basically horizontal gradients) of both the meteorological elements and air pollution characteristics. If the terrain is entirely flat, such changes occur at much greater distances. The indicated factors lead to the formation of Sofia City's specific microclimate. In the presence of such peculiarities, the City can be divided into both, microclimatic regions and air pollution levels. According to studies carried out by the National Institute of Meteorology and Hydrology (NIMH) (Blaskova *et al.*, 1983), there are four microclimatic regions in the city of Sofia and the Sofia hollow valley: 1) open hollow field; 2) central city part; 3) peripheral part of the city; 4) foot of the mountains.

The first microclimatic region "Open hollow field" is the lowest part of the Sofia valley, at 520-560 m altitude. It is surrounded by mid-altitude (Vitosha and Stara planina mountains) and low-altitude mountains (Ljulin, Viskjar, Lozenska and Vakarelska). The local climatic conditions in this region are frequently unfavourable for the dispersing of pollutants in air. A reason for this is the frequent and long-lasting temperature inversions. Thus, for example, in 75% of the days in winter in the layer up to 2000 m altitude, there is some inversion with a duration of up to 3-4 24-hours periods. The average thickness of the ground inversions in winter is 350-400 m. In these cases the conditions are unfavourable for the dispersion of pollutants both from low and high sources, because the smoke plume from even the highest chimneys remains in the inversion. The temperature inversions are a frequent phenomenon also in summer, but then they are less thick and of shorter duration – they are destroyed in the morning hours. They also obstruct the dispersion of pollutants from low sources and can lead to higher pollutant concentrations at night and in the morning hours. Because of the frequent inversions in the region, the frequency of fog during the cold half-year period is also greater – average annual number from 30 to 50 days, while the foggiest months are December (9-10 days) and November (5-6 days).

The second microclimatic region "Sofia City center" covers the city's most densely built-up part and is of 530-580 m altitude. Here, the city's warming influence is greatest and the so-called "city heat island" is present. That is why air temperature here is considerable higher than in the "Sofia field", as the difference for the absolute minimum temperature is around 6-7°C and for the average temperature for the coldest month – January – it is around 1°C. Here, the influence of the city on microclimate is well expressed, i.e. the influence of heating of the city is greater when the minimal air temperature (T_{min}) in the open field is lower. Thus, for example, when in the field T_{min}= -10°C, in the city it is 1-2°C warmer, and at T_{min}= -30°C, in the city it is 6-8°C warmer on average. The frequent temperature inversions in the Sofia hollow valley lead to an increased number of fog days within the city in winter, reaching an average of 35-40 days for all of the three winter months, with maximum in December (13-15 days). The cause of this is the intensified pollution of city air and that is why fog is most frequent at the lower locations of the central city parts, i.e. the Hadji Dimitar district, around Vazrazdane sq., Stochna gara, the Central railway station, etc. It is characteristic that fog is longer-lasting in the city than in the open field. This creates conditions of higher levels of air pollution. Fog in urban and industrial areas, where considerable amounts of SO_2 are emitted, create "sulphur-acidic (winter) smog", and the fog droplets contain toxic compounds. The centralization of home heating decreased air pollution in the city of Sofia and especially in its central parts. After its large-scale introduction, the frequency and the duration of fog diminished considerably and, respectively, the level of air pollution dropped.

The third microclimatic region "Peripheral districts of Sofia" or "Peripheral city area" covers the districts around the center. The region can be separated into two parts: low (520-550m altitude) and high (550-580m). The low part encompasses wholly or partially the districts of Gara Iskar, Hristo Botev, Vassil Levski, Suhata reka, Malashevci, Orlandovci, Voenna rampa, Ilijanci, Nadezda, Momkova mahala and Vrabnica. By location, as well as by microclimate, this zone takes a transitional position between the hollow field and the city centre. The low terrain location determines the great frequency of temperature inversions and, therefore frequent fogs (30-40 days on average in winter months). The percentage of calm weather or winds up to 1m/s is high (about 65% of the days). This weak ventilation, frequent fogs, and the presence of many industrial plants cause high levels of air pollution. This can be seen from the average concentrations of pollutants, and the level is very high during calm weather. The high part of the peripheral city region covers wholly or partially the districts of Zapaden park, Razsadnika, Ivan Vazov, Hipodrouma, Iztok, Geo Milev and Slatina. Here conditions are more favourable for living compared to the low part. This relates both to micrometeorological conditions (greater altitude, better planting, proximity to the Vitosha mountains for some districts) and to air purity (lack of big industrial polluters). Here the ventilation is improved (windless days are 30-40%), fog is rarely formed (20-30 days in winter) and has a shorter duration and lower intensity. At these conditions, the level of air pollution is lower in the high part compared to the low part of the city peripheral region.

The fourth microclimatic region "Foot of the mountains" can also be divided into two areas. The low part (580-600 m altitude) includes the districts of Pavlovo, Buckstone, Ovtcha kupell, Borovo, Juzen park, Losenec, Ljulin (the southern parts), Mladost (the northern parts), and Gorubljane.

The middle-high part (600-700 m altitude) includes districts and near-city villages like Bankja, Ivanjane, Suhodol, Gorna Banja, Knjazevo, Bojana, Dragalevci, Simeonovo, Hladilnika, Dianabad, Student city and district "Mladost" (the southern parts). These are parts of the Sofia valley with less densely built-up areas, and with green areas located at the foot of the Vitosha, Ljulin and Lozenska mountains, so the adverse influences of the city complex is significantly reduced. These parts are characterized by rapid horizontal changes in the values of meteorological elements that allows the division of the region into the above-mentioned two parts. For example, the frequency of fog in the winter is 20-25 days in the low part, compare to only 7-8 days in the highest part. The intensity of fog here is also considerably lower compared to other microclimatic regions of the city of Sofia. The value of the total solar radiation during winter is higher, getting up to 15-16 kcal/cm^2 as compared to values of 10-13 kcal/cm^2 in the central parts of the city. This is a result of the higher air transparency in the considered region. The decreased number of days with fog is also an indicator of better air quality. Therefore, the living conditions in this region are more favorable compared with that in the other regions of the city from both a microclimatic (higher temperatures in winter, cooler days in summer, higher intensity of the solar radiation, decreased number of days with fog) and an air quality point of view (lack of big industrial enterprises, better ventilation). The presence of local mountain-valley wind during calm weather (anticyclonic or low pressure gradient) contributes to better air quality, too. This wind usually blows in the night and early in the morning as it is a light (velocity of 0.5-3.0 m/s), fresh and from the south (S, SSE, SE, SW). It is observed mainly in August and September.

Conventional measurement instruments have their peculiarities, transforming into weaknesses in some specialized studies. Thus, for example, the balloon radiosounding is not appropriate for studying the diurnal evolution of the atmospheric boundary layer because of the relatively high inertia of sensors at relatively high elevation speeds of the balloon. We have also noted that the sensors' inertia requires a comparatively slow elevation of an observation balloon, and an appropriate method of time interpolation is needed for calculating data towards the same moment in time. That is why for some studies the use of other measurement methods is appropriate. An example is the complex experiment in Sofia in the summer of 1994 using a lidar system for determining the concentration of aerosol particles in air together with equipment for direct meteorological measurements (a universal ground station, an observation balloon, pilot balloons). The aim was, with frequent measurements of the spatial distribution of aerosol particles and profiles of temperature, humidity and wind, to study the diurnal evolution of the atmospheric boundary layer in general, and also over different ground surfaces in the city. The lidar and meteorological equipment was based in the southeastern part of Sofia – the Institute of Electronics and NIMH-BAN. Here, the route for lidar sounding started with a 900 m^2 of grass cover area and then it moved to a residential area with 8-10 stories high blocks of flats (Mladost 1A). The forming of a stably stratified boundary layer at night, which was destroyed after sunrise, when the formation of a convective boundary layer (also called mixing layer) begins, represented considerable interest. The two-dimensional lidar schemes of the aerosol stratification in Fig. 12 show that the altitude of the mixing layer over the park zones is lower than over the residential areas (respectively around 100 and 180 m around 1 hour after sunrise and up to around 260 and 470 m at noon).

Some useful results were also obtained with the adapted thermodynamical model of Stull (see Donev *et al.*, 1995). For example, for the vertical heat flux that causes the growth of the mixing layer, a value of 0,15degK.m/s is obtained over the earth surface in residential areas. The average speed of growing of the mixing layer was determined for the period of measurement (from 07:30 to 11:10 hrs) – around 45 m/h over the park zone and 85 m/h over the residential area. The probable cause for this is the difference in intensity of the heat flux.

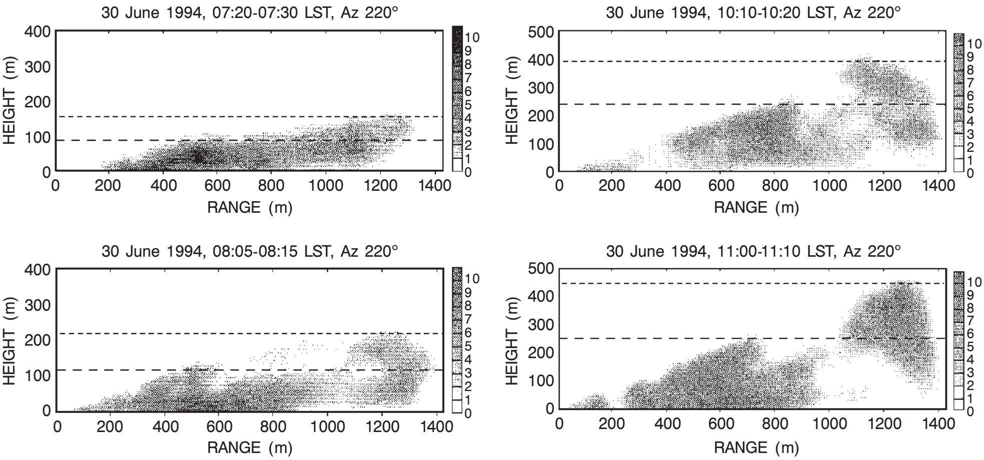

Fig. 12. Schemes of the vertical distribution of aerosol particles (concentrations are given in grayscale) by which the altitude of the mixing layer over the park zone (broken line) and over the living areas (broken line with dots) is determined.

The results concerning the interaction of the mountain-valley circulation and the city heat island allow (see Kolev *et al.*, 2000) for the building of a physical model (Fig. 13) for the local air flows and for the structure of the boundary layer over a city, situated in a complex orography region such as the Sofia valley. It is flanked on the south by the Vitosha mountains (altitude around 2200m and an average slope of 10^0) and on the north by the Stara planina mountain (altitude around 1500m and an average slope of 5^0).

At the developed night scheme of the mountain-valley circulation, the cold air flows moving down the mountain slopes begin to fill the volume of the valley and form a "lake" of cold air and its depth increases during the night. The warmer air of the *"residual layer"* remaining from the daily (convective) mixing layer is left over the lake of cold air. The descent of the cold layer down

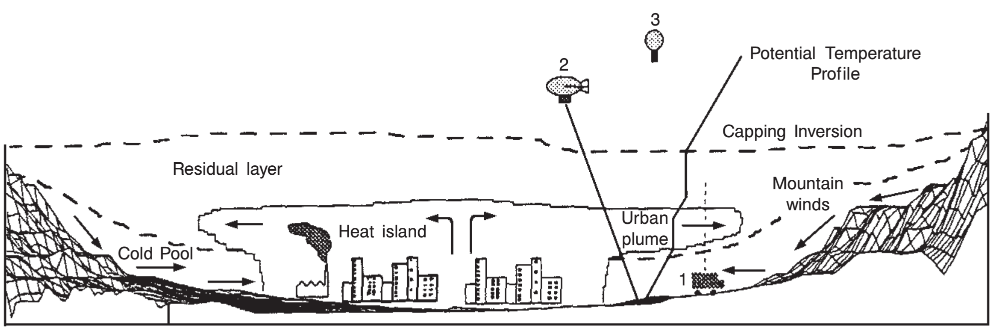

Fig. 13. A scheme of the model of local air flows and the structure of the boundary layer at night over Sofia City at air-mass weather; 1-Lidar system (three-rayed aerosol lidar or Raman lidar); 2-observation balloon; 3-pilot-balloon (see Kolev *et al.*, 2000).

the slopes continues until the lake reaches an altitude where the air has the same temperature. In this way, the so called "valley inversion" is most frequently formed, which is a stable stratification in the volume of the lake (Whiteman, 1982). The mountain wind gradually destroys the city heat island and a ground inversion is formed. The result is that air flow from opposite directions is formed at some altitude over the city. It transports warm air and aerosol particles from the central part of the city heat island and creates the so-called *"urban plume"*. In the air above the city, between the urban plume and the residual layer, the first layer of an upper inversion is formed (see Potential Temperature Profile in the right part of Fig. 13). The second upper inversion is called "capping inversion" because it capped the mixing layer during the day.

The complex lidar and direct meteorological measurements allowed us to form general schemes for the typical vertical profile of the potential temperature and the characteristic altitudes of the layers with an increased concentration of aerosol particles over Sofia City during the experiment in 1994 (Fig. 14). These are typical for air-mass synoptic situations.

The first characteristic layer is the ground temperature inversion with a thickness of around 100 m. It is formed due to radiation cooling of the earth surface and the surface air after sunset and the advection of cooler ambient air in the valley at night. This advection causes compensational fluxes in height, leading to the formation of a layer of warmer air over the ground inversion, called the urban plume of warm air. The plume transfers air from the central city parts (with a greater concentration of aerosol particles in it) and the potential temperature is almost constant with height. Thus, between altitudes of 200 and 400 m, the first aerosol layer is formed due to the retention of aerosol particles by the first ground inversion, situated in the layer between the urban plume and the residual layer, most frequently between 300 and 400 m. The aerosol particles that are emitted in the air from sources at the earth surface, elevate in height by means of the diffusion

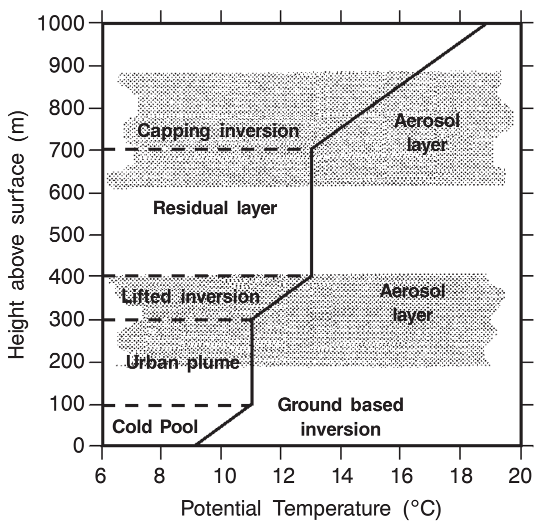

Fig. 14. Typical profiles of the potential temperature and altitude of the aerosol layer disposition over Sofia City, obtained by complexion of lidar and direct meteorological data during short-term experiments.

processes in the mixing layer forming during the day. After sunset, a portion of these elevated particles stay at the residual layer, under the capping inversion, its base being situated at around 700 m. It must be noted that the values of the parameters of the inversion and aerosol layers depend on the meteorological situation and the season of the year.

As was noted, the local wind field can be deformed over complex relief areas. We do not have an idea of the local wind field and its deformations in different synoptically defined winds. This is because, in practice, it is not possible to carry out a meteorological network with regular observations by automatic or conventional instruments that is dense enough for registration of microscale processes. Such direct observations in the natural atmosphere are rarely organized in the frames of special projects by temporary networks. These can, however, be replaced with surrogates such as laboratory (analogue) and numerical (computer) models. We were introduced to the results of Tucker (1989) that refer to laboratory modeling of the local flows over the Sofia valley. He used the water tank in which a model of the relief of the valley is towed to represent air flow from each of the four cardinal directions. Visualization of the water flow was achieved by emitting dye from eight small tubes placed around the valley and one in the industrial town of Pernik. The dye was emitted at a height which corresponds to 400m above the valley floor. Neutral buoyancy for the dye is obtained by drawing fluid from the level of the exit tubes. Vertical stratification of the water is obtained by adjusting the proportion of fresh to saline water as the tank is being filled. This study refers to the atmospheric situations characterized by stable conditions and light but well-defined prevailing winds in the valley.

The laboratory experiments show the following. When northerly winds occur, flows from the western and central parts of the Sofia valley (e.g. from directions of Dragoman and from Sofia City respectively) converge onto the Pernik area where a lee eddy sometimes occurs. There are short periods of blocking of the circulation in the area to the south-west of Sofia before the fluid moves on southwards.

In periods with easterly winds, blocking occurs over Sofia, while an eddy in the lee of Vitosha mountain causes a local circulation of air over Pernik; occasional insertions of air from Sofia can be observed.

In the case of southerly winds, flow over the western half of the Sofia valley, the fluid moves northwards over the low hills and north-westwards out of the valley. The central and eastern parts of the valley are prone to blocking. Lee eddies occur at various times and the air appears to be trapped over the whole of the eastern half of the valley.

In situations with westerly wind, the main flow is formed by fluid entering the valley from the northwest, near the town of Dragoman, and moves south-eastwards across the northern part of the valley. It is interesting that a flow from the Pernik area moves north-eastwards into the Sofia valley and then moves south-eastwards, staying on the southern side of the valley. In the eastern part, these two streams converge and flow down the Luda Yana and Topolnitza valleys, probably causing a zone of stagnation in the upper part of the Maritza valley.

The quasi-hydrostatic meso-scale model, developed by Ganev K. *et al.* (see Ganev, 1993) has been adapted for the Sofia valley (Dimitrova & Ganev, 2000) and used for determining the meteorological fields. The adaptation was made by means of numerical experiments with a two-dimensional version of the model and their comparison with measurements made during laboratory experiments in an aerodynamic tube.

The modeling calculations are conducted at the local scale (dimensions of region 105 and 75 km and 1.5 km step at 20 vertical levels) at the following stationary meteorological conditions: windless or different directions of a given weak background wind; stable and unstable stratification of the air temperature. The modeling results in conditions of stable stratification coincide qualitatively with conclusions for the local air flows from laboratory water tank experiments (Tucker, 1989) and with air pollutant distributions from field campaigns (Andreev, 1998).

Fig. 15 shows the fields of the simulated wind at a height of 100 m in the Sofia valley at northern and southern background winds. It can be seen that considerable parts of the valley are occupied by flows in the opposite direction to the given background wind.

With a lack of background synoptic wind, the slope and mountain-valley winds have a determining role in the creation of air circulation at local areas such as the Sofia valley (Fig. 16) at both stratifications.

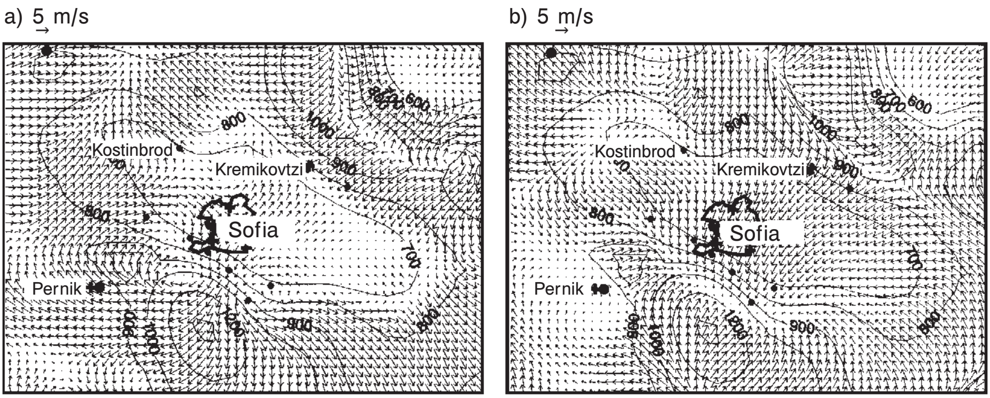

Fig. 15. The fields of simulated winds in the Sofia valley at 100 m altitude and given (a) north and (b) south background synoptic winds and a stable temperature stratification.

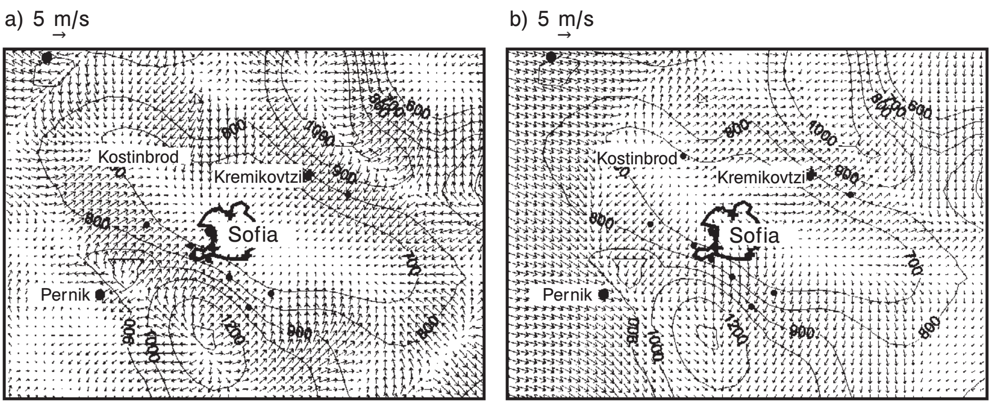

Fig. 16. The fields of simulated winds in the Sofia valley at 100 m altitude with no background synoptic wind and (a) stable and (b) unstable temperature stratification.

In some of the numerical experiments, the influence of factors such as wind speed, cloud cover and the anthropogenic heat flux from city sources was observed on the formation and the diurnal development of the city heat island (Dimitrova, 2000). The greatest contribution comes from the air humidity and the heat conductivity of the earth surface, and the contribution of roughness is negative. Wind and dense cloud cover have the greatest influence of all atmospheric parameters.

To evaluate *the human comfort conditions* in Sofia and its surroundings, data from the meteorological stations Sofia-NIMH, Gorni Lozen, Simeonovo, Pancharevo, Buhovo and Busmantsy were used from 1990 onwards when a maximum number of stations worked simultaneously; this period is 1990-1994. After 1994, stations Simeonovo, Buhovo and Pancharevo were closed. Data are for the climatic terms 07, 14 and 21 hrs for the months July and January, which are representative for warm and cold half-year periods.

In order to obtain assessment of climate comfortableness in the region of Sofia, the cooling index K was used, calculated using formula (1), through which, according to Siple & Passel (1945), different classes (types) of weather can be introduced (Table 1).

The most favourable class of weather from human perspective is the *neutral class* when the human body neither looses, nor receives heat. The neighbouring classses of weather can still be considered comfortable and close to the comfortable types of weather. The *hypotonic type* corresponds to heat energy reception weather that can be regarded as warm subcomfort, and the *tonic weather type* is favourable for sporting activities. The remaining weather types are uncomfortable. Thus, for example, at the *cooling weather type*, the human body cools down due to loss of heat. *The endothermic and atonic types* are also uncomfortable because then the human body receives heat. Here it should be noted that for sea resorts the preferable weather type by tourists is atonic. In mountain resorts during the skiing season, the cooling weather type is favourable.

In winter, naturally, endothermic and atonic types of weather are not observed (Table 2). The most favourable weather type is therefore the neutral comfortableness class (K=3). The frequency of this class is greatest in the region of Gorni Lozen, followed by Mladost 1 - NIMH. The tonic class (K=4), i.e. cool subcomfort suitable for normal activity in the open, is most frequently observed in the area of the village Buhovo (62%) and Busmantsy (53%). The cold discomfort or the cooling weather class prevails also in the area of Busmantsy (47%) and Buhovo (30.8%).

Table 1. Definition of the bioclimatic weather types (classes) by means of the cooling index K

Type (class) weather		**Values of the cooling index K [W/m^2]**
Endothermic	(K=0)	$K \leq 0$
Atonic	(K=1)	$0 < K \leq 174$
Hypotonic	(K=2)	$175 \leq K \leq 349$
Neutral	(K=3)	$350 \leq K \leq 699$
Tonic	(K=4)	$700 \leq K \leq 1049$
Cooling	(K=5)	$K > 1050$

Table 2. Frequency percentage of the different bioclimatic weather types in the Sofia valley (% in winter / % in summer). The symbol "∑" means the sum of the percent of the types with K equal to 2, 3 and 4.

Type (class) station	K=0	K=1	K=2	K=3	K=4	K=5	Σ
NIMH	-	- /39.1	12.1/40	47.3/20.4	26.1/ -	14.5/ -	85.5/60.4
Gorni Lozen	-	- /21.3	9/44.5	50.2/33.3	28.7/ -	12.2/ -	87.9/77.8
Simeonovo	-	- /18.1	- /54.3	30.6/37.6	46.8/ -	21/ -	77.4/91.9
Pancharevo	-	- /26.5	2.4/29.4	36.6/44.1	31.7/ -	19.3/ -	70.7/73.9
Buhovo	-	- /8.6	- /29.8	7.2/60	62.0/ -	30.8/ -	69.2/89.8
Busmantsy	-	-/18	- /77	- /5	53/ -	47/ -	53/82

Interestingly, at some stations separate occasions of warm subcomfort are observed (hypotonic class, K=2), probably connected with periods of warming weather. This class of weather is quite favourable, especially in the cold half-year period.

To determine the degree of human comfort, it is better to summarize the frequency percentage of classes with K 2, 3 and 4 as shown in Table 2 with the symbol "∑". With this assessment, the living conditions in winter are again best in Gorni Lozen and Mladost 1-NIMH.

Living conditions in winter, using this indicator, are close to good in the regions in close proximity to Simeonovo and Pancharevo. The conditions are most uncomfortable in Busmantsy and Buhovo where the cold discomfort prevails due to the openness of the terrain and the conditions for forming of low temperatures. It must be noted that by using this summary indicator, the built-up part of Druzba as a whole has relatively high comfortableness conditions due to higher air temperatures and weaker wind.

In summer (Table 2), naturally, the cold discomfort – the cooling comfortableness class (K=4) – is absent. Comfortable conditions are present most frequently in Buhovo – 60%, and most rarely in Busmantsy (5%). The percentage of this class is relatively high at Pancharevo (44%), Simeonovo (38%) and Gorni Lozen (33%). The hot discomfort (K=1) prevails in the city parts – NIMH station – 39%, and is most rarely observed in Buhovo, Busmantsy and Simeonovo. The hot subcomfort (K=2) is present everywhere, when in spite of the relative overheating of the organism, the conditions are still favourable for activities in the open. For this season, an assessment is also made for the human comfort conditions, based on the summary frequency of classes K=3 and K=2. According to this assessment, the climatic comfort conditions are most favourable in Simeonovo and Buhovo. So, the summary indicator at Busmantsy is relatively high (82%) due to the high percentage of hot subcomfort (77% of hypotonic class, K=2) in spite of the low frequency of the comfortable class (neutral type, K=3). The sum of classes with K equal to 2 and 3 is favourable for Gorni Lozen (78%) and Pancharevo (74%).

CONCLUSIONS

Local conditions and especially the relatively high altitude, relief and city complex, enhance continental features of Sofia City's climate. One of the most characteristic features of the city climate – "the heat island", is found here too, but its intensity is studied only as the difference (ΔT) between temperatures in singular urban, suburban and rural stations. The average value of ΔT is $\geq 3°C$ with highest values reaching up to 10°C. An idea of the form of the heat island is given by experimental studies, but the small number of stations within the city does not allow us to study its structure thoroughly, including determining the presence, number and parameters of the secondary islands. A secondary heat island is detected in the Druzba district (see Fig. 11). The influence of wind speed and cloud cover on the difference in ΔT is also studied.

Wind change in different parts of the city is obtained by data from short-term experiments and mobile measurements. The spatial distribution of the wind change coefficient Kv confirms the reducing influence of the city on wind speed. The presence of slope wind from the Vitosha mountains was detected in the southern districts of the city at high pressure fields, including small gradient ones. Wind appears mainly at night during the 17-07 hrs period. This is favourable regarding air pollution, because clean mountain air enters the city by such winds. An important result is that high buildings can stop this wind in the periphery of the city. This is an important weakness of the city planning of Sofia.

A very useful result from climatic studies in cities is the implementation of a reliable microclimatic regioning. It is done on the basis of relatively long series of observations (e.g., for least a 10-year period) at a sufficiently large number of stations in diffrent regions of the city. Fortunately, such series of observations are available for a few climatic stations in Sofia, though most were closed during the last 10-15 years. Regioning divided Sofia into four microclimatic regions. For each region, the characteristic values and changes throughout the year of the basic meteorological elements as well as air quality and human comfort values are given.

This microclimatic regioning should be the basis for city planing. Unfortunately, this is not the case for any town in Bulgaria, including the capital. When determining the location, the prevailing orientation of buildings and some other characteristics of the big complexes in Sofia, other considerations than the determining role of climate and microclimatic peculiarities of the city have been taken into account. Only in this way can we explain why most of the city complexes are situated not only in the industrial, but also in the lowest parts of the city, from where it naturally follows that they are the regions with highly polluted air and with a relatively low degree of comfortableness. At the same time, large parts of the Sofia valley and Sofia City situated at the foot of the Vitosha mountains, Ljulin, Lozenska, and even Stara planina, remain uncultivated. From this point of view, the big complexes Mladost and Ljulin have a more suitable location. There, though, other planning defects with respect to climate and microclimate exist. Thus, for example, it is not known why the main part of the apartment blocks in Mladost have a west-east orientation, i.e. against the prevailing winds. A decisive factor for this was probably the use of the already existing main street, now called Al. Malinov Bldv. It was possible, however, for the orientation to be south-north as it would lead to better inner comfort of the blocks. Then the heat regime of the buildings would have been improved considerably. Now, however, heating is low due to the strong cooling influence of the frequent west, north-west and east winds.

In the complexes close to the mountains, i.e. the mountain Vitosha, other planning errors were allowed: very high and very wide apartment blocks were built at the periphery of the complexes towards the mountains. Besides, there are no boulevards and streets that start from the mountains and enter radially towards the center of the town. These routes would ensure greater penetration of mountain winds that bring clean mountain air into the city at night, and also coolness in summer.

Overcoming these city planning defects is one of the main goals of the prognosis part (until 2020) of the "General Structural Plan of Sofia" (2002).

The greatest advantage to be achieved is to divide the city into regions based on a complex characterization of the separate city parts such as microclimate, climatic comfort conditions and levels of air pollution with harmful compounds. Some of the authors of this publication completed a complex regioning on two indicators – microclimate and level of air pollution at the request of a construction company (still unpublished) – see the article of Andreev *et al.*: "Air Quality of Sofia – Meteorological Aspects" (this book).

ACKNOWLEDGMENTS

We thank the editors L. Penev, J. Niemelä, D. J. Kotze and N. Chipev for the invitation to participate in compiling this interesting collection and for final editing of the manuscript.

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Urban Climate and Air Quality - a Review

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Summary

Humans in urban areas are exposed to the simultaneous influence by agents of meteorological, geophysical and air quality origins. Urban climate and air quality are interesting problems as people all over the world are highly urbanized. A review of the knowledge of these agents is offered in this article. The following problems are considered: in-canopy energy budget, urban heat island and local convective circulation; the structure of the "urban boundary layer" in conditions of different wind speeds; the influence of the city on the atmosphere over the downwind regions and on cloud and convective precipitation processes, synoptic wind speeds and other weather conditions over the urban area. The major factors (sources of harmful emissions; meteorological conditions; chemical transformations) which determine air pollution in any region are also considered. The paper also focuses on: episodes with high air pollution, including winter and summer smog; Air Quality Guidelines and measures for the preservation of favourable air quality in urban areas and the necessity for an air quality monitoring network; meteorological data; emission inventories and numerical models for urban air pollution management are also discussed. Detailed predictions and real time control of air quality demand the development of complex sub-mesoscale models to understand the relations between the physical-geographical conditions, regional meteorology, local pollutant sources and the monitoring measurements.

Key words

Urban climate, urban canopy, urban heat island, in-canopy energy budget, local convective circulation, urban boundary layer, air quality, air pollutants, air pollution sources, air pollution episodes, winter and summer smog, "hot spot", Air Quality Guidelines, monitoring network, emission inventories, urban flow models, urban dispersion models, Sofia, Bulgaria.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 55-82

INTRODUCTION

Humans are exposed at every moment to the simultaneous influence of both meteorological (temperature, air humidity, wind speed, etc.) and geophysical (solar radiation, Earth magnetism) impacts. In urban and industrial areas, air quality is a third important agent. The mutual action of this agents is not equivalent to the sum of their separate actions. Knowledge of these agents is important because of an urbanized world. For instance, more than 70% of Europeans are living in urban areas today.

The structure of the lower urban atmosphere and the local air quality in large cities are resulting from the interactions of processes taking place at three different scales. Most meteorological processes can be described at the *meso-scales* (atmospheric boundary layer height – several tens of km) although meteorological forcing is known to be due to larger scales. Urban ground is covered with natural and artificial materials, buildings and other obstacles. The heat budget as well as the flow structure close to the ground depend largely on the height and density of these constructions. Flow structure varies from a series of turbulent wakes due to isolated obstacles, to strongly interacting turbulent streaks and even to turbulent flows having some similarities with flows in semi-porous media. The atmospheric layer below roof level is called the *urban sub-layer or urban canopy* (see Fig. 1a), by analogy with the atmospheric layer between ground and trees of dense forest. Kondo and Yamazawa (1986) defines its height by the integral of the building heights: $h= (\sum H_i S_i)/S,$ where S is the total area under consideration, H_i and S_i are the height and area of the individual obstacles (buildings).

Many dispersion processes are studied in the immediate vicinity of the sources, or at the impact targets, and therefore must be studied at small scales within the urban canopy; this is especially true for those emissions of pollutants which transform rapidly and interact chemically. Most of the pollutants of interest for evaluating the impacts on human health, vegetation, materials, monuments or on the long term atmospheric content (global change) are secondary compounds, not directly produced by anthropogenic sources. So, when it is considered that urban dispersion problems must be regarded most of the time as the dispersion of photo-chemically transformable pollutants, it is realized that an intermediate range of processes must be studied. Their scales are those of the turbulent mixing of the not-so-rapid chemical transformations, and of the interactions between the source layers and the atmospheric boundary layer, because the dispersion processes of photochemical compounds depend on the dynamic, physical, micro-physical, chemical and radiative structures of the neighboring atmospheric layers. These are at the scales of the local convection movements that are specific to the urban environment and are due to local, even weak orographies combined with strong heterogeneities in the surface temperatures and in the canopy dynamic structure (Fig. 2). These scales are called *sub-meso scale* because they are smaller than the scales usually simulated by meso-scale models. Indeed, the meso-scale models are usually unable to simulate the fine decametric scales and are so heterogeneous in urban areas that it is not well known how to model them. Up to now, meso-scale models cannot correctly predict the pertinent urban patterns, even in combination with sophisticated photochemical models, because of their inability to simulate the necessary details of the air movements (Moussiopoulos *et al.*, 1992).

URBAN CLIMATE

The actual climate of urban areas are formed in the background of the regional climate typical of the geographical area but is deformed under the influence of the local relief and human-made fabrics. On the other hand, there is a complex connection between the elements of urbanization (a building, a street, a plant, a park, a parking lot, etc.) and the environment in which it exists. As a result, these elements or a complex of elements form their own, specific microclimate. That is why only a few micrometeorological rules are general enough to be exported from one city to another.

The most studied climatologic effect of cities is the *urban heat island*, i.e. the systematic higher temperature of the atmosphere over the city compared to that of the upwind neighbouring rural area. Because there is no recent reference handbook on the urban meteorology in Bulgaria, following the paper of Mestayer & Anquetin (1995), we first survey the observations assessing the heat island, its traditional conceptual description, its causes and extents and the induced climatic perturbations at the regional scale, i.e. the city effects on the regional physics and microphysics of the atmosphere due to the altered fluxes of sensible heat and moisture, and the production of pollutant gases and particles: among them are the increases in cloud coverage, precipitation and fog.. Then we studied the consequences of heat island on the dispersion at meso and sub-meso scales, and on its simulation. We found that large problems remained in connection with the structure of the flows close to city roofs: this leads to a focus on the urban canopy, and a review of our knowledge of the in-canopy energy budget and pollutant dispersion. Finally we examine the present trends in climatology and dispersion at sub-mesoscales in the urban atmosphere.

Heat islands have been detected in the XIXth century by European scientists examining historical records of large cities such as Paris, Berlin, Vienna and London (Landsberg, 1970). It appeared that the temperature differences between typical urban and rural stations ΔT_{u-r} increased with time and are dependent on the city size, from 2^0C for small towns up to 12^0C for very large ones. Measurements over large urban areas show that the internal patterns of the heat islands are rather complicated in space, as a result of the 3-dimensional influence of terrain heterogeneity. Usually, in big towns, there are many heat islands - a "main" one and a few – "secondaries". They are also changing rapidly during the diurnal cycle and are dependent on the meteorological conditions with, for example, maximum levels appearing at the end of the afternoon or the beginning of the night in conditions of weak winds and clear air, and in winter (see Mestayer & Anquetin, 1995).

Oke (1990) reviewed about 700 papers on this subject. The following *physical processes* have been considered as taking part *in the heat island generation*: anthropogenic sensible heat production due to house heating, vehicles and industries; reduction of wind speed due to the presence of buildings; alteration of the water balance due to the reduction of vegetation evapo-transpiration and to the water vapour directly released by industrial activities; alteration of the radiative budget, including the effects of greenhouse gas production; heat storage the constructions; local topography and local wind flows; alteration of the diurnal cycle of sensible heat flux, radiative heat flux, and conductive heat flux, especially the reduction of nocturnal cooling. The role and importance of these various processes appear to be dependent on the solar cycle and on season; e.g., the alteration of the water budget is a dominant factor in summer, while the dominant factor in winter seems to be the anthropogenic heat flux. A large number of measurements have been taken to assess these effects in all types of cities, but most of the our knowledges are from three large experiments (see Mestayer & Anquetin, 1995):Vancouver, Canada (1973), St. Louis, USA (project METROMEX - Metropolitan Meteorological Experiment, 1974-1976) and Toulouse, France (1978).

The first conclusion from these measurements is that the temperature differences can reach a very high value in a large and dense megalopolis. It is also interesting to note that even a small town of 1000 inhabitants, generates a noteworthy heat island. The structure of the town is also a factor of high importance, probably through the effect of ventilation that depends not only on the building density but also on building height. These studies have demonstrated that the heat island effect is important not only close to the ground but also higher in the atmospheric boundary layer and that it generates either "heat bubbles" or "heat plumes" (Fig. 1). During weak winds (or no wind), local circulations are formed because of the influence of the thermal convection caused from the heat island (Fig. 1b). This circulation consists of closed convective cells with an ascending branch over the heat island (the city center) and a descending branch over the suburbs. The surface branch of the convective cell brings clean and fresh air towards the warmer and polluted city parts. The aerodynamic model in Fig. 1a shows that in conditions of moderate to strong synoptic wind, an internal boundary layer inside a 2-D urban boundary layer over a flat relief develops, due either to a change in roughness (dynamic internal layer) or to a change in the surface heat flux (thermal internal layer). As a rule, these model flows are studied in wind tunnels.

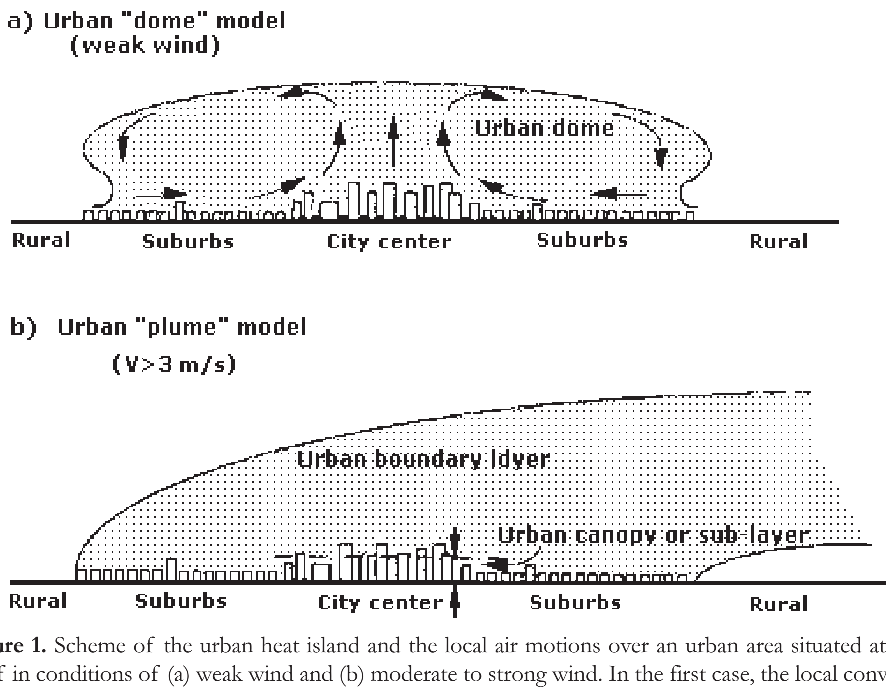

Figure 1. Scheme of the urban heat island and the local air motions over an urban area situated at a flat relief in conditions of (a) weak wind and (b) moderate to strong wind. In the first case, the local convective type circulations are formed under the influence of the urban heat island (by Mestayer & Anquetin, 1995)

The schemes in Fig. 1a and Fig. 2a show the development of the urban boundary layer as one (or a few) internal layer(s). It shows that the city constructions are, essentially, a carpet of roughness elements and that the city landscape is a very complex terrain.

Due to the induced city thermal and dynamic convection, the frequency and intensity of the inversion layers tend to decrease over the urban areas, and the "urban boundary layer" therefore tends to be, more often, close to neutral. The model of the structure of this boundary layer in Fig. 1 is a classical but crude approximation, corresponding to the pioneering modeling efforts of the 1970's. Actually, all meteorological conditions produce some combination of the two situations in Fig. 1 and the picture is in fact more complicated: the structure of the "urban boundary layer" is 3-D, depends largely on the local orography (Fig. 2) and on the heterogeneity of the different districts within the city. Most of the studies of the last 25 years, however, have been developed within the framework of these conceptual models.

Results from the three large experiments indicate the decreasing influence of the city on the synoptic wind speed. In summer, in the conditions of anticyclonic weather, the appearance of "slope wind", also called "mountain (valley) breeze" is characteristic for the districts of urban areas, situated at the foot of a mountain (e.g. at the northern slope of Vitosha – the mountain near the city of Sofia). During the daytime and close to the earth surface, wind should blow from the city upwards on the mountain slope (anabatic wind), but it is very slight. The night slope wind, which is a katabatic type wind (as at Fig. 2) is well expressed, especially in the

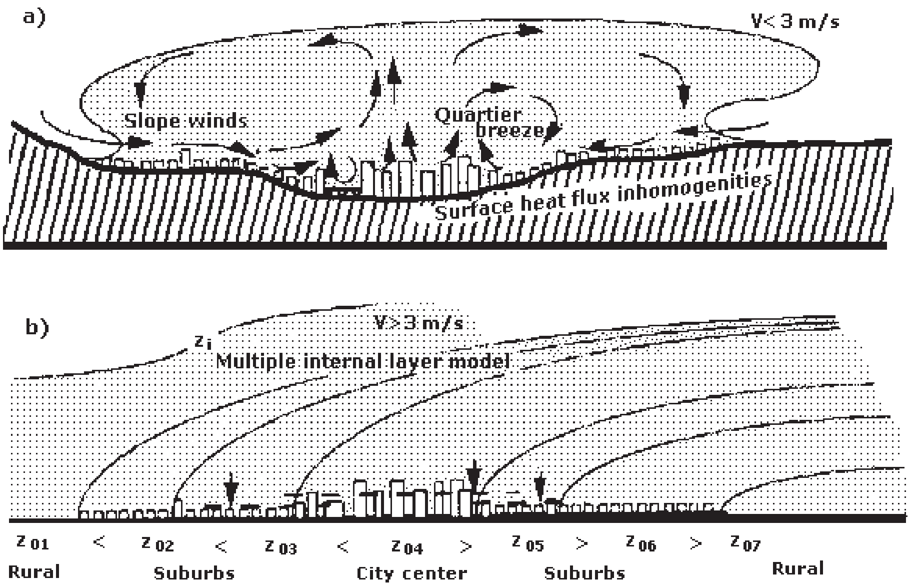

Figure 2. Refinements of the scheme of the local air motions in Fig. 1 including an urban area situated in a complex relief. In this case (0), the local circulations are formed not only under the influence of the urban heat island but also as the effect of the local orography (the night "slope" wind) (by Mestayer & Anquetin, 1995).

middle of the summer in conditions of weak winds and cloudless weather. It begins to blow at the end of the afternoon (or the beginning of the night) and calms down shortly after sunrise. In clearly anticyclonic weather at night, this wind brings clean air, rich in negative ions from the mountain slope towards the polluted city parts. Because its vertical growth (up to 30-40m) and speed (1-3m/s) are minimal, the high buildings situated crosswise can stop the clean air at the periphery of the city.

The observations show that the heat island appears to be a characteristic feature of the urban atmosphere and is evident over built-up areas of all sizes, even over small villages or isolated large districts, shopping centers, etc. The heat island parameters depend on the city size, structure, density, energy consumption and degree of pollution. Where pollution is low, the main factor seems to be the impact of solar radiation on the urban surfaces. Where pollution is high, energy consumption is also usually quite high and the anthropogenic energy flux seems to be the determining factor. It is, of course, always a combination of various factors.

Oke (1973), on the base of experimental data, expressed the maximum urban-rural temperature difference as a function of the population size and of wind speed, as:

$$\Delta T_{u\text{-}r} = P^{0,27} / (4{,}04 . U_r^{0,56}) \tag{1}$$

where P is the number of inhabitants, U_r – the wind speed measured outside the city at a reference level of 10 m. It is obvious from this and other research (see Mestayer & Anquetin, 1995) that other factors need to be taken into account. For example, the structure of the heat island is considered to be of the "dome" type (Fig. 1b) for reference wind speeds lower than 3 m/s and of the "plume" type (Fig. 1a) for U_r>3 m/s. There are several parameterizations of the vertical extent of the heat island in Kimura *et al.* (see Mestayer & Anquetin, 1995):

$$H_{max} = a.R^{-L/6} \quad \text{where} \quad R = \beta . g . \Delta T_u . L_t^{\,4} / v_t \tag{2}$$

where L_t is city length in meters; β – the coefficient of thermal expansion per unit volume; g – gravity; ΔT_u – the vertical temperature gradient over the urban area and v_t the average turbulent diffusivity. Based on the St Louis METROMEX measurements, Auer and Changnon (see Mestayer & Anquetin, 1995) proposed a relationship between the heat island height and wind speed

$$H = 1265 - 87{,}2\, U \quad \text{for} \quad 2 \le U \le 8 \text{ m/s} \tag{3}$$

The heat island is also determined by the development of the dynamic internal boundary layer when the wind is not weak. Its height is usually parameterized as a function of the fetch *x,* i.e. the distance in the change of roughness and of either the roughness lengths of the two surfaces z_{01} and z_{02} or that of the rougher surface z_{0M}. The various formulae are shown in Mestayer & Anquetin (1995). They note that Jensen (1981) proposed to take into account the thermal stratification by parameterizing the internal layer height with Monin-Obukhov length scale *L*, as

$$z_{IBL}(x) = x^{3/2}.L^{-1/2} \qquad \text{for unstable stratification,}$$
$$z_{IBL}(x) = x^{1/2}.L^{1/2} \qquad \text{for stable stratification.} \tag{4}$$

All these parameterizations enter into the framework of the original 2-D scheme of the urban heat island. Some interactions of the heat island with atmosphere at the meso scale or with the meso scale climate have been studied with a meso scale meteorological 3-D model. However, the meso-scale simulations considered relatively simple parameterizations of the canopy "terrain" that appear inadequate, particularly with respect to the parameterization of the surface sensible and latent heat fluxes, the subsurface heat storage and the role of urban geometry upon the surface energy budget. Most of our knowledge of the interaction of urban areas with the atmosphere comes mainly from natural experiments.

The heat island in principle is related to the heat exchanges and energy budget within the canopy layer, and also to exchanges at the canopy layer - boundary layer interface, and therefore to the interaction between the meteorology and the canopy structure. At least six causes of heat build-up can be listed : the increase of long wave radiation from the sky; the decrease of solar radiation reflection due to radiative trapping; the increase of solar radiation absorption by urban materials due to their lower albedo; the increase of heat storage by the urban wall and ground materials; anthropogenic sources of heat and energy; and the decrease of latent heat consumption due to reduced vegetation and to the water collection networks. Four processes remain as possible causes of the heat island development in the urban boundary layer above roof level (see Fig. 1): the warm air provided by the canopy layer; the direct anthropogenic heat inputs by chimneys and high stacks; the entrainment of warm air by induced convective movements; and the increase of radiative transfers due to atmospheric pollution.

It is interesting to analyze the difference in the atmospheric energy budgets over city surfaces and over rural areas, which can help us to understand the origin of a heat island. Following Mestayer & Anquetin (1995), the steady state energy budget over a flat surface can be written as follows:

$$(Q+q)(1-a) + \varepsilon I_{total} - \varepsilon\sigma T^4 = H+G+LE \tag{5}$$

where Q is direct solar radiation, q is diffuse solar radiation, a – surface albedo, ε – surface emissivity, I_{total} – hemispherical long wave radiation, σ – Stefan-Boltzmann constant, T – surface temperature, H – sensible heat flux, G – conduction and LE – latent heat flux. This equation (5) can be rewritten to let the radiative budget appear on the left hand side and the heat budget on the right hand side of the equation. The budget over the urban canopy must include an additional anthropogenic source term F, essentially due to fuel consumption. In this case, it is usually signifying H and LE – the turbulent heat fluxes in the air, G – the ground-and-construction storage, R – the radiative budget, i.e.

$$R+F=H+G+LE \tag{6}$$

If the urban canopy is considered a nearly horizontal surface, the radiative budget R can be simplified, i.e.

$$R=(1-a).S+\Delta L=S-a.S+L_a-L_s \tag{7}$$

Here S is received (direct + diffuse) solar radiation, $(a.S)$ – part of the solar radiation that is reflected by the canopy, L_a – long wave radiation emitted by the atmosphere downwards to the ground and L_s – long wave radiation emitted by the canopy upwards to the sky. Solar radiation S can be attenuated by 2 to 20% over urban areas. Air pollution is the main cause of this reduction. Short wave (solar) radiations are absorbed by small aerosols, water vapour, oxygen and ozone. A part of the aerosols are condensation nuclei that increase the formation of clouds that also absorb short and long wave radiations.

The part of the solar radiation that is re-emitted to the atmosphere by the urban canopy is essentially depending on the albedo of the urban surfaces. The albedo of a surface characterizes the visible radiation reflection of the surface; it is 1 for a surface that perfectly reflects all radiations, and 0 for a surface that totally absorbs all visible radiations. The albedo of a surface depends on its material, colour and surface state. It can vary with time, due to surface processes such as the deposition of dust or the elevation of the sun (glass surfaces have albedos varying from 0,08 to 0,5 as a function of solar incidence angle). Urban surfaces present a very large palette of albedos from 0,08 for tar and asphalt to 0,5 or 0,9 for white-painted walls. Most of these have albedos between 0,1 and 0,2, but, as a rule, urban albedos are lower than albedos over rural surfaces: the average urban albedo is about 0,13 while it is 0,16 over rural areas. As a whole, the canopy presents an even less effective albedo due to the radiative trap effect of street canyons and building yards: much incoming radiation undergoes multiple reflections on building walls and interspersed ground surfaces. Building height and density, and solar elevation influence both the radiative trap effect and the shadowing effect of one building on another. Oke (1988) showed that the effective albedo of an array of street canyons can vary by as much as a factor 2 under the combined effect of solar incidence and street geometry.

Due to the presence of more clouds and particles, the long wave radiations emitted downwards by the atmosphere are greater over the city than over the country-side, by up to 5%. According to the Stefan-Boltzmann law (the long wave radiations emitted by a surface are proportional to its temperature to the 4th power), the radiative emission of urban grounds and surfaces is considered to be much larger than that of rural surfaces and it presents a maximum around mid-day. This flux can be as much as 20% higher over cities than over the country-side (Oke, 1979). The lower atmosphere absorption of the long wave radiation emitted by urban surfaces is also enhanced by the presence of particles and greenhouse gases like carbon dioxide, and the two effects combine to increase the temperature of the urban atmosphere.

Assessment of the various terms in the radiative budget of the urban atmosphere compared to the neighbouring rural atmosphere shows that the decrease in solar radiation is quite well balanced by the effect of the lower albedos. The long wave radiations are greater in both directions and these increases tend to balance each other. Although the urban structures do transform the various terms of the radiative budget (sometimes largely), *the net budget imbalances are, on average, of the same order of magnitude over urban and rural areas*. Oke (1979) even considers that there is a slight deficit in the urban radiative budget compared to the rural one. Therefore, it does not seem that the radiative budget is the main direct cause of the heat island. What do we know about the urban heat budget?

The sensible heat flux H is mainly due to the transfer of heat from surfaces to the air due to temperature differences between air and surfaces. The latent heat flux LE is mainly due to the release of water vapour by uncovered grounds, vegetation and the porous surfaces. But anthropogenic sources of sensible and latent heat (house and factory chimneys, traffic emissions etc.) are also present in the urban atmosphere. The magnitude of these sources is a function of the city energy consumption that results from the population density and of socio-economical factors as the average standard of life and the city organization. Anthropogenic fluxes increase with density and with standard of living; in large, dense and rich cities, *F* can be greater than the solar radiative flux. In general, *H* is higher in cities but *LE* is lower. There is less vegetation and less bare soil that are potential surface water storages, but the anthropogenic sources of latent heat can be very intense and are mainly isolated, large sources (factory exhausts) that generate strong heterogeneities into the surface patterns and the atmosphere. Conduction *G* is much larger in cities due to the capacity of urban materials to store heat and because of the absence of vegetation. Heat storage varies between 15 and 30% of the total heat budget due to the radiative trap effect. The reduction of vegetation cover of a great number of the vertical walls increase the area collecting solar radiative flux. Although the net radiative budget has about the same value over rural and urban areas, the multiple reflections of radiation between the vertical surfaces multiply the transfers from radiative energy to heat that is stored in the city components. Heat storage accumulates during the day and is progressively released to the air during night: conduction (*G*) is often the largest sink of heat by day and always the largest source at night, when it almost balances the radiative heat loss. This explains the more intensive heat island during night and its maximum often observed between 3 and 5 hours after sunset: the country-side stores little heat that can be rapidly re-emitted and cools rapidly after sunset while the heat stored in and re-emitted by the artificial ground and wall materials in the city reduces the cooling of the air included in the canopy layer (Fig. 3).

The parameters of the urban heat island depend also on water vapour and latent heat budgets. Water that is stored in the superficial layers of the natural ground also represents a negative latent

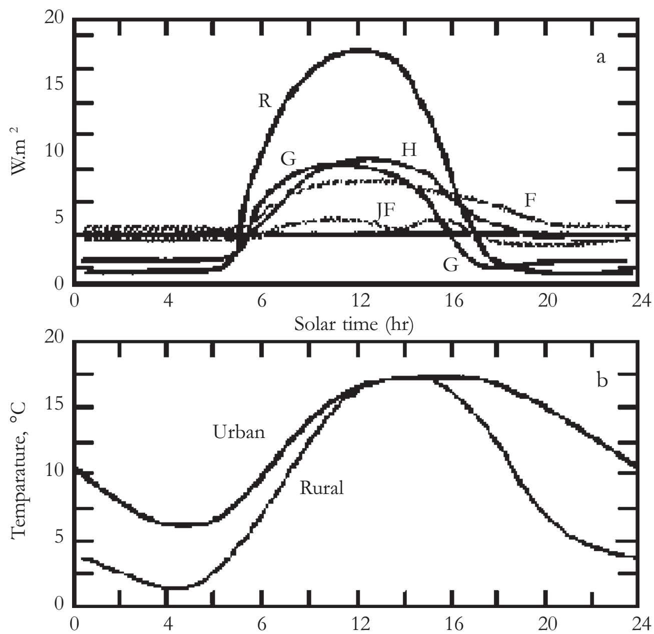

Figure 3. Typical diurnal evolution of (a) the heat budget terms over the urban canopy (the symbols are in the text) and (b) the urban and rural temperatures (adapted by Mestayer & Anquetin, 1995 from several authors).

heat storage that is released when the water is released to the air by the vegetation. Evaporation induces a large consumption of heat in the air, about 2 500 J per gram of evaporated water (580 Cal/g). In cities, most of the water that is deposed to the surfaces is collected by the draining network to the sewers and finally to rivers and the sea. This is why *evaporation is much reduced in the urban atmosphere and the latent heat that is not pumped from the energy budget is one of the major causes of the heat island.*

Finally, it must be noted that a negative temperature difference $\Delta T_{u\text{-}r}$ is sometime observed. However, while it is rarely observed in city centers, it occurs quite often in suburban areas due to the presence of artificial ground surfaces and the absence of strong heat sources and heat storages (Myrup *et al.*, 1993). This increases the complexity of the local flows over the city and the urban "ground" description for dispersion modeling.

Urban areas can induce some meso-scale perturbations in the atmosphere. One of these, demonstrated by the urban "plume" model of Fig. 1a, shows that the climatic perturbations generated by the city are transported by the wind, like a meso-scale "plume" of anthropogenically-modified and polluted air as large as the city itself. This plume can generate a series of perturbations over the downwind regions at distances of several hundreds of kilometers, as, e.g., the "Ozone plumes" during photo-oxidant episodes. Analyzing climatic records, Landsberg (1970) and Huff & Changnon (1973) showed that urban areas influenced warm season rainfall. In humid continental climate areas, urban influences on convective rainfall were most evident when the atmosphere was highly unstable and producing heavy (>25mm) rainfall events. The urban influences on cloud and precipitation processes have been difficult to measure and became the focus of several studies in the USA during the 1960's. Changes in clouds and rainfall were suggested in an area extending 50 km east of Chicago, focusing attention on the question of the reality of urban influences on precipitation (Changnon, 1980). Studies on climate records at several North American cities (Huff & Changnon, 1973) revealed the presence of urban anomalies in precipitation and storm conditions for cities with populations greater than a million. In general, the area extent and magnitude of the precipitation anomaly were found to be related to the size of the urban area.

The urban-industrial influences on the atmosphere of the St. Louis metropolitan area, and especially the regional influences on clouds and precipitation, have been studied in the METROMEX (Changnon *et al.*, 1981). Urban causes of altered clouds and precipitation included: (a) changed in-cloud processes by urban-additions of cloud condensation nuclei; (b) altered fluxes of sensible and latent heat from the metropolitan area, which helped create and enhance vertical air motion; (c) increased convergence and updrafts from momentum shifts due to the city and its structures, and from differential heating, all of which affect the urban boundary layer and perturb the atmosphere; (d) enhanced moisture, largely from industrial sources. METROMEX established the causes of urban-induced cloud changes, the reality and magnitude of warm-season rainfall increases, and the types of increases in storm activity such as more thunderstorms, lightning, hail and damaging surface winds (Changnon *et al.*, 1981). These climate changes occurred in a broad region embracing the city and a large fan-shaped area extending as far as 65 km east of St. Louis. In a study of summer rainfall over Washington it was found that the urban area caused showers, i.e. the heat island led to preferential meso-scale forcing and localized cloud development and enhancement.

The sizeable changes in local, urban and regional climates due to anthropogenic activities have produced many changes in the biosphere and a mixture of winners and losers in the socio-economic context (see Mestayer & Anquetin, 1995). In the lee side of St. Louis, where the climate had been altered, the 25% increase in average summer precipitation and reduced visibility due to pollutants have led to more automobile accidents, less leisure time, increased storm damages, more suburban and farm land flooding, and more soil erosion, but a net increase in crop production and increased cropland values. The migration away from urban centers leading to suburban development over the last 100 years was partly due to the less-than-pleasant climate, including poor air quality and worse human comfort in the urban center. Studies of the relocation process of wealthier urban residents and the stay-in-place decisions of affected farmers located beyond the cities is important. These findings are important for those concerned with the environmental impacts and socio-economic adjustments to large-scale changed climatic conditions.

The alteration of one of the basic abiotic factors of the city ecosystem – the climate, as an effect of the process of city development, leads to a change in the degree of *comfortableness of the climatic conditions for the city population.* As was stated before, air pollution is also a part of the conditions defining the quality of humans in urban areas.

URBAN AIR QUALITY

Urban air quality is important because of the highly urbanized human population. Many urban activities (e.g., traffic, combustion processes, industrial production) are accompanied by emissions into the air, yielding elevated concentrations of pollutants. This is especially significant when a large number of activities are concentrated together, as in an urbanized area and in big towns.

Air pollution at the urban scale is the source of a range of problems: health risks mostly associated with inhalation of gases and particles, accelerated deterioration of building materials, damage to historical monuments and buildings, and damage to vegetation within and near the cities. In order for these problems to become smaller, it is necessary to understand: what characterizes urban air quality; what are the sources of urban air pollutants and the conditions of air pollution levels, and which exposures are associated with the high concentrations of air pollutants occurring in cities.

Air pollution in any region is determined by two major factors – the parameters of the sources of harmful emissions and the meteorological conditions at regional and local scales. These factors determine the possible chemical transformations that could be realized in the atmosphere. The actual occurrence, frequency and level of increased urban air pollution concentrations depends primarily on the magnitude, business hours and space distribution of emission sources, on local topography (e.g., flat terrain, basin or valley) and on local meteorological conditions (e.g., wind characteristics, frequency of calm weather, occurrence of inversion layers).

The fate of air pollutants is determined mainly by the height of release and the prevailing weather. Therefore, the spatial or temporal distribution patterns and effects of air pollution will range from local (up to a few tens of kilometers; time-scale less than one day), through regional (up to a few hundred kilometers; time-scale between a day and a week), to continental and global (up to a few thousand kilometers; time-scale longer than a month). Concentrations of air pollutants will vary greatly with time (daily, weekly and seasonally) and in space. In fact, air pollution at a certain location in an urban area is a result of (a) *the regional background air pollution*; (b) *the urban background air pollution*; and (c) *the local air pollution.*

Regional background pollution is transported over long distances, e.g. from other urban areas or by recirculation in the region. The air pollutants have had time to react with other pollutants or natural components of the atmosphere. It is difficult to estimate this pollution and it depends on climatic conditions. In the northern part of Europe, the dispersion of pollutants is mainly determined by air flow due to the prevailing winds and surface roughness. In the southern parts of Europe the dispersion is highly determined by thermal convection and local wind flow systems. Regional air pollution can be measured at stations outside greater urban areas, typically 25-50 km from the city center or by tracing the air parcels. In fact, at large scales, the dispersion in South Europe, is more complicated due to the complex flow structure. Long residence times may also lead to more complicated chemical processes, which are not easy to describe. In these cases the models for dispersion and chemical reactions need further development and our present knowledge is mostly based on measurements (Palmgren, 1996).

Urban background pollution consist of the regional background pollution plus the air pollution from the urban area. It is a result of the city as a whole and the chemical reactions, which have reached a certain level and have been influenced by solar insolation and other components in the air. This pollution can be measured by a few measurement stations, located far away from local sources, e.g. above the roof tops. The representativeness of such stations for the whole urban area must be documented.

Local air pollution is emitted close to the measurement/exposure location. That is why, it depends much on local sources, e.g., traffic in the street and local dispersion conditions, e.g., the surrounding buildings. Only the fastest chemical reactions are important for the locally emitted pollutants. Its concentrations are mainly determined by the dispersion.

Therefore, urban pollution is the result of a superposition from large scales, regional and local emissions from natural and man-made sources, transported and dispersed by meteorological processes of the same scales, and transformed by chemical reactions in the atmosphere.

Three main types of *air pollution sources* exist in urban areas: large stationary sources with one or a few tall stacks (*point sources*), small stationary sources distributed in an area (*area sources*) and mobile sources, i.e. traffic (*line sources*).

The significance of any pollution depends ultimately on the type of pollutants, the resulting exposure and the health and other effects associated with this exposure. Air Quality Guidelines (AQGs) from the World Health Organization (WHO) have been taken as reference values to assess where ambient concentrations may possibly cause effects on human health and where further studies may be necessary (see, e.g., *Europe's Environment,* 1995).

Pollutants, including noxious substances, in the urban environment may be "primary", i.e. emitted directly from car traffic, domestic heating, industrial or other man-made and natural processes, but may also be "secondary", i.e. the result of chemical reactions (photochemical and non-photochemical) in the atmosphere.

A specific feature of air pollution, especially in cities, is the existence of short-lasting, comparatively high concentrations, called *"episodes"*. They may last from one to several days, and should be discerned from "momentary" peaks of several hours' duration, and from the "background" variability of monthly and seasonal characters. The episodes are connected with a combination of meteorological factors – poor ventilation or, in some cases, unfavorable transport and transformation processes. The episodes are often divided into *"winter episodes" ("sulphuric acid smog epi-*

sodes"), connected mainly with an increase of SO_2, and suspended particulate matter (SPM) concentrations, and *"summer episodes" ("photochemical smog episodes")*, connected with the production of ozone (O_3). Air pollution episodes usually represent local problems and should therefore be studied at an appropriate scale (horizontal resolution of about 1km) (Moussiopoulos, 1996). A requirement for such studies is the availability of a comprehensive emissions inventory including both anthropogenic and biogenic emissions.

Winter episodes occur when low winds and a strong temperature inversion impede the vertical mixing and dilution of pollutants in the lowest atmospheric layers. Low temperatures increase the demand for energy, resulting in increased emissions and the further accumulation of pollutants. During these episodes, emissions related to domestic heating can be up to 70% higher than the winter season average. As well as SO_2 and SPM, the winter smog mixture contains compounds such as carbon monoxide (CO), nitric acid (HNO_3), nitrogen dioxide (NO_2) and aerosol particles of variable content such as soot, sulphate, nitrate, ammonium, metals and organic compounds, such as polycyclic aromatic hydrocarbons (PAH). The concentrations of strong oxidants such as ozone are low during winter smog. Under winter smog conditions, daily average SO_2 concentrations in rural areas can reach 400 $\mu g/m^3$; it may be higher in cities (see *Europe's Environment*, 1995). The most severe smog episode ever reported was in London in December 1952 when SO_2 and SPM daily average concentrations reached values of about 5000 $\mu g/m^3$ each. In the two-week period during and immediately after this smog episode, a total of approximately 4000 excess deaths were observed compared to such period in previous years.

Europe's Environment (1995) announced that in 61 of 87 surveyed cities of Europe, the winter smog concentration of SO_2 and/or SPM exceed Air Quality Guidelines (AQGs) of the WHO. Such excesses occur in general over a large part of the city during periods (days) with poor dispersion conditions. In 24 of the 87 cities (about 28%), concentrations around or higher than twice the AQG have been measured during recent years. Sofia is among these cities.

It is essential to note that the winter smog episodes often extend across several European countries due to long-range transport across the continent.

Photochemical smog episodes occur under conditions of high insolation and low winds, when the concentrations of ozone and photochemical oxidants can build up to high levels which are damaging both to human health and to vegetation. Usually such situations take several hours to develop. Photochemical smog is formed particularly in land basins, and in coastal areas where air pollutants may be contained in a land-sea breeze circulation system as in Barcelona or Athens. However, under high-pressure conditions, ozone concentrations often reach serious levels over much larger areas in Europe and may reach Scandinavia and other more remote areas following transport of ozone and its precursors from the more central source areas. Because of the strong link to particular meteorological situations, the occurrence of "ozone episodes" in Europe is very variable from year to year in both space and time.

The main cause of photochemical oxidant and ozone formation are the emissions of NO_x ($NO+NO_2$) and VOCs (Volatile Organic Compounds) from motor vehicles, which are densely concentrated in city areas as well as from industry (in particular, combustion of fossil fuels, solvent use and evaporation losses). VOCs present in the air from anthropogenic and natural emissions are oxidized in the atmosphere in the presence of sunlight. The process generally starts through reaction with the very reactive hydroxyl (OH) radical, by reaction with ozone or by direct action of sunlight. The oxidation processes are complex, and NO_x play an important role as necessary catalysts. A host of secondary products is formed during this oxidation; they are usually called *photo-oxidants*. Ozone is by far the most important of these in terms of the adverse effects it has on human health and ecosystems. Several international bodies such as WHO, UNECE (UN Economic Commission for Europe) and EC (European Community) proposed, or set guideline values for ozone for the protection of human health and/or vegetation. These guideline values indicate levels combined with exposure times during which no adverse effects are currently expected. For example, the 150 $\mu g/m^3$ hourly concentration level and 100 $\mu g/m^3$ for 8 hours are proposed for the protection of human health (for ozone, 1 ppb ≈ 2 $\mu g/m^3$). Bulgarian guideline values for ozone are: 110 $\mu g/m^3$ – average value for 8 hours – for human health protection and 200 $\mu g/m^3$ (hourly averaged) – for the protection of vegetation. The hourly averaged values of 180 and 360 $\mu g/m^3$ are the guidelines for information or alert for the inhabitants, respectively (see Regulation No 8, 1999). Progress in scientific understanding may lead to revision of these guideline values.

The photochemical smog episodes are not only a local scale phenomenon. Oxidation takes place at time-scales ranging from a few hours to several months. During this period, the polluted air is transfered due to long-range transport. This is why the influence of these episodes on air quality and deposition of pollutants can extend over hundreds or several thousands of kilometers, i.e. they are as well a regional or continental scale phenomenon.

The term *"hot spot" pollution* may be used to describe the high short-time pollution concentrations to which the population may be exposed when located close to pollution sources. "Hot spot" pollution includes urban streets with busy car traffic, and the pollution impact from industrial stacks in cities. In all European cities, smog occurrences and long-term average concentrations of harmful compounds such as lead, benzene, SPM and benzo(a)pyrene (BaP) receive a significant contribution from emissions from road transport. Benzene and BaP are indicators of organic compounds associated with volatile organic hydrocarbons and with soot and PAHs from small-scale combustion processes, respectively. Road transport contributes, on average, more than half to the nitrogen oxides and about 35% of the VOC emissions in Europe.

While NO_x emissions from stationary sources have decreased in many urban areas, emissions from motor vehicles have increased because of the growth in the number of vehicles, and the distances traveled per vehicle have been much larger than the reduction of emissions. Since the lifetime of vehicles is typically more than 10 years and in some countries as Bulgaria more than 10-15 years, reductions of emissions will be slow even if vehicle numbers and distances traveled size decrease. More rapid improvements in air quality in the short term can only be achieved by limitations on road transport in urban areas.

In some cities, air pollution from road transport and domestic heating is supplemented by that from local industry. The impacted area is usually a few kilometers from the emission sources, depending on the height of the stacks and the prevailing wind directions. In many cities, monitoring stations are operated in areas where principal industries are expected to have a large impact. In many cities, these "hot spot" stations indicate a significant impact from industrial emissions, i.e., air concentrations of SO_2 and/or PM are considerably higher than in the city center. Such distributions of pollutant concentrations is often observed in some industrial zones of Sofia. Most of the primary pollutants from cars, domestic heating and some industrial sources are emitted and transformed by the chemical reactions at ground level where severe pollution levels might be found. This is why, *for the preservation of a favorable air quality in urban areas, anthropogenic emissions must be controlled.*

Successful measures for reducing air pollution in cities over the past 30 to 40 years have included the regulation of fuel for domestic heating (low sulphur content in oil and coal, introduction of natural gas instead of coal and oil), development of district heating, reduced lead content in petrol and restriction on the use of cars in the city centers. Furthermore, dust removal from industrial sources and large boilers has resulted in major improvements. These measures have been particularly successful in reducing SO_2 particles and lead emissions, and hence daily and annual average urban atmospheric concentrations, by significant amounts in many cities. However, there has been little or no evidence of similar downward trends in NO_x concentrations. During smog conditions, emergency actions are taken by some cities (e.g., Rome, Milan, Athens, Prague) involving, for example, restrictions on car traffic and fuel substitution in power plants/ industries. Cost-effective energy conservation measures and substitution of fossil fuels with renewable energy resources have a large potential for reduction of emissions.

As a result of such simple premises, urban air pollution management requires knowledge of the parameters related to four important aspects: a) *air quality monitoring network,* which provides measurements and data relevant to several pollutants, their occurrence in time, their spatial distribution and, eventually, episodes exceeding the quality standards; b) *meteorological data* not only from the surface but also from boundary layer measurements in the meteorological network; c) *emission inventories,* which provide information on the emitting source and their temporal evolution; d) *numerical models,* which provide information on the prediction of air quality from emission and meteorological data.

These components are interrelated – monitoring data are used to validate models; meteorological and inventory data are used as input for models, which are able to provide numerical prediction. The expected meteorological situation and results from the model application and inventory data might suggest the formulation of proper control strategies. This is the most important problem for air pollution management.

Air quality and the state of the atmosphere are usually fixed through corresponding *systems for air quality monitoring and for meteorological measurements*. They have the most essential module - the air quality monitoring and meteorological networks, which are made up of many measuring stations. One of the main purposes of these systems is to produce information for understanding the basic processes, which are responsible for atmospheric pollution and to take measures required for reducing the risk for health and the environment from air pollution. The air quality monitoring stations are composed of many chemical and physical-chemical sensors, which provide the concentration of selected compounds. Unfortunately, only a few parameters can be measured automatically and, if a complete picture of atmospheric processes is needed, manual chemical procedures must be employed. These are required for inorganic as well as organic components. Two kinds of permanent networks and systems for air quality monitoring are used in dependence on the necessity to take either long-term or short-term measures for reducing the risk from pollution. They are : *networks (systems) for general monitoring of air quality*, and *air pollution informative-warning systems (networks).* General monitoring systems are considered the basic systems in urban areas. Manual measurements of 24-hour concentrations, with samples taken on a site and then analyzed in a laboratory, still predominate in countries of Central and Eastern Europe. Data produced in the system are used for long-term environmental programs; for assessment of the effectiveness of a long-term policy, of the air pollution level in connection with the national ambient air quality standards, of the trends and validation of mathematical models; for documentation of population exposure to air pollution; for town and country planning; for scientific investigations etc. The stations of the urban general monitoring systems are located in inhabited areas, where the expected long-term concentrations of a particular pollutant are higher than in other areas of the town as well as, where concentrations of a particular pollutant may be treated as average for densely populated parts of the town. These stations can also provide feedback for many other specific purposes.

The informative-warning systems are also of two kinds – *warning systems,* based on air-pollution forecast, which, in most cases are for information only, and *alarm systems,* based on actual measured concentration values, which are connected with enforcement of compulsory preventive actions. In the case of alarms, the responsibility of an informative system is higher, because the operation of emergency emission-reduction system is expensive and may be troublesome for citizens (e.g., traffic limitations). The informative-warning systems collect data in real time by means of continuous monitors. The main task of these systems is to provide data for short-term pollution abatement procedures. They should be established only in densely populated areas with frequent occurrence of high concentrations of pollutants caused by different sources and especially from a particular industrial plant or from distant plants as well as from traffic. The meteorological data, necessary for the functioning of the informative-warning systems, are received through meteorological observations either at the same point where air pollution is measured, or at the nearby meteorological station. During field experiments these two types of data – for the concentrations of pollutants and atmosphere physical parameters, are most frequently conducted simultaneously at the same points.

It can be noted that during episodes extraordinary measures can be applied to protect the population. There are two kinds: *active measures* – emergency reduction of local emissions, and *passive measures* for a reduction of health hazards.

The procedures for the realization of *emission inventories* are well established. But the assessment of the emissions, due to the trans-boundary transport of pollutants, represents not only a national, but also an international problem. This fact necessitates the establishment of an inventory not only of pollution sources in separate plants, but also *integrated inventories* of emissions for a certain city, area, country, region and even a continent. The first inventory system of this type in Europe was established in the 1980s and was called CORIN (CO-oRdination of INformation on the environment), and one of its projects focused on air, and was called CORINAIR. In the inventory procedure, conducted in 1990, around 250 activities and 8 pollutants were covered for Europe in accordance with the development of continental modelling within the EMEP programme (Cooperative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe). The inventory methods were improved in 1995 – CORINAIR'95.

Another set of methods of wide international use is the IPCC/OECD (Intergovernmental Panel of Climate Change/Organization for Economic Cooperation and Development). It is related to the inventorying of basic "greenhouse gasses" and also to the assessments of gasses influencing stratospheric ozone.

The processes that determine the distribution of gas pollutants in air and that must be considered in the *atmospheric dispersion models* are: advection and convection (horizontal and vertical transport); diffusion on the three directions in space; dry deposition in the moment of contact of pollutants with the earth surface; the washing off of pollutants by precipitation (wet deposition); chemical transformations and/or radioactive decay. When having pollutants, carried by aerosol particles, one must additionally include the processes of gravitational sedimentation and transformation of particles. These depend on the spectrum of particle sizes that itself changes in time as a result of interactions among particles in a gas or liquid environment (processes of decay or coagulation). These processes, as well as the chemical transformations, develop differently in the dry atmosphere, in a cloud environment and in precipitation. Adding that because of chemical transformations some gasses transform into aerosol particles and vice versa we can obtain a notion of the complexity of the distribution of air pollutants.

Each of the latter processes can be described mathematically with a different degree of complexity and with different time and space characteristics (scale and resolution). It is obvious that with such a number of processes in a continuous medium like the atmosphere, the only way to describe them is through numerical modelling. In the international literature there is a large number of numerical dispersion models with different purposes and degrees of complexity. The different models can describe the distribution of one or many pollutant, emitted in the atmosphere by different types of sources at various time and space scales.

In accordance with the approach for the description of dynamic processes, the models can be separated generally into 4 classes: *Gaussian plume models; Lagrangian-Eulerian cloud models (puff models); Eulerian models; Lagrangian particle models (Monte-Carlo models).*

Plume models are the simplest and historically the first models, based on many simplifications of the dispersion processes. They describe the distribution of a weightless gas from a continuous point source in an environment of constant wind speed (stationary conditions). The result of this idealized setting is the formation of a plume that widens while drifting away from the source under the influence of air turbulence. The distribution of the pollutant concentrations in the plume follows a Gaussian process. During the development of studies and increased requirements of practice, the Gaussian models have experienced a considerable evolution, a result also of the gathering of much experimental material. First, the improvements encompass the means of reading the intensity of the turbulence, which is a result of the atmospheric boundary layer stability. The most utilized description is through the Pasquil classes where, on the basis of ground measurements of different air characteristics, a gradation of the turbulence intensity is entered, and from there – a gradation of the different parameters of the model as well. At first, this affects the values of the dispersion coefficients in the Gaussian formula – a quicker or slower widening of the plume depending on stability. Other parameters of the model also depend on the Pasquil classes such as the wind profile with altitude, the degree of the plume meandering, etc. Some considerable improvements of this type of models were achieved with the implementation of the so-called plume-rise, i.e., the elevation of the plume axis over the earth surface as a result of overheating and the forced speed of emission of the pollutants in the stack. Other improvements allowed the application of the Gaussian model with line, area and volume sources, for descriptions of aerosol pollutants or the flows around the buildings. An adequate parameterization of dry and wet deposition rendered the possibility to calculate, apart from concentration, the deposition of the pollutants on the earth surface. These type of models are widely applied in modelling the distribution of air pollutants in urbanized areas. These models are also used for regulatory purposes, as, for instance, determining the suitable height of stacks of new-built plants and assessment of the impact of existing and future sources on the environment. In the latter, case series of hourly meteorological measurements for a long period of time are used for meteorological input of models, as well as climatic characteristics of the area like the complex rise of wind (direction-speed-stability class). In spite of their considerable improvements, Gaussian models have essential limitations. The greatest one is that they can only be applied to limited areas of up to 30 km of homogeneous surfaces, and for time scales not greater than 1 hour, for which it can be assumed that no substantial changes in the wind field occur and the model can only operate with a single wind value.

The puff models are similar to the Gaussian models, but here the limitation for stationary and homogeneity of the wind field no longer exist. Therefore these models can be applied at various time and space scales. The emissions from sources with a single action in this type of models are approximated with a puff of polluted air that is caught and carried by the air flow while simultaneously the puff widens under the influence of air diffusion. The continuous sources are approximated with a series of puffs emitted at some time intervals. It is accepted that there is Gaussian distribution of the substance in the puffs. As long as the diffusion equation is linear, the principle of superposition allows for the calculation of the total field of concentration by a summation of the pollution fields created by the separate puffs. The principle of superposition allows for the description of pollutants at which linear transformations occur. Examples include simple schemes for sulphur and nitrogen. More complex schemes such as photo-oxydation are generally not linear and cannot be used in puff models. The puff models are most suitable for a small number of point sources and especially for a single point source as is approximated, for example, a nuclear accident.

Eulerian models are based on the Euler approach for describing hydrodynamic fields. Here the observer is positioned at a fixed point in the fluid and the alteration of the characteristics at this point is a result of the passage of all new particles, carrying different characteristics. In the Eulerian models the half-empirical advection-diffusion equation is solved (see e.g. Berlyand, 1985). The space within these models is discrete and that is why the input information and the calculated characteristics are related to these points, i.e. these are values characteristic for the cells around each point. Due to this, the resolution capacity is an essential characteristic of the models and of the input information. The processes with a smaller scale than the step of the network are parameterized by expressing their characteristics through the parameters of the processes having scales encompassed by the model, i.e. with scales larger or equal to the step.

Different numerical schemes can be used in modelling the separate terms in the advection-diffusion equation and that determines the variety of models, not only according to the type of pollutants and the task scale, but also the memory and calculation rate of the present equipment, the capacity of the interface for feed-up with information, etc.

The Eulerian models are the most developed means for dispersion calculations (see Syrakov & Ganev, 1994; Syrakov, 1997). These are the most complex existing models, due to their capacity to accommodate complex, not-linear chemical schemes with around 100-200 air pollutants. Due to the great number of points in the model network, the number of network values can reach a few million. This places high demands for computer memory and calculation rate. This is why Eulerian models are implemented on the most powerful supercomputers with vector and parallel calculation. These are usually coupled with the most complex global and regional atmospheric models providing the necessary input information for the fields of the meteorological elements.

Lagrangian models developed more recently. The name comes from another approach for describing hydrodynamic quantities – the Lagrangian. Here the observer is positioned in a fixed fluid particle and moving with it, he follows the alteration of its characteristics. The Lagrangian models describe most directly the transport and diffusion in the atmosphere. The pollution source emits a great number of particles and each one is observed. For one step in time the particle is moving in accordance with the values of the wind components in the point where it is situated. Along with this, some shifting is necessary as a result of turbulent diffusion. Shifting is calculated from three coordinates and its value is determined using a random numbers generator (the Monte Carlo method). Maximum shifting depends on the turbulent characteristics of the atmosphere, the stability of layers, etc. Thus, each particle, apart from moving in the flow, receives pushing away and in result the group (ensemble) of particles forms a constantly widening puff. The Lagrangian models are suitable for calculating the distribution of emissions by single momentary sources, but require great memory and calculation rates. Still, great difficulties exist in describing the other processes such as chemical transformations, dry and wet deposition, etc. Nevertheless, due to the direct approach for describing the two most important processes, these models are actively developed and used.

Recently, *air pollution models* have reached a sufficient degree of accuracy. The simulation of dispersion of pollutants over urban areas is the best performed using meso-scale models. Dispersion modeling in the canopy layer is of primary importance for human life and activity. The structure and stratification (dynamic and thermal) of the air flows over cities are important for any kind of model for the dispersion of pollutants over this area. The simplest approach in the simulation of dispersion over meso-scale urban areas, is that flow over an urban area is similar to the flow over a "normal" rough surface, with a given, large roughness length z_o and a defined surface heat flux. Assuming that the city is large enough to ensure a locally "sufficient" horizontal homogeneity, the Monin-Obukhov's similarity theory can be apply to meso-scale dispersion calculations (see Mestayer & Anquetin, 1995), although their applicability to cities seems highly questionable. Then the Monin-Obukhov parameters can be defined in the usual way and flow structure can be characterized by the surface stress ru_*^2, and sensible (H_s) and latent (LE) heat fluxes. Due to the great height of the roughness elements, it is needed to introduce a *zero-plane displacement height d* in the parameterization of the mean wind profile. z_o and d can be either computed from measured profiles of $U(z)$ or deduced from empirical relationships, relating these variables to the density and geometric characteristics of the roughness elements (buildings, trees etc.). These calculations can be of value when the details of the ground structure cannot greatly influence transport and diffusion, as e.g. buoyant plumes emitted from outside the city and transported high above ground level in convective meteorological conditions.

The most recent investigations of flow and dispersion in urban and industrial areas are represented in the handbook of Hanna *et al.* (2001), which is summarized in the paper of Hanna and Britter (2001). A review of the literature was carried out, which led to the recommendation of a hierarchy of methods for estimating the parameters z_o (a roughness length), and *d* (a zero-plane displacement height) that are introduced in the parameterization of the mean wind profile. The simplest methods, based on land-use classes, lead to estimates of z_o of about 1 m and *d* of about 5 m in urban and industrial areas. More accurate estimates of z_o and *d* have been suggested by many researchers, based on parameterizations involving the height of the roughness obstacles, H_r, and measures of their spacing, λ_f (λ_f=obstacle frontal area/obstacle lot area). H_r and λ_f can be estimated based on experience of certain well-known urban and industrial land-use types (Grimmond and Oke, 1999), or can be calculated in detail using data on actual building shapes and sizes in an area. According to Hanna and Britter (2001), the average building or obstacle height, H_r is about 10 m and the values of the obstacle densities, λ_f are between 0,1 and 0,3. The methods for determining z_o and *d* at different values of H_r and λ_f, as well as formulas for their calculation are presented in Hanna and Britter (2001). Given the estimates of z_o/H_r and d/H_r using these methods and assuming neutral conditions, the friction velocity can be estimated from a wind speed observation or estimate, *u,* at some height, *z,* which is above H_r:

$$u^* = 0,4 \; \frac{u(z)}{\ln \frac{(z-d)}{z_0}}) \qquad (8)$$

Hanna *et al.* (2001) show that within the urban or industrial site, the wind speed, u_c, below the obstacle heights, H_r, is given by:

$$u_c/u^*=(z_o/2\,H_r)^{-1/2} \quad \text{or} \quad (\lambda_f)^{-1/2} \qquad (9)$$

The log-linear wind equation (1) is assumed to apply down to a height, z_{int}, such that $u(z_{int})=u_c$.

The turbulent velocities in urban or industrial regions are given by the following relations at all heights, above and below H_r (Roth, 2000):

$$\sigma_u/u^*=2,4, \quad \sigma_v/u^*=1,9, \quad \sigma_w/u^*=1,3 \qquad (10)$$

Given z_o, *d,* H_r and l_f and using standard Monin-Obukhov similarity theory it is possible to express wind and turbulence profiles as a function of height, for elevations near the ground well bellow H_r to elevations at 10 or more times H_r. These fundamental boundary layer formulas are valid over a very rough surface, as long as H_r is less than the surface boundary layer height (about 50 to 100 m). The friction velocity, u^*, is a key scaling parameter for all boundary layer phenomena. The effects of roughness on stability (as measured by Monin-Obukhov length, *L*) can be estimated, using the fact that an increase in u^* over a rough surface can lead to much larger *L* (due to the dependence of *L* on u^{*3}).

Transport and dispersion models for air pollutants can typically be run in the hypothetical or "what-if" mode, or in the real-time or retrospective mode. In the first mode, the worst-case conditions may be arbitrarily chosen as light winds and stable conditions. But in the second mode, where observations must be used, the available observations are usually not from the best location.

Hanna and Britter (2001) argue that the wind speed at a height of 30 m, say, will be similar at the site of interest (with z_{02}) and at a flat measuring station nearby. Then

$$U_2\ (10m)=u_1(30m).ln(10m/z_{02})/ln(30m/z_{02}) \qquad (11)$$

Because of the increased mechanical turbulence over an urban or industrial site, at any given time the stability is closer to neutral than the stability over the airport or other nearby flat site. This is because the increase in z_0 over the rough site causes increases in u^*. And since the stability parameters such as L depend on u^{*3}, a two-time increase in u^* results in an eight-time increase in L.

A less simplistic approach considers the atmospheric flow transformation due to the internal boundary layer (IBL) in development along the wind direction as 2-D models (Figs. 1 and 2) as well as in formula (4), where several empirical parameterizations of the IBL depth z_{IBL} as a function of the fetch x are shown. Melas & Kambezidis (1992), reviewing some recent models of the thermal internal boundary layer (TIBL), divide them in 3 categories: (a) *empirical models* of the form $z_{IBL}=a.x^b$; (b) *similarity models* where the growth of the TIBL is parameterized by analogy with the spread of a smoke plume from a ground-level source (an analogy quite valid in the case of near-neutrality for a very weak transition in roughness and surface heat flux, based on the equality of the diffusivities for momentum and matter); (c) *slab models* assuming that the TIBL is composed of a mixed layer, where the vertical profiles are uniform, bordered by thin layers, surface layer at the bottom, and entrainment layer at the top. In these assumed thin layers, the temperature gradients are forced to match the ground temperature and the unperturbed temperature profile above the TIBL top, identical to the profile upstream of the transition (Fig. 4). Melas

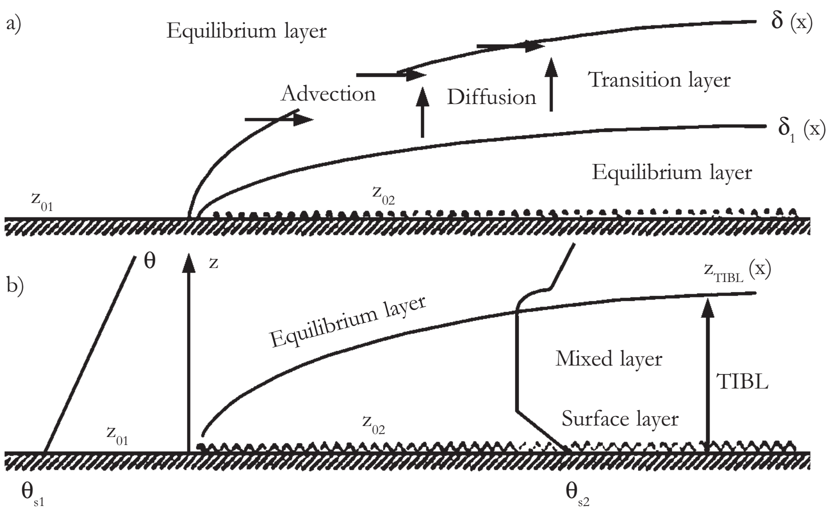

Figure 4. Schematic representation (adapted by Mestayer & Anquetin, 1995) of the development of an internal boundary layer at a transition to a rougher surface ($z_{02}> z_{01}$): (a) after Hunt & Simpson (1982) and Folcher (1989) (in the case when $z_{02}< z_{01}$, the diffusion is downwards in the transition layer); (b) after Melas and Kambezidis (1992).

& Kambezidis (1992) have noted that the "slab" models as those of Gryning & Batchvarova (1990), which are of higher complexity, present good agreements, at the mesoscale, with the experimental data over the Athenian urban coastal area, when the meteorological conditions are close to neutrality and the fetch is large. Mestayer & Anquetin (1995) showed that none of these models are able to correctly represent the structure of the flow altogether at short and long fetches (the slab models are better for long fetches, mesoscale dispersion, while similarity models are well adapted to short fetches, small scale dispersion) and to represent the structure of the lowest layers of the urban areas (just over the roofs). Experimental data obtained inside large cities show that the vertical structure of the low atmosphere is more complex than that in Fig. 4. As is seen in Fig. 5, there is a perturbed layer over the canopy layer where Monin-Obukhov surface layer similarity theory does not hold.

Below the roof top height, the urban canopy layer is characterized by flow recirculations and radiative trappings. Just above the roofs, the flow is close to horizontal on average but highly perturbed by individual building wakes and heat flux variations. Above this transition layer, if the city fabric is not too heterogeneous, the atmosphere eventually "feels" the lowest layers as a rough warm terrain; its structure can resemble that of a surface layer at (local) inertial equilibrium, and it can be characterized by locally-defined Monin-Obukhov similarity parameters. This "local surface layer" can be capped by a "mixed layer" that actually is itself a growing TIBL. Simulations of mesoscale dispersions of pollutants generated inside the canopy and diffused up- and out-wards, or of those coming from the city outskirts and eventually penetrating the canopy down to the pedestrian level, must take into account this multiple layer structure of the urban lower atmosphere that is largely dependent on the structure of the canopy elements.

The basic elements of the urban canopy are the isolated or in-group buildings and the street-canyons. The geometry of the buildings, their orientation and angles, the properties of their surfaces, their albedo and emissivity, the shadowing effects and the reduction of the optical aperture to the

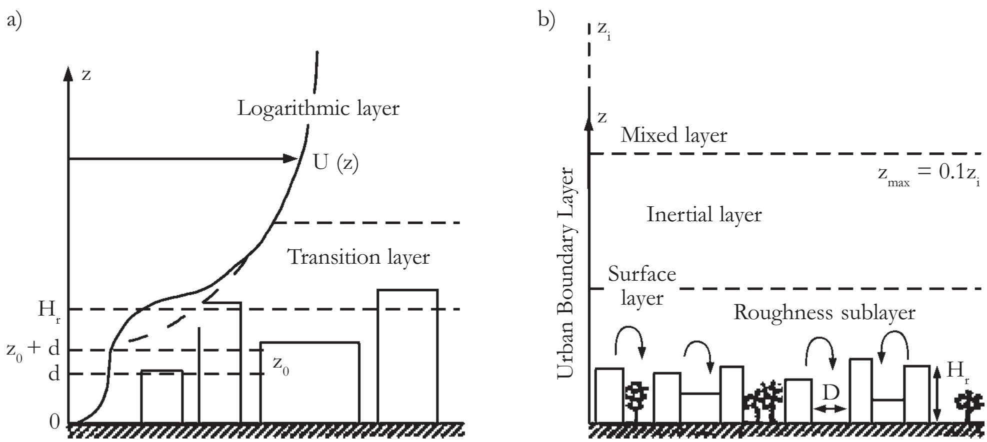

Figure 5. Schematic representations of the urban boundary layer presented by two groups of authors, pointed at Mestayer & Anquetin (1995), which have adapted these schemes, too.

sky are the physical factors intervening in the radiative budget and significantly modify the energy budget. In addition to a very large number of isolated experiments, a large part of our knowledge comes from the continuous series of studies and numerical simulations of the groups of the University of British Columbia (see, e.g., Nunez and Oke, 1976; Oke, 1973 to 1988) and the University of California, Los Angeles (e.g., Todhunter & Terjung, 1988). The former used mainly an empirical and experimental approach that allowed to obtain most of the basic knowledge into the processes taking place in real streets, but are difficult to extrapolate to other sites and to build quantitative predictions. The second group essentially used and developed numerical models to realize series of numerical experiments and process studies in order to assess the influence of the different climatic and anthropogenic parameters of importance in the energy budget.

The North-South orientation of streets improves the maximum radiative heating of the ground at mid-day. The maximum net radiative imbalance, with a clear dry atmosphere, is on the order of 400 W/m^2 at noon. About 60% of the energy is then transformed into sensible heat in the air and 30% is stored in the canyon materials; the remaining 10% are either stored in the ground materials or used for evaporation. Oke (1988) shows that the effective albedo is a function of the solar elevation angle and the canyon geometry. He expressed this dependence by means of a sky view factor that is a function of the height-to-width ratio H_i/W where H_i are the building heights and W the street width. An essential issue in the prediction of the energy budget is the effect of the multiple reflections of the incident radiations over several surfaces of the canyon (radiative trap). It goes from a billiard 3-band looking trajectory in the case of moderately high buildings to a very large number of successive reflections in the case of arrays of elevated mirror towers (see Mestayer & Anquetin, 1995). The radiative trap, that is a major cause of heat storage, can also be seen as a reduction factor of the effective albedo. It can be summarized that the present knowledge of the process' interactions is insufficient (Todhunter & Terjung, 1988).

There are three aspects of *the dispersion of pollutants inside the canopy layer:* dynamic, thermal and chemical. Most of the knowledge of the in-canopy dispersion comes from simulations in aerodynamic tunnels, essentially in isothermal conditions, very few dynamic measurements on site, and a handful of neutral tracer dispersion experiments at small scales in the atmosphere (see, e.g., Mestayer & Anquetin, 1995; Hunter *et al.*, 1992; Oke, 1988). Essentially, two types of canopy flows have been simulated in wind tunnels: flows around and behind isolated buildings, and in groups of buildings. Real size measurements of flows in streets are rare. Examples include the Lagrangian balloon experiments of DePaul & Sheih (1986) in a long street of Chicago, USA; Nakamura & Oke's (1988) measurements in one cross-section of a street in Kyoto, Japan as well as such a cross-section of Baranger (1984) in Nantes, France and measurements at the canopy-atmosphere interface in Zurich of Rotach (1991). More details on the aerodynamic effects of urban structure can be found in Mestayer & Anquetin (1995).

In the 1980's, there were few models specifically developed for simulating contaminant dispersion within the urban canopy. Only some of these took into account the effects of a building's wake on the dispersion of a plume, by extending the Gaussian plume approach or by simulating the building wake by a secondary source of contaminants. More references can be found in the controversial article of Ramsdell (1990) and the subsequent discussion of Briggs *et al.* (1992). It must be noted that these studies have been performed mainly in near neutral conditions, with little or no thermal influence on the flow. The numerical simulations realized by the group in Nantes, France (see Mestayer & Anquetin, 1995) clearly demonstrated that temperatures of the street walls and the ground largely influence the in-street flow structures and velocities, and the dispersion of the contaminants. Many of the concepts that are now considered as "standards" must certainly be revisited by combining radiative, thermal and dynamic simulations. New on-site experiments with a large concentration of sensors allowing extremely detailed documentation of flows and climate in typical canopy geometries are necessary to validate the available mathematical models.

Present-day dispersion models in urban and industrial areas are divided by Hanna *et al.* (2001) into the following 5 groups (H_r – height of the roughness obstacles):

1) Dispersion models for clouds extending above H_r. These models often require flow parameters such as z_0, d and u^*. For passive releases at any height, Hanna *et al.* (2001) suggested the Gaussian model for concentration in terms of the dispersion coefficients, which are expressed in terms of u^* and (in the far-field) the integral time scale T_t.

2) *Dispersion models for clouds released above or near* H_r. These models are similar of the previous models. The implication of this choice is that the flow in which the release is dispersing is determined by the underlying roughness. This will be a less valid assumption for releases well above H_r and when the release is close to the upwind edge of the roughness but this would be an unlikely situation. This statement holds for passive and light gas releases. It is likely to hold for heavy gas releases until the cloud trajectory descends well inside the roughness obstacles.

3) Dispersion models for clouds below H_r. There is evidence that a Gaussian model is appropriate for this case, but there are no widely-used operational models for this scenario. They require specification of a characteristic velocity, u_c, and correlations for the dispersion coefficients. For a continuous plume, the concentrations initially decrease with increasing roughness but eventually become constant and then may increase for very high roughness. For puffs, the correlations predict a monotonic decrease in concentration with increasing roughness. These statements are applicable for passive and light gas releases. For heavy gas releases, a modification would be required to existing operational models; the principal modification being the modification to the velocity profile within the roughness.

4) Dispersion models for clouds at a downwind of the roughness. These models only account for the effects of roughness downwind of the source. Thus the roughness to be considered is an average of the roughness between source and receptor. This approach may lead to concentration over-prediction close to the source for the situation where the source is near the downwind edge of the roughness.

5) Dispersion models for clouds released upwind of the roughness and traveling into and through the roughness. This approach considers the roughness between source and receptor, and by implication uses an advection velocity determined by this roughness. This is a very simplistic model of the complex flow as the atmospheric boundary layer impinges upon a finite area of increased roughness.

Urban planners, local decision-makers and city leaders, as well as responsible officials of the environment, need more complicated data to understand the results of their polices, especially concerning traffic management, to assess the actual air quality with regard to secondary pollutants, to finely predict all-type impacts of new chemical sources, as well as to foresee the effects of new regulations. The need for estimations of secondary pollutant concentrations is especially demanding, since they depend on mixing and reactive processes: this implies a simultaneous knowledge of chemical kinetics and of transport-dispersion behaviour of primary and intermediate compounds.

Recent research at the canopy scale aiming at more general descriptions of urban climatology are developed towards three main directions (Mestayer & Anquetin, 1995): (a) The combination of local on-site measurements with numerical simulations of the radiative heat budget allows to further develop comprehensive urban radiative models and operational codes; (b) the intensive use of 3-D computational fluid dynamic numerical codes with high resolution and a complete turbulence model, allows systematic studies of in-canopy flows and canopy-atmosphere exchanges as a function of building geometries and surface temperatures; (c) the development of street air quality models, that were originally of a box-type with primary pollutants, include now geometrical features of streets and of several chemical reactions to predict secondary pollutants. These three approaches are merged into the recent dispersion models.

A very important fact in recent years is that co-ordinated efforts have been undertaken within the European framework to use and/or adapt mesoscale meteorological codes to the study of the urban climate as, e.g., the Athenian Photochemical Smog Intercomparison of Simulations (APSIS). It was shown that several mesoscale models can predict correctly the air flows at the regional scale but that practically none can detail the flows just above roof level responsible for pollutant dispersion in the complex area of Athens, an urban, coastal, hilly and mountainous site. Furthermore, serious tests of the models, especially those combining dynamics and photo-chemistry are required to organize experiments with extensive documentation of micro-meteorology, emission inventory and compound monitoring.

Another important development of meso-scale studies is the comprehensive use of satellite observations to analyze the city fabrics and land uses over entire urban areas. The combinations of several channels of the same satellite (Lee, 1993) or of different instruments as, e.g., NOAA's AVHRR, Landsat and SPOT visible and IR channels allows detailed analysis of the apparent ground temperature, albedo, reflectance and heat emission. Pixel sizes can be as small as 20 m (SPOT) and multiple image processing could even provide final resolutions smaller than 10 m. Similar airborne radiative measurements can also be of importance for calibration purposes and finer scale analysis (Takamura, 1992).

In conclusion, concerning pollutant dispersion at the mesoscale, it must be noted that the Hybrid Plume Dispersion Model (HPDM) is an interesting attempt at solving the problems because it takes into account urban land use categories and their distribution along the wind path as in Fig. 2a (Hanna & Chang, 1992). Such an urban operational dispersion system (LOSTRAC) is being constructed in co-operation by French and Danish institutions (see Mestayer & Anquetin, 1995). Furthermore, reliable parameterizations of the roughnesses of urban gorund and of heat fluxes do not exists, and of the transformation of the orographic effects by constructions such as, e.g., downslope "street winds" and "quartier breezes" (Fig. 2b).

Concerning *urban sub-mesoscale research*, it appears that the multiplication of measurements will not suffice to assess and to predict flow structure, dispersion processes and air quality or pollutant contents, and their impacts, because of the large structural, temporal and spatial variability of the urban lower atmosphere. The improvement of our knowledge on the combined physics and photochemistry of the urban atmosphere calls for the development of a new generation of numerical simulation codes. Indeed, partial simulations of the radiative, thermal and dynamic processes taking place within the urban canopy are still essential, but the assessment of photo-chemical compound behaviours require combined simulations, including fast photo-chemical reactions. More impact studies at the scale of the urban area itself require sub-mesoscale models able to simulate the dynamics and the physics altogether over the whole atmospheric boundary layer height and a meso-γ scale, and at the decametric scales of the local convective movements in the lower layers. These processes are responsible for the pollutant mixings and the chemical interactions between compounds generated by sources as different as industrial stacks, intense or dispersed traffics, individual heating or remote "background pollution". Not only the detailed prediction, but also the real time control of the air quality demand the development of these complex numerical models to understand the relations between the physical-geographical conditions, the regional meteorology, the local pollutant sources and the monitoring measurements.

The development of sub-meso models will allow us to study the interactions of the city fabrics and urban sources of heat and pollutants with the surrounding orography. This is of special importance for cities located in valleys or valley systems, where the urban radiative budget interacts with the along-valley and katabatic cross-valley winds; this can produce extreme pollutant traps. This model development is possible only if the structure of the flow in the intermediate layer just above the roofs is better understood (Fig. 5). In sub-meso models, the urban canopy structure is usually replaced by a "terrain", composed of a patchwork of homogeneous parts of a city, sometimes named "quartiers", for which specific 'wall laws' are defined. These laws are more complicated than the usual roughness length laws based on relations (formula 8) from the previous text. New parameterizations are also needed to improve operational models; they include not only drag and thermal fluxes but also the ability of the canopy to exchange matter with the atmosphere downwards and upwards. Also, they will not depend exclusively on the average structure of the quartier but as well as on its position with respect to the distribution of quartiers and wind direction. In the modeling activity, the *aerodynamic quartier* is often defined as a part of a city that has homogeneous features for numerical flow and dispersion simulations. To develop and assess these parameterizations, three types of research are urgently needed, preferably in co-ordination: (a) numerical simulations of the development of multiple three-dimensional boundary layers over patchy terrains; (b) numerical simulations of the vertical exchanges in the interfacial layers between canopy and atmosphere, combining dynamic and thermodynamic models in homogeneous quartiers; (c) on-site experiments, documenting with great detail, at the same time, the flows at street level and the flows in the atmospheric layers from the roof level to the inversion height.

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Air Quality of Sofia City – Meteorological Aspects

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Summary

The main factors and terms forming and defining air pollution are introduced. Urban air pollution management requires knowledge related to four important aspects: air quality monitoring network; meteorological data; emission inventories and numerical models. The main purposes, uses and requirements for the two kinds of air quality monitoring systems (an informative-warning and for general monitoring) are described and four dispersion model classes are examined. On the basis of mainly Bulgarian studies, results on the following questions on air pollution of Sofia are presented: the pollution potential of Sofia; lidar measurement results; an influence of the atmospheric parameters on surface air pollution; an air pollution distribution over the town territory; regionalization of Sofia according to air pollution levels; periodic fluctuations of air pollutant contents; space-time statistical structure of town air pollution fields; wind field deformations over complex relief areas; the influence of Sofia on air pollution of downwind areas; local scale air pollution modeling by the EPA Plume model, meteorological meso-scale and Eulerian dispersion models; a synoptical-statistical method for the air pollution level prognosis; and the chemical composition of precipitation in the town.

Key words

Air quality, monitoring network, meteorological data, emission inventories meteorological and dispersion models, lidar measurements, space-time statistical structure, synoptic-statistical prognosis method, Sofia, Bulgaria.

INTRODUCTION

Air quality in a region is determined by two main factors - the sources of harmful emissions and the meteorological conditions at regional and local scales. These factors determine chemical transformations in the atmosphere. Air quality of the city of Sofia is worsened as a result of

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 83-127

mutual actions of these two major factors. One reason is the location of the city in a mountain valley. This is because meteorological conditions during a considerable part of the year are mainly characterized by calm weather and temperature inversions, which can be very intensive during winter. Another factor is the presence of many and various types and capacity sources of air pollutants since the city is a big residential and industrial centre.

Contemporary knowledge of urban climate and air pollution are reviewed in the article "Urban climate and air quality – a review" by V. Andreev (this volume). The main findings are shortly represented here.

Air pollution at an urban scale is the source of a range of problems: health risks mostly associated with inhalation of gases and particles, accelerated deterioration of building materials, damage to historical monuments and buildings, and damage to vegetation within and near the cities. In order to tackle these problems it is necessary to understand: what characterizes urban air quality; what are the sources of urban air pollutants; and which exposures and conditions are associated with the high concentrations of air pollutants occurring in cities.

Air Quality Guidelines (AQGs) of the World Health Organization (WHO) are taken as reference values to assess where ambient concentrations may possibly affect human health and where further study may be necessary (see, e.g. *Europe's Environment,* 1995). The significance of any pollution depends ultimately on the type of pollutants, the resulting exposure, health and other effects associated with this exposure.

Pollutants, including noxious substances, in the urban environment may be "primary", i.e. emitted directly from car traffic, domestic heating, industrial or other man-made and natural processes, but may also be "secondary", i.e. the result of chemical reactions (photochemical and non-photochemical) in the atmosphere.

Urban pollution results from a superposition from large scales, and from regional and local emissions from natural and man-made sources, transported and dispersed by meteorological processes at the same scales, and transformed by chemical reactions in the atmosphere. This is why the concentrations of air pollutants vary considerably with time (daily, weekly and seasonally) and in space. The actual occurrence, frequency and level of increased local urban air pollution concentrations depends primarily on: (a) the magnitude, business hours and spatial distribution of local emission sources situated close to the measurement/exposure location (e.g., traffic in the street) and (b) local climatic conditions (e.g., wind characteristics, frequency of calm weather, occurrence of inversion layers) that originate from the influence of regional climate on the local topography (e.g., flat terrain or basin or valley).

Three main types of air pollution sources exist in urban areas: (a) large stationary sources with one or a few tall stacks (*point sources*), (b) small stationary sources distributed in an area (*area sources*) and (c) mobile sources, i.e. traffic (*line sources*). Only the fastest chemical reactions are important for locally emitted pollutants. Their concentrations are mainly determined by dispersion.

A specific feature of air pollution, especially in cities, is the existence of short-lasting and comparatively high concentrations of pollutants, called "episodes". These may last from one to several days, and should be discerned from "momentary" peaks of several hours' duration, and from the "background" variability of monthly and seasonal character. Episodes are associated with various meteorological factors such as poor ventilation or, in some cases, unfavorable transport and transformation processes. There are two kinds of episodes with high concentrations of pollutants – "winter episodes" ("sulphuric acid smog episodes"), characterised mainly by an increase of SO_2, and suspended particulate matter (SPM) concentrations, and "summer episodes" ("photochemical smog episodes"), characterised by the production of ozone – O_3.

Winter episodes occur when low winds and a strong temperature inversion impede the vertical mixing and dilution of pollutants in the lowest atmospheric layers. During these episodes, emissions related to domestic heating can be up to 70 % higher than the winter season average. As well as SO_2 and SPM, the winter smog mixture contains compounds such as carbon monoxide (CO), nitric acid (HNO_3), nitrogen dioxide (NO_2) and aerosol particles of variable content such as soot, sulphate, nitrate, ammonium, metals and organic compounds, such as polycyclic aromatic hydrocarbons (PAH). Under winter smog conditions, daily average SO_2 concentrations in rural areas can reach 400 µg/m^3; it may be higher in cities (e.g. in December 1952, daily average concentrations of SO_2 and SPM in London reached values of about 5000 µg/m^3 each).

It is essential to note that the winter smog episodes often extend across several European countries due to long-range transport across the continent.

Photochemical smog episodes occur under conditions of high insolation and low winds, when the concentrations of ozone and photochemical oxidants can build up to high levels which are damaging both to human health and to vegetation. The main cause of photochemical oxidant and ozone formation are the emissions of NO_x ($NO+NO_2$) and VOCs (Volatile Organic Compounds) from motor vehicles, which are densely concentrated in city areas as well as from industry (in particular, combustion of fossil fuels, solvent use and evaporation losses). VOCs present in the air from anthropogenic and natural emissions are oxidized in the atmosphere in the presence of sunlight. The process generally starts through reaction with the very reactive hydroxyl (OH) radical, by reaction with ozone or by direct action of sunlight. The oxidation processes are complex, and NO_x play an important role as necessary catalysts. A host of secondary products is formed during this oxidation; they are usually called *photo-oxidants.* Ozone is by far the most important of these in terms of the adverse effects it has on human health and ecosystems. Several international bodies such as the WHO, UNECE (UN Economic Commission for Europe) and the EC (European Community) proposed or set guideline values for ozone for the protection of human health and/or vegetation. These guideline values indicate levels combined with exposure times during which no adverse effects are currently expected. For example, the 150 µg/m^3 hourly concentration level and 100 µg/m^3 for 8 hours are proposed for the protection of human health (for ozone, 1ppb » 2µg/m^3). Bulgarian guideline values for ozone are: 110 µg/m^3 – (average value for 8 hours)- for human health protection and 200 µg/m^3 (hourly averaged) – for the protection of vegetation. The hourly averaged values of 180 and 360 µg/m^3 are the guideline for information or alert for the inhabitants, respectively (see, Regulation No8, 1999). Progress in scientific understanding may lead to revision of these guideline values.

The photochemical smog episodes usually take several hours to develop. But such situations are not only local scale phenomena. Because of the strong link to particular meteorological situations, the occurrence of "ozone episodes" in Europe is very variable from year to year in both space and time. Oxidation takes place on time-scales ranging from a few hours to sometimes, several months. During this period, the polluted air is transfered due to long-range transport. That is why the influence of these episodes on air quality and deposition of pollutants can extend over hundreds or several thousands of kilometers, i.e. they are as well regional or continental scale phenomena.

The term *"hot spot" pollution* may be used to describe the high short-time pollution concentrations to which the population may be exposed when located close to pollution sources. "Hot spot" pollution includes the case of urban streets with busy car traffic, and the pollution impact from industrial stacks in cities. In all European cities, smog occurrences and long-term average concentrations of harmful compounds such as lead, benzene, SPM and benzo(a)pyrene (BaP) receive a significant contribution from emissions from road transport. Benzene and BaP are indicators of organic compounds associated with volatile organic hydrocarbons and with soot and PAHs from small-scale combustion processes, respectively. Road transport contributes, on average, more than half to the nitrogen oxides and about 35% of the VOC emissions in Europe.

While NO_x emissions from stationary sources have decreased in many urban areas, emissions from motor vehicles have increased because the growth in the number of vehicles and the distance traveled per vehicle has been much larger than the reduction in emission factors. Since the lifetime of vehicles is typically more than 10 years and in some countries such as Bulgaria more than 20 years, reductions of emissions will be slow even if vehicle numbers and distances traveled were to stop increasing. More rapid improvements in air quality in the short term can only be achieved by limitations on road transport in urban areas.

In many cities, air pollution from road transport and domestic heating is supplemented by that from local industry. The impacted area is usually a few kilometers from the emission sources, depending on the height of the stacks and the prevailing wind directions. Monitoring stations in most cities are operated in areas where principal industries are expected to have a large impact. These "hot spot" stations indicate a significant impact from industrial emissions, i.e., air concentrations of SO_2 and/or PM are considerably higher than in the city center. Such distribution of pollutant concentrations should often be observed in some industrial zones of Sofia. Most of the primary pollutants from cars, domestic heating and some industrial sources are emitted and transformed by the chemical reactions at ground level where severe pollution levels might be found. However, people live and realize the prevailing part of their own activity in the surface layer of the atmosphere. That is why, for the preservation of a favorable air quality in urban areas, anthropogenic emissions must be controlled.

Successful measures for reducing air pollution in cities over the past 20 to 30 years have included the regulation of fuel for domestic heating (low sulphur content in oil and coal, introduction of natural gas instead of coal and oil), development of district heating, reduced lead content in petrol and restriction on the use of cars in the city centers. Furthermore, dust removal from industrial sources and large boilers have resulted in major improvements. These measures have been particularly successful in reducing SO_2, particle and lead emissions, and hence daily and annual average urban atmospheric concentrations, by significant amounts in many cities. However, there has been little or no evidence of similar downward trends in NO_x concentrations. During smog conditions, emergency actions are taken by some cities (e.g., Rome, Milan, Athens, Prague) involving, for example, restrictions on car traffic and fuel substitution in power plants/

industries. Cost-effective energy conservation measures and substitution of fossil fuels with renewable energy resources have a large potential for the reduction of emissions.

As a result of such simple premises, urban air pollution management requires knowledge of the parameters related to four important aspects: a) *air quality monitoring network,* which provides measurements and data relevant to several pollutants, their occurrence in time, their spatial distribution and, eventually, episodes exceeding the quality standards; b) *meteorological data* not only from the surface layer but also from the boundary layer in the meteorological network; c) *emission inventories,* which provide information on the emitting source and their temporal evolution; d) *numerical dispersion models,* which provide information on the prediction of air quality from emission and meteorological data.

Air quality and the state of the atmosphere are usually fixed through corresponding networks for air quality monitoring and for meteorological measurements. They are composed of many measuring stations. One of the main purposes of these networks is to produce information for understanding the basic processes, which are responsible for atmospheric pollution and to take measures required for reducing the risk for health and the environment from air pollution. Two kinds of permanent networks and systems for air quality monitoring are used in dependence on the necessity to take either long-term or short-term measures for reducing the risk from pollution. They are: *networks (systems) for general monitoring of air quality*, and *air pollution informative-warning systems (networks).* General monitoring systems are considered the basic systems in urban areas. Data produced in the system are used for long-term environmental programs; for assessment of the effectiveness of a long-term policy, of the air pollution level in connection with the national ambient air quality standards, of the trends and validation of mathematical models; for documentation of population exposure to air pollution; for town and country planning; for scientific investigations etc. The stations of the urban general monitoring systems are located in inhabited areas, where the expected long-term concentrations of a particular pollutant are higher than in other areas of the town as well as where concentrations of a particular pollutant may be treated as average for densely populated parts of the town. These kinds of stations can also provide feedback for many other specific purposes.

The informative-warning systems are of two kinds – *warning* and *alarm systems. Warning systems* are based on air-pollution forecast, which, in most cases are for information only. *Alarm systems* are based on actual measured concentration values, which are connected with enforcement of compulsory preventive actions. These systems collect data in real time by means of continuous monitors. The main task of them is to provide data for short-term pollution abatement procedures. They should be established only in densely populated areas with frequent occurrence of high concentrations of pollutants caused by different sources and especially from a particular industrial plant or from distant plants as well as from traffic. The meteorological data, necessary for the functioning of the informative-warning systems are received through meteorological observations either at the same point where air pollution is measured, or at the nearby meteorological station. During field experiments these two types of data - for the concentrations of pollutants and atmosphere parameters, are most frequently conducted simultaneously at one and the same points.

It can be noted that during episodes, extraordinary measures can be applied to protect the population. They are two kinds: *active measures* – emergency reduction of local emissions, and *passive measures* for a reduction of health hazards.

The procedures for the realization of emission inventories are well established. It can be noted that there is no sufficiently comprehensive and well-founded emission inventory for Sofia city.

The processes that determine the distribution of gas pollutants in air and that are considered in the *atmospheric dispersion models* are: advection and convection (horizontal and vertical transport); diffusion into the three directions in space; dry deposition at the moment of contact of pollutants with the earth surface; the washing off of pollutants by precipitation (wet deposition); chemical transformations and/or radioactive decay. When having pollutants, carried by aerosol particles one must additionally include the processes of gravitational sedimentation and transformation of particles. These depend on the spectrum of particle size that itself changes in time as a result of interactions among particles in a gas or liquid environment (processes of decay or coagulation). These processes, as well as the chemical transformations, develop differently in the dry atmosphere, in a cloud environment and in precipitation. Adding the fact that as a result of chemical transformations, some gasses transform into aerosol particles and vice versa, we can obtain a notion of the great complexity of the distribution of air pollutants.

Each of the latter processes can be described mathematically with a different degree of complexity and with different time and space characteristics (scale and resolution). It is obvious that with such a number of processes in a continuous medium like the atmosphere, the only way to describe them is through numerical modelling. In the international literature, a great number of numerical dispersion models have been created with different purposes and degrees of complexity at realization. The different models can describe the distribution of one or many pollutants emitted in the atmosphere by different types of sources at various time and space scales.

In accordance with the approach for the description of dynamic processes, the dispersion models can be separated generally into 4 classes: *Gaussian plume models; Lagrangian-Eulerian cloud models (puff-models); Eulerian models; Lagrangian particle models.* The nature and main characteristics of each of these types of models are described in the article "Urban climate and air quality – a review" by V. Andreev (this volume).

Urban ground is covered with natural and artificial materials, buildings and other obstacles. The heat budget as well as the flow structure close to the ground depend largely on the height and density of the constructions. Flow structure varies from a series of turbulent wakes due to isolated obstacles to strongly interacting turbulent streaks and even to turbulent flows having some similarities with flows in semi-porous media. The atmospheric layer below roof level is called the *urban sub-layer or urban canopy* by analogy with the atmospheric layer between ground and the trees of dense forest. The dispersion of pollutants in the canopy layer has a primary importance because human life and activity are mainly in this sub-layer. But experimental data obtained inside large cities show that the vertical structure of the urban low atmosphere as a rule is very complex. Its multiple structure largely dependent on the structure of the canopy elements (see Andreev, this volume). One may suppose, that new on-site experiments with a large concentration of sensors allowing extremely detailed documentation of flows and climate in typical canopy geometries are necessary to validate the available mathematical models. However, according Mestayer and Sandrine (1995), it appears that the multiplication of measurements will not suffice to assess and to predict the flow structure, the dispersion processes and the air quality or pollutant contents, and their impacts because of the large structural, temporal and spatial variability of the urban lower atmosphere. The detailed prediction and real time control of air quality call for the development of a new generation of complex numerical models combining physics and photochemistry of the urban atmosphere. This will aid in the understanding of the relations between the physical-geographical conditions, the regional meteorology, the local pollutant sources and the monitoring measurements. The development of sub-meso models will allow for the study of the interactions of the city fabrics and urban sources of heat and pollutants with the surrounding orography. This is of special importance for cities like Sofia, located in valleys or valley systems, where the urban radiative budget interacts with the along-valley and katabatic cross-valley winds; this can produce extreme pollutant traps. This model development is possible only if the structure of the flow in the intermediate layer just above the roofs is much better understood.

Urban planners, local decision-makers and city leaders, as well as responsible officials of the environment, need more complicated data to understand the results of their policy, especially concerning traffic management, to assess the actual air quality with regard to secondary pollutants, to finely predict all-type impacts of new chemical sources, as well as to foresee the effects of new regulations. The need for estimations of secondary pollutant concentrations is especially demanding, since they depend altogether on mixing and reactive processes: this implies the simultaneous knowledge of chemical kinetics and of transport-dispersion behaviour of primary and intermediate compounds.

MATERIAL AND METHODS

Present knowledge of air pollutant dispersion is based on three types of data: *on site measurements; numerical model results,* and *wind tunnel and water tank simulations*. It must be noted that a significant part of this knowledge also comes from field campaigns and even from incident results of research and observations in the neighbouring fields of dynamic meteorology, air flow over complex terrains and wind engineering. We must add the useful measurements of the urban atmospheric phenomena by lidars, sodars, radar profilers and satellites.

Perennial data from the National network for air quality monitoring should be used to characterise the concentration fields of air pollutants in the Sofia hollow valley and in Sofia City. Systematic measurements of the air quality in Sofia City and around the metallurgical plant "Kremikovtzi" have been conducted since 1969, first by the Hygiene and Epidemiology Inspection and the Hygiene Center, and later by NIMH (since 1973) and the Ministry for the Environment and Waters. The number of stations in the monitoring system in Sofia changed, but reduced substantially during the recent 10-15 years. This limits the variety of scientific research in this field. Data from the general monitoring network have many methodical peculiarities, marked in official state documents (see "National Action Plan on Environment and Health...", 1996 or "National Environmental Strategy and Action Plan 2000-2006", 2001). Some of these, in connection mainly with the duration and frequency of manual air sampling, are inadequate when it is necessary to use the data for other purposes, as meteorological ones for example. The most important peculiarity in the functioning of the stations with manual manipulations, is that air sampling continues to be performed only during working days with a frequency of four times during daytime (see Regulation No 8, 1999). This means that all mean concentration values determined on these measurements are incorrect - the mean diurnal, because there are no measurements at night; the mean monthly (or weekly), because no measurements are conducted during weekends and holidays. Naturally, all other mean values for longer periods (seasonal, yearly) cannot be properly calculated with this measurement regime. Therefore we do not have at our disposal representative perennial mean air pollutant concentration values from a 24 hours or longer period. It is clear that with this regime, no representative values can also be obtained for extreme concentrations (the maximal ones) from single samplings. The use of data from the monitoring network was considerably limited with the introduced by Regulations No 8 and No 9 (1999) (one-hour duration) of the single manual samples for SO_2, NO_2, ozone and fine dust particles (the time for averaging for the automatic stations is also one hour). It is, probably, suitable for the purposes of healthcare, but it is not suitable for other purposes like meteorological. The analysis of turbulent energy fluctuations of the meteorological elements shows that the most stable mean values for air characteristics are obtained at an interval of between 10 and 30 minutes. This is why the introduced one-hour sampling, instead of the former 30-minutes, leads to an uncertainty in comparing the measured concentrations with the models.

The general settings show (see Palmgren, 1996 or Walczewski, 1996) that when a general monitoring network for air quality is being constructed in an urban or an industrial center, attention is paid mainly to finding the level and peculiarities of air pollution in the whole city. When a study of this problem is necessary for a local area in the city, this network can be expanded with an increased density for that area. This was done, for example, by the sanitary agency (HEI)-Sofia in the region of MP "Kremikovtzi". This approach, however, is expensive and is rarely applied. The air quality in local areas is studied most frequently by "field (natural) experiments", also called "Field campaigns". They are necessary during the initial stage of creating general monitoring networks or in reorganization or regular optimization of functioning networks. The experiments are usually conducted for representative periods (from 15 days to one or a few months) from the cold and warm half-year periods by increasing station density and frequency of measurements, accompanied obligatorily by ground and higher level measurements (Palmgren, 1996). Such experiments are necessary in research on air pollution in Bulgaria at least because of the marked peculiarities of the data from the national monitoring network. In this publication the measurements on air pollution in Sofia City will be reported that are obtained on the basis of short-term experiments encompassing the whole city and are noted as "Sofia'76" (Andreev et al., 1982) and "Sofia'82" (Andreev, 1984) or parts of it (Sofia-Drujba'93) (see Syrakov, 1992-1994). The experiments were conducted during typical winter (25.11.-9.12.1976; 20.11-20.12.1981 and 15-26.11.1993) and summer (10-25.06.1976; 15.06-15.07.1982 and 10-30.06.1992) periods respectively at 14 and 19 points in the whole city or 8 points in the Iskar district (Drujba).

The concentrations of air pollutants in Bulgaria are measured only at ground level. The measurements at altitude are realized only with lidar systems by methods developed in the Institute of Electronics of BAS (see Donev et al., 1995; Kolev et al., 2000; Syrakov D., 1992-1994 - report for I stage). The use of lidar systems in a range of cities in Bulgaria, including

Sofia, shows that at least at present this is the best method for the diagnosis of the distribution of layers of aerosol particles in the air, as well as its change in time. This allows for the documentation of intensive emissions by local sources and to register smoke plumes. In our opinion it is important to measure the absolute concentrations of aerosol particles in air using lidar systems. Such measurements were conducted, for instance, in 1992 in the Iskar district, and in the report for the I stage (Syrakov, 1992-1994) the horizontal and vertical sections of the aerosol concentration fields at different altitudes during different time periods are presented. A method should be found for comparing such results with data by direct measurements of the concentrations. In this sense, the use of a "relative" concentration, as it was done by another group of researchers also from the Institute of Electronics during measurements in 1994 and later (see Donev *et al.*, 1995; Kolev *et al.*, 2000), is better.

In the National Institute of Meteorology and Hydrology (NIMH) some versions of most of the basic classes of mathematical models for the distribution of pollutants in the atmosphere were developed. Thus, for example, a set of Gaussian models, built on formulas and parameterizations recommended by the Environment Protection Agency (EPA) of the USA is available. The most important characteristics of these models are as follows: a) Stability is determined depending on the meteorological conditions in accordance with the classification suggested by Pasquil; b) formulas of Briggs are used for the dispersion functions and for the elevation of the plume over the opening of the stack in result of inertial and Archimedean forces; c) wind speed at the stack opening is determined by the ground wind and the power law recommended by the EPA; d) in the dispersion functions, a correction of sampling time is introduced at concentration measurements, taking into account the effect of the plume meandering; e) the model takes into account the altitude of the mixing layer if such data are available; f) calm weather conditions are treated as the plume formed at wind speeds of 0,5 m/s in all directions. In the case of a gas pollutant, the processes of dry and wet deposition are taken into account, as well as the decrease of the pollutant's mass as a result of chemical transformations. Modules for calculating the distribution of aerosols are introduced – gravitational deposition and specific washing. As one of the pollutant's characteristics, along with the speed of dry deposition, the mean speed of degradation (radioactive decay) is also introduced. The transformation processes that the pollutants experience are also calculated in the models. The dry and wet deposition not only lead to a decrease of the pollutants' concentrations in the air, but also form a field of accumulation on the earth surface.

Entry into the models is interactive, but using the capacity of the Disk Operational System, the responses to all the questions put by the program can be saved in advance in a text file that can be specified as the entry file. The meteorological entry is both a situation series and climatic information. The result of the models is a GRD file of the SURFER graphics package in text format. Thus it can be used both as numerical values and the field can be presented graphically as an isoline or a 3D surface.

NIMH has a well developed puff-model, called LED (**L**agrangean-**E**ulerian **D**iffusion) that is used for solving different problems such as pollution with sulphur and nitrogen oxides, formation of acid rains, continental and regional pollution with heavy metals, etc. In the LED model the horizontal distribution of the concentration is Gaussian, while the vertical distribution is different depending on the boundary conditions on the earth surface and at the upper boundary of the mixing layer (if it is present). In the model there are calculated the other processes accompanying the transport and diffusion - the dry deposition, the washing by precipitation and the chemical or radioactive transformations. In order to provide data for wind in the center of every puff, and also data for the diffusion capacity of the atmosphere, a relatively simple, but effective model of the atmosphere boundary layer is included, that is supplied with standard meteorological data from only two levels - the earth surface and the upper boundary of the boundary layer (approximated with a level of 850 hPa). For feeding the LED dispersion model, meteorological data obtained by the global prognostic Brecknell model is used in a network of 2.5 at 2.5 degrees.

In NIMH an Eulerian model is available, called *EMAP*, an abbreviation from *Eulerian Model for Air Pollution.* Up to now, a few versions of EMAP have been proposed – for describing the distribution of an inert gas, of sulphur compounds (SO_2, $SO_4^=$), of heavy metals and long-life air pollutants carried by aerosols (Pb, Cd, Benz(a)pyrene, etc.), and of mercury. EMAP is a three-dimensional model for numerical simulation of a range of processes determining the distribution of air pollutants. Here a Cartesian coordinates system is used with an invariable step on the horizontal and variable step on the vertical. The horizontal coordinate surfaces that follow the relief shape are denser at ground level and are rarefied in altitude corresponding to the typical profiles of the meteorological elements in the atmospheric boundary layer - quick changes near the ground and smoother changes in altitude. A detailed presentation of this model is presented in BC-EMEP (1995) and Syrakov (1997). The EMAP model is used in important tasks like representing Bulgaria in the European EMEP program or the NIMH system for early warning in the case of a major nuclear accident that supplies Civil Defense and the Crisis Team of the Bulgarian Committee for Nuclear Energy Utilization with a 3-days prognosis for the evolution of the radioactive pollution patches. Until 2-3 years ago, a special modification of the LED puff-model was used for this purpose.

The great variety of dispersion models poses questions like which type of models to choose from and to what degree the results from the different models could be trusted.

The answer to the first question can be given only by experts in that field and depends on a range of factors - the character of the task, the available equipment, information base and models. The second question is the subject of intensive experimental, theoretical and modeling activity at an international scale. The process of comparing the modeling results with experimental ones is called *verification, validation* or *inter-calibration*. Without discussing the differences among the three terms we must note that considerable effort was put into creating the methods for such comparison, showing that it is not an elementary task. The problem is that, on one hand, the measurements that are usually conducted at one point in space are burdened with inevitable measurement errors. These errors are even greater for field experiments where measurements are done simultaneously at a large number of points with simpler equipment than can be installed in laboratory conditions. On the other hand, the modeling results are usually not related to a fixed point, but characterize some area around that point having sizes equal in resolution. All these considerations must be regarded in comparing results.

RESULTS

Main air pollution sources in Sofia City. According to the Concept of the social-economic development of Sofia up to 2020 (see General Structural Plan of Sofia, March 2002) about 27% of the territory of Sofia city are production areas, while only 5-8% in the capitals of advanced European countries. It is a characteristic for Sofia City that 34% of the production areas are located no more than 4 km from the city center and a considerable number of enterprises are within residential districts or in close proximity to them. According to this Concept, the production zones in Sofia are combined in the following 3 large industrial complexes: (a) *Northern industrial complex* including the production zones Levski-north, Hadji Dimiter-Malashevtsi, Area rear the Central railway station, Voenna rampa-west and east, Iliantsi-west and east, Novi Iskar-Kurilo, Svetovrachane; (b) *Eastern industrial complex* from the production zones Iskar-north and south, Kazichene, Hristo Botev-Slatina, Gorubliane, Izgrev, Vitosha, Sredets; (c) *Western industrial complex* from production zones Zaharna fabrika, Orion, Lulin, Voluiak. Similarly, around the city there are 3 large industrial and transport complexes namely Kremikovtsi-Gara Iana, Gara Elin Pelin-Ravno pole, along a direction Sofia-Slivnitsa.

The contribution of *transport* should be noted, because a great part of the country's automobile park is used in Sofia. This park consists mainly of old cars (mean age 14 years, 8-10 years for busses). They travel on roads having technical characteristics (dimensions, coverings, radius, length slope etc.) that do not comply with normative requirements and are badly maintained. The result is a decreased traffic capacity, traffic jams and accidents. That is why the auto-park in Bulgaria and Sofia in particular has a low ecological index, i.e. it is one of the most serious air pollutants.

Another emission source is *domestic heating*. It is characterised by inefficient heater that are mainly concentrated in the districts with individual houses located on the northen slopes of the Vitosha mountains as well as in Lozen, Malinova dolina, Vitosha, Krastova vada, Manastirski livadi, Gorubliane, Orlandovtsi, Malashevtsi, Fakulteta, Hristo Botev and Iliantsi.

Furthermore, dust, in considerable quantities, is present in the air because of the bad status of streets during times of communal and repair activities.

These various sources, concentrated in a relatively small area, cause a comparative high level of the air pollution in Sofia city. The concentrations of air pollutants can exceed the sanitary standards during adverse meteorological conditions.

Air pollution levels in a certain area is determined by two major factors – the parameters of the sources of harmful emissions and the meteorological conditions at regional and local scales. Air pollution, formed under the influence of the climate and microclimate of an area, assuming that the sources' parameters remain constant, can be defined as the "air pollution potential". The latest assessment of this potential in Sofia City was conducted by M. Teneva, P. Ivanov and others in 1980's (see Blaskova *et al.*, 1983; Teneva & Batchvarova, 1989), applying a physical-statistical approach created at the General Geophysics Observatory–St. Peterburg, Russia. Data for the frequency of ground temperature inversions were used along with the frequency of weak winds (up to 1m/s) and fog, as well as from a of combination of these factors. According to this approach, the relative pollution potential during city conditions, calculated for low sources and cold emissions, is classified into 6 degrees (Table 1). In Table 2

Table 1. Degrees of the Air Pollution Potential (APP).

Degrees	Level of APP	Interval of APP
I	Low	0,0÷2,4
II	Moderate	2,5÷2,7
III	Increase	2,8÷3,0
IV	High	3,1÷3,3
V_A	Very high	3,4÷3,6
V_B	Unusually high	3,7÷4,0

Table 2. Air Pollution Potential of Sofia.

Hour	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
02^h	3,7	3,4	3,3	3,2	3,5	3,7	3,7	3,6	3,9	3,7	3,8	4,0	3,6
08^h	3,8	3,7	3,1	2,8	2,8	2,8	2,8	2,9	3,0	3,5	3,8	3,6	3,1
14^h	3,1	2,6	2,4	2,2	2,4	2,4	2,4	2,4	2,4	2,5	2,9	3,1	2,4
Mean	3,6	3,0	2,8	2,7	2,8	2,8	2,8	2,8	3,0	3,0	3,4	3,7	3,1

mean values are presented for three climatic terms of observation (02, 08 and 14h local time) and for the whole 24 hours period at station NIMH-Sofia.

In Sofia City at 02h at night, during the whole year, climatic conditions are present that help the retaining of compounds in the surface air. Due to this, the pollution potential throughout the year appears very high (V_A degree), and except for the February-May period it is exceptionally high - V_B degree. The potential in Sofia at 08h in the morning is very high for the April-September period, and during the cold half-year period - high and very high. The conditions for dispersion of compounds are considerably better at 14h and during the greater part of the year the potential is moderate; only for the November-January period it is high.

Discussion on air quality in a certain region begin with characterizing the concentration fields of the main air pollutants. It is reasonable to use generalized indicators such as, for example, mean concentrations defined by perennial observations in a network of stationary air quality monitoring points. As it was already pointed out, this cannot be done for any city in Bulgaria, including the capital, due to the insufficient reliability of the mean concentrations determined only by measurements of a part of the 24 hours period and a part of the week. These flaws considerably limit the use of data from this system. This is so at least for research on the meteorological aspect of the air pollution problem. These data allow us to show only some of the characteristics of the concentration fields of air pollutants in Sofia City. For example, comparing the annual changes in SO_2 concentrations at different points in the city, Batchvarova and Teneva (1989) have shown (Fig.1) that in the south-eastern part of the city (curve 1) SO_2 concentrations are lower than in the northern industrial zone (curve 3) and in the town center (curves 2 and 4). The differences are larger in morning hours and in winter than in the afternoons and during summer.

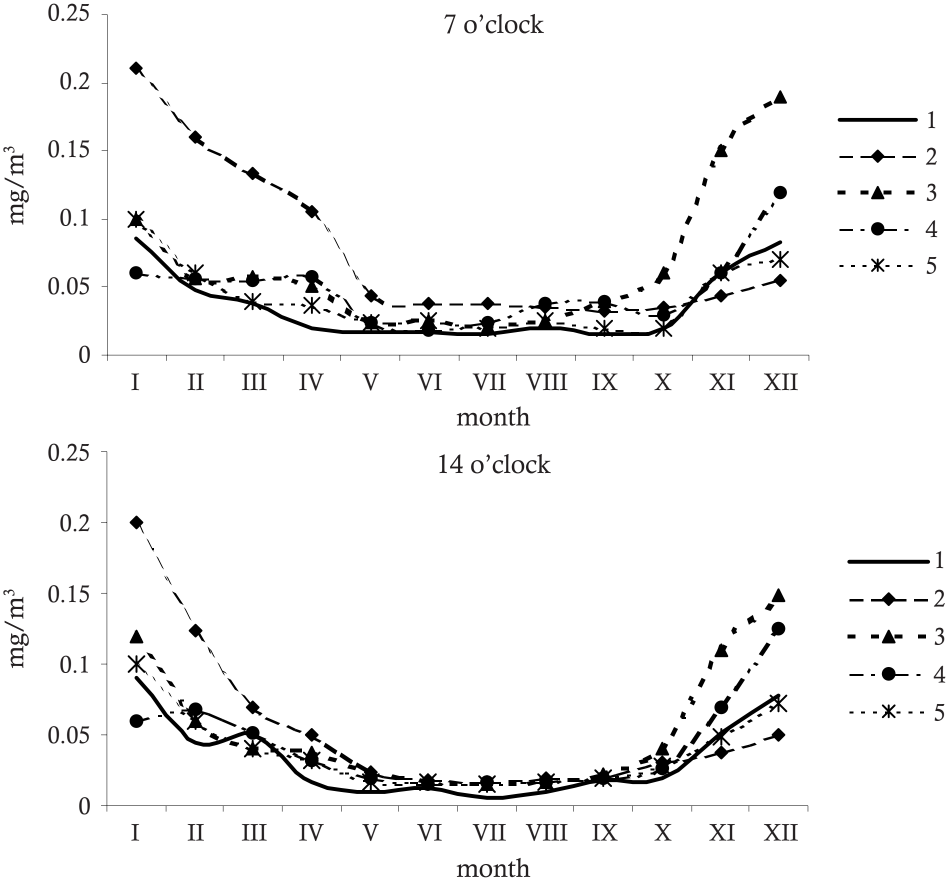

Fig. 1. Annual changes in SO_2 concentrations at different points in the city of Sofia. 1-NIMH (Hydrometeorological service), 2- V. Levski sq., 3- Tolstoy district, 4- Vasrajdane sq., 5- V. Levski district (Batchvarova & Teneva, 1989).

The hollow valley character of the Sofia field suggests a substantial influence of temperature inversions and related fog on air pollution. The most important peculiarities of the diurnal and annual evolution of SO_2 concentrations by regular sampling at NIMH in the city of Sofia, can be seen on Figs. 2 and 3. The expected increase of air pollution is observed during days with inversions and fog.

Concentrations are increasing rapidly during days with fog conditions and the increase is quite acute during night hours, while extreme values appear around 3 hours later. Fog also represent a subject of interest because at high concentrations of pollutants, fog drops can become toxic with participation of sulphur dioxide (SO_2) and particulate matter (PM), and form a winter-type smog. The influence of ground and high inversions is relatively equal with the exception during winter months when emissions by the increased number

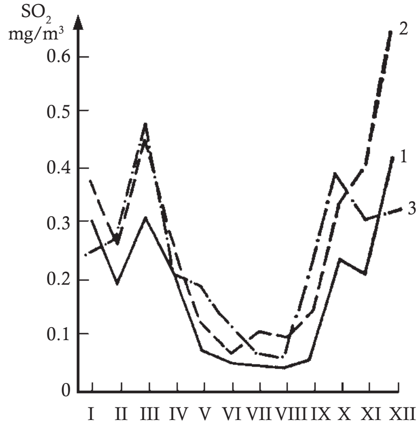

Fig. 2. Annual evolution of SO_2 concentrations in NIMH–Sofia in days without inversion (1), in days with ground inversion (2) and in days with high inversion (3) for the 1973-1980 period (Teneva & Batchvarova, 1989).

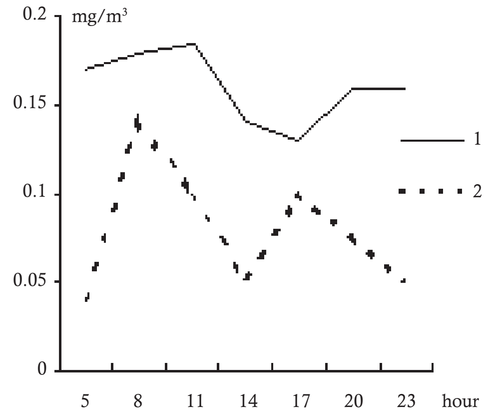

Fig. 3. Diurnal (24 hours) progression of the SO_2 concentrations in NIMH-Sofia in days with fog (1) and without fog (2) for the 1973-1980 period (Teneva & Batchvarova,1989).

of low sources are retained in the ground inversion layer and form high concentrations in ground air.

The high inversions that are observed in spring and autumn appear with air pollution, capping the convective boundary layer. Teneva *et al.*, (1989) studied 24 such situations in the 1983-1987 period. The concentrations of the measured air pollutants in Sofia – SO_2, NO_2, H_2S, PM and phenol - were considerably higher than the mean monthly values, calculated for a 14-years observation period (1974-1987) and also the Maximum Acceptable Concentrations (MAC) by Bulgarian Air Quality Standards. The excess above the mean values are 3-4 times on average, 7-8 times on separate occasions and even 25 times. MAC were exceeded 2-3 times on average, up to 6 times on separate occasions, and even up to 50 times.

For more than 20 years, members of the Institute of Electronics (IE-BAS) have successfully applied lidar measurements for determining dependencies of the positioning of the aerosol layers in relation to the layers of temperature inversions in the atmospheric boundary layer. The lidar measurements were most frequently conducted in summer during the second part of the night, from 02 to 05h local time, when a quasi-stationary period is observed in the development of the temperature inversions. These measurements were compared to the aerological air soundings in the region. It was shown that the aerosol layer is becoming denser in the area of inversion (200-300m). In situations with a low inversion, this layer is observed below the inversion. This is the most probable positioning of the aerosol layer in different versions of this type of situations.

As was noted before, a more reliable notion of the field of air pollutants concentrations and its connection with meteorological conditions is obtained through data from field experiments when it is possible to increase the density of stations and the frequency of measurements even only for short periods of time. The first such possibility for Sofia City was created by the "Sofia-76" experiment (see Andreev *et al.*, 1982). A range of articles were published on data from the experiment, the first ones by its organizers. The purposes of the following complex experiments "Sofia-82" (Andreev, 1984) and "Sofia-Drujba'93" (Syrakov, 1992-1994) were similar. It was confirmed by these experiments that there are two clearly expressed dangerous meteorological situations: a) stagnation of air, usually in combination with radiative temperature inversions when a simultaneous increase of air pollution is observed in different parts of the city; b) a stable wind directed from the main pollutant sources (mainly for SO_2) as so-called "critical wind speed" blowing from the sources. It is interesting that during the summer period the highest single dust concentrations are observed not during calm weather but during weak to moderate wind conditions. This dust is likely from the city industry or from the earth surface, being lifted by the wind. The contribution of the secondary source is quite obvious at stronger (over 10-15m/s) southern winds during winter. The increased density of observation points allowed us to get a notion of the form and structure of the "heat island" in the city (see Blaskova et al., 1983; Teneva & Batchvarova, 1989). Some expected results were confirmed as, for example, that the central part of the city is not only the warmest, but also with the most polluted air and the tendency for increasing concentrations of gas pollutants with an increase of thickness of the ground inversion. A range of quantity assessments were obtained like, for example, that in the case of high inversions, the highest concentrations of SO_2 are obtained for inversions with 600-800m of altitude for the base of every period of the day and night. In precipitation conditions there is usually a local minimum of pollution. A specific conclusion was made, however, that the concentrations of dangerous gasses and dust in ground air are relatively lower up to around 3 hours after the end of the precipitation. Measurements at two altitudes (1 and 21m) showed that the lowest layer of the atmosphere is most frequently well mixed vertically. Some essential differences were obtained in only a few measurements when the turbulent exchange was decreased as, for example, in a ground inversion. A correlation was established between the mean diurnal speed of ground wind and the SO_2 and $NO_{2,}$ concentrations from where some specific conclusions followed for the connection of air pollution with the synoptic situation and especially with the pressure field. This fact gave reason to begin activities (see Andreev, 1984) on applying the synoptical-statistical approach suggested in 1971 by Sonkin (1991) for the prognosis of the air pollution level in Sofia City. A method was created for such prognosis, valid for the cold half-year period (see Vassilev *et al.*, 1989 or Vassilev, 1998) when air pollution reaches high values.

The field of air pollution and the spatial distribution of the meteorological parameters in a local area of industrial and residential zones of Sofia have been studied during the experiment "Sofia-Drujba'93" (see Batchvarova *et al.*, 1996).

The regionalization of an urbanized and industrial center, like the city of Sofia, according to air pollution levels represents an interest for some purposes. This is a difficult task because of the lack of representative mean values as was already discussed. That is why the studies we conducted on this subject are based on data from the above mentioned short-term experimental measurements for the content of some major gas pollutants, and dust and lead in the dust. Such regionalization is difficult also due to the variegated picture of the concentration fields of the pollutants. This is well expressed in the presence of weak to moderate wind when the distribution of concentrations at calm weather is disturbed.

In the absence of wind, the isolines of equal concentrations, for example, of SO_2, represent concentric ellipses with the major axis of a north-south direction. This can be seen in Fig. 4, that is related to the mean SO_2 concentrations measured in calm weather during a short-term experiment lasting one winter month in 1976. In calm weather, the most SO_2 polluted parts of the city are the central areas and especially Vassil Levski sq. and the region of Stochna Gara. The isoline 200μg/m^3, characterizing the highest concentrations, includes the city centre and the local centers of districts. This zone of maximum concentration envelops the northern districts near the center, the main center and reaches the southern and south-western districts, including Krasno selo and Losenetz. A well expressed development appears in the east towards the Vassil Levski district. The isoline 150μg/m^3 (this is the mean 24 hours MAC for SO_2) covers practically the whole city, including the districts Pavlovo and Dragalevtzi. The south-western bordering districts of the city are comparatively cleaner.

Considerable heterogeneity is shown by the concentration fields of this pollutant during this experiment but for periods of weak to moderate southern wind (Fig. 5). Due to the blocking of air circulation over Sofia the direction of the local air movement is varied. Due to this, the max-

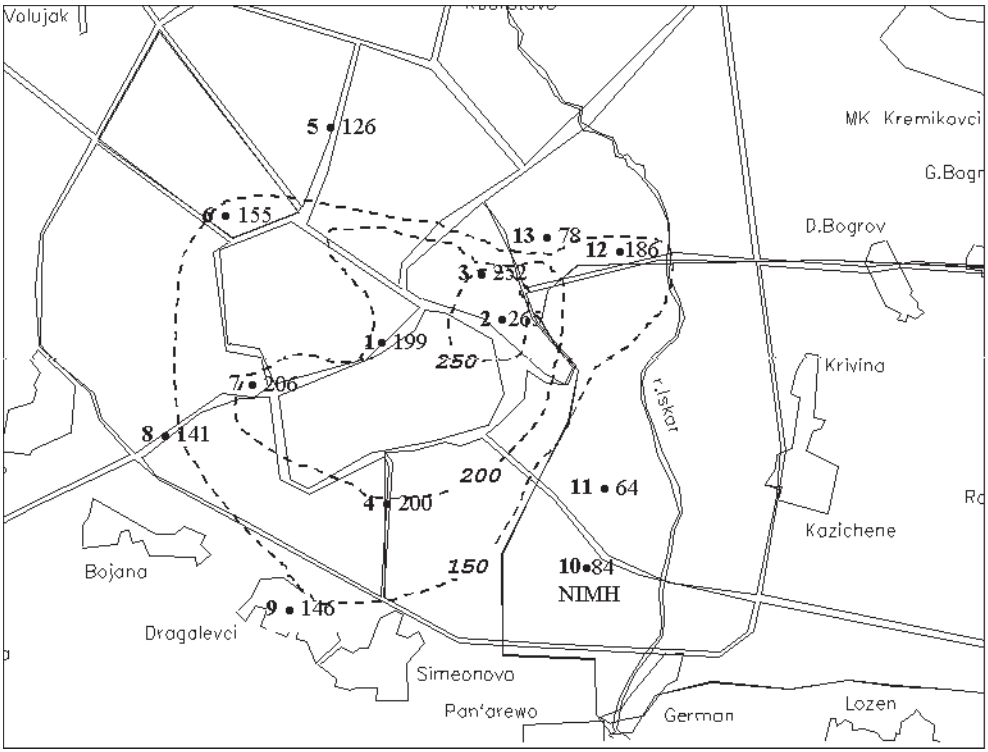

Fig. 4. Scheme of mean SO_2 concentration isolines (mg/m^3) in the air above the indicated points in Sofia City during a period 30.11-1.12.1976 (averaged from 11 single samples) under no wind (calm) conditions in the layer from surface to 400 m height. The air sampler stations are: 1-Vazrajdane square, 2-Levsky square, 3-Stochna gara, 4-Lozenetz, 5-Tolstoj blocks, 6-Zapaden park, 7-Krasno selo, 8-Pavlovo, 9-Dragalevtzy, 10-H&M Service, 11-Gara Iskar, 12-Levsky district, 13-Hadgy Dimiter district.

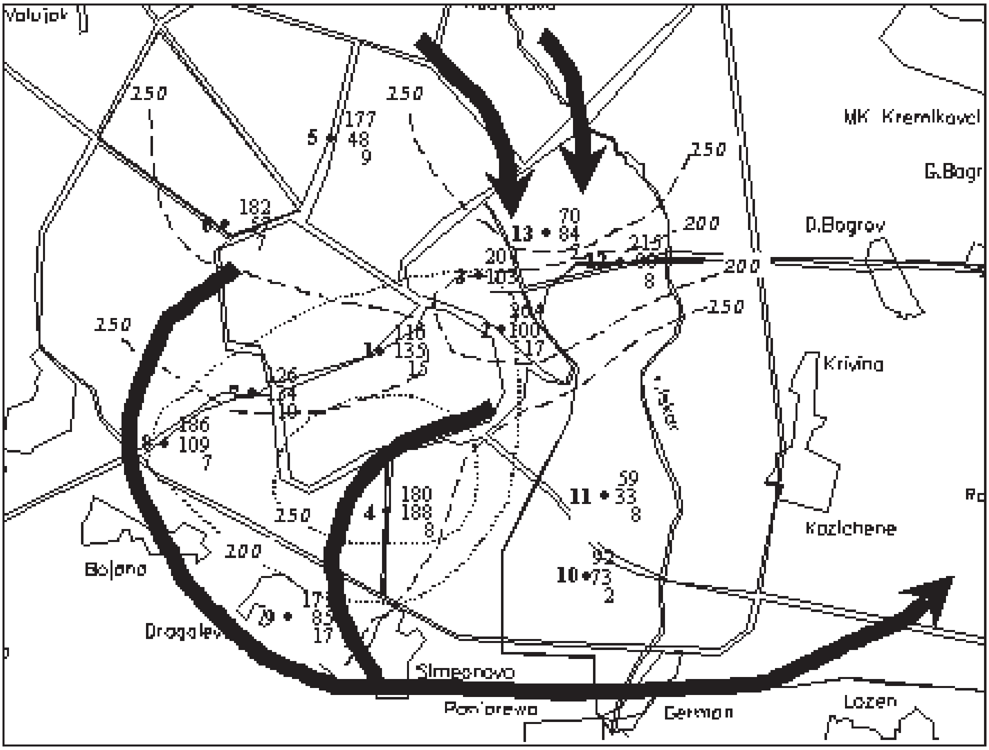

Fig. 5. Scheme of mean SO_2 concentrations isolines (mg/m^3) in the air above the same sampler points in Sofia City as in Fig. 4 during a period 1-5.12.1976 observed at a Southerly wind, categorized by the mean speed in the layer to 400m as: weak (0-3 m/s; the concentrations are the top numbers in the column near to each station), moderate (3-9 m/s; the middle numbers in the column) and strong (larger than 15 m/s; the lowest numbers in the column). The directions of the local air flows, according to Tucker (1989), are shown by thick, dark lines with pointers.

imum values of SO_2 is not in the centre at moderate wind speeds. It has moved from the area of Stochna Gara - V. Levski sq. to the southern Losenetz district (point No. 4). The reason for this is probably the northern component in transient lee eddies formed in the windward side of the mountain Vitosha. It transports cleaner air from the suburban parts towards the northern districts and the northern part of the centre, thus leading to an increase in air pollution in the south-western and southern districts. In Fig. 5 it can also be seen that during weak to moderate southern winds, some polluted air from the town of Pernik can be transported to the western parts of the Sofia valley, including the town of Bankja. In strong southern winds the SO_2 level in Sofia is low and the distribution is homogeneous due to intensive turbulence.

From these examples, we conclude that although the pollution sources do not change in intensity, depending on meteorological conditions and mainly the direction and speed of the wind, the distribution of air pollutants can be very different in the city space and it can also change over time. Thus it can appear that some parts of the city that are normally cleaner than the others, are substantially polluted at certain meteorological conditions. Still, however, these situations appear in a relatively low number of days throughout the year (for example, with southern winds – no more than 10-20 days per year). Cases with calm weather and temperature inversions are frequent. Its numbers are different for the different microclimatic regions of the city. That is why a good set of characteristics would be the mean seasonal and annual concentrations of pollutants. To look for such a representative empirical regionalization of the city, however, a large number of stations for pollution study are needed, enveloping all microclimatic regions of the city. There are, however, only 7-8 such stations working throughout the year in Sofia. The working regime of these stations do not allow the correct determination of mean values for 24 hours, per month, per season or per year. This is why the regionalization was conducted on the spatial distribution of the basic gas pollutants (SO_2 and NO_2), and dust and lead in the dust on data from experiments in 1981-1982. For this purpose, during a one-month period in cold (20.11-20.12.1981) and warm (15.6-15.7.1982) half-year periods, 17 and 16 points were organized respectively for manual sampling that gathered 16 sample times in 24 hours at equal time intervals.

Summarizing the regionalization of Sofia, during the distribution of the major air pollutants (SO_2, NO_2, NO), a good agreement with the microclimatic regionalization suggested by Blaskova *et al.*, (1983) (see the article of Andreev *et al.* in this volume) was obtained. Well defined regions of the city from the viewpoint of the mean monthly concentrations were the "Foot of the mountain" and "Open hollow field". This is a natural result of the micro-meteorological conditions for the dispersion of air pollutants, although some of the regions are situated in close proximity to the northern industrial zones, or powerful pollution sources like MP"Kremikovtzi". Similary, the most polluted areas, according to mean concentration values, are ones of the microclimatic region "City Centre".

In research on *the regionalization of Sofia from the concentrations of dust particles in the air*, robust evaluations are suitable. In Fig. 6, the distribution of one of these is presented, marked as TRIM (mean value of the central 70% of the concentration values - Trimmed mean) on measurements of dust concentrations during winter (20.11 - 20.12.1981). Most polluted (see isoline TRIM=50$\mu g/m^3$) are the north-eastern districts (mainly H. Dimitar), the part of the main centre between the astronomical observatory in Borisovata gradina (point No18 by P. Javorov bld.) and the observatory in the Ivan Vazov district (No. 19), and around the Dianabad district. Cleanest areas are points at the foot of mountains like Bankja and Bojana.

During summer (15.6-15.7.1982), dust pollution is lower and more uniformly distributed. Only two points are distinguished: H. Dimitar with the highest and Bankja with the lowest dust concentration. The values of the variation coefficient (Ê= s/-*q*) during both seasons are less than 1. This shows that pollution is of the diffusion type, i.e. the dust concentrations are weakly influenced by local sources and form after some time during which transport and diffusion occur. It should be noted that the dust sources are not only of anthropogenic origin; dust elevated and carried by wind also influences the process. This is probably why air pollution is relatively lower in the main city centre where the streets and squares have artificial coverings and are maintained better than in the outlying districts or where intensive construction work was under way during this period (e.g. in No. 19).

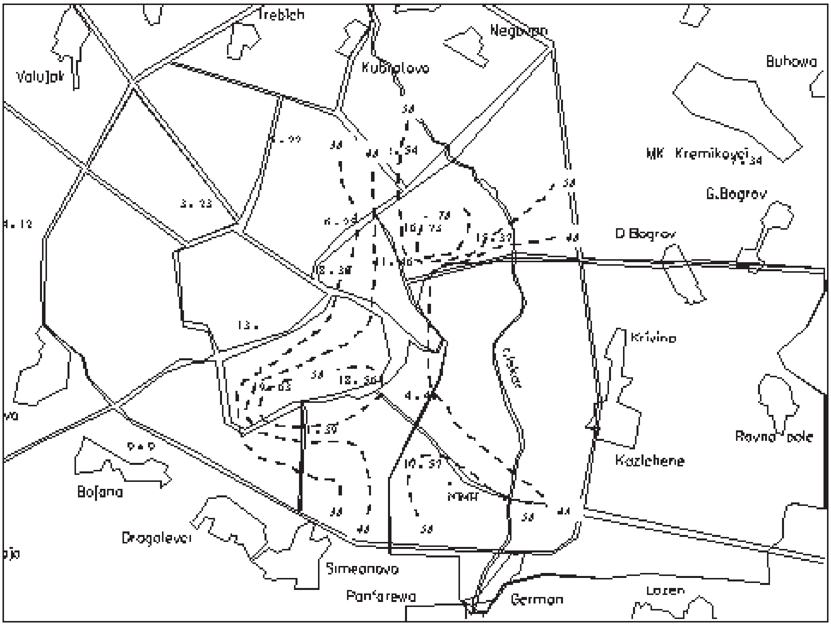

Fig. 6. Distribution of the robast assessment TRIM for dust concentrations; 20.11 – 20.12.1981.

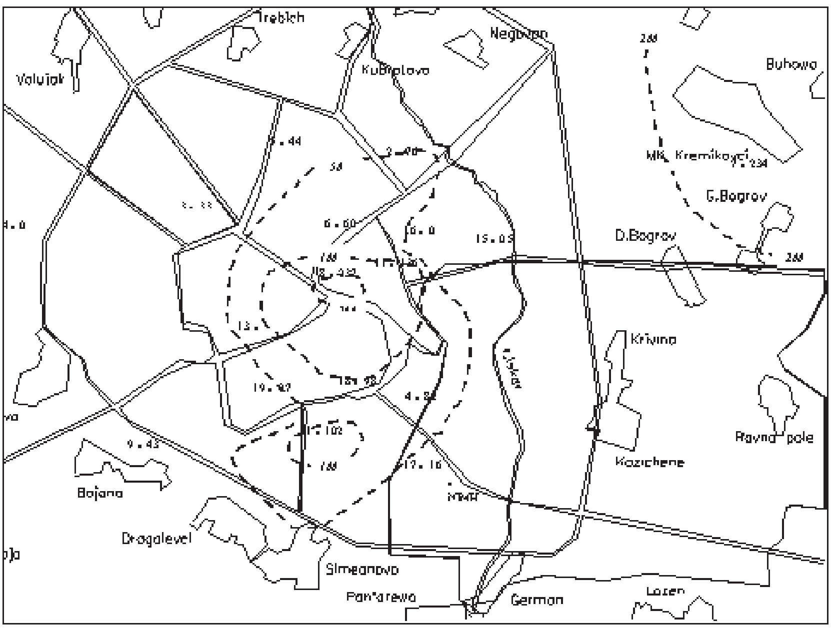

Fig. 7. Distribution of the robast assessment TRIM for lead concentrations in dust; 20.11 – 20.12.1981.

The distribution of the same robust characteristic TRIM is given in Fig. 7 but here on data of the lead content in dust particles for the winter period. The distribution of this pollutant is noteworthy. The mean concentration of lead at the most polluted point No. 8 (HEI - 39, Stambouliiski bld. close to Vazrazdane sq.) is almost 33 times greater than at the cleanest point - No. 14 (Bankja). The central city parts are most polluted, including the Astronomical observatory (No. 18) and the Krusta district. This can be explained by the greater concentration of transport vehicles in these areas. The high dust concentrations around the National observatory in Ivan Vazov and Dianabad districts are probably not connected to automobile transport because the lead content in dust is relatively low at these points. This is probably due to the influence of the nearby construction work. At the same time, the relatively low quantity of dust in the air (Fig. 6) in the Hladilnika district (point No1 - Krusta) contains considerable lead quantities, probably due to the intensive road traffic. A very high lead concentration is shown by the point in the Botunetz district, probably due to the proximity to MP "Kremikovtzi".

As was mentioned before, the lidar measurements give an unique area overview for the formation, location and evolution of aerosol layers in the atmosphere. In the 1994 experiment (see Donev *et al.*, 1995 or Kolev *et al.*, 2000), it was shown that the aerosol particles (as other scale characteristics of the atmosphere) being emitted in a stable boundary layer tend to distribute horizontally (i.e. in the shape of layers), usually below the inversions. The cause for this is that the temperature inversions act by retaining the transfer phenomena in the atmosphere including the turbulent diffusion. It appears that the lidar registration of the location and evolution of the aerosol layers in the atmosphere allows us to obtain interesting characteristics of the atmosphere (like some meteorological elements or the mixing layer) and also some processes in this environment (see the article by Andreev *et al.*, this volume).

The results from measurements with an impulse lidar conducted during the period 10-30.06.1992 in the Iskar district by a team (G. Kolarov, Tzv. Mitzev, V. Simeonov, R. Stoyanov) from the Institute of Electronics (BAS) are given in the report for the I stage (Syrakov, 1992-1994). Figures 8 and 9 represent maps of the aerosol concentration in a horizontal section at 50-60 m above the terrain. The scanning time is 10 minutes.

The field in Fig. 8 has not sizable heterogeneities and concentrations around 0,15mg/m^3 prevail. The next map (Fig. 9) was completed 20 minutes later (0:14h on 1.07.1992). Here a decreasing (diffusive) smoke trace appears over point No. 3 (4th Workers' Hospital) extending in a north-eastern direction. Its cross-sizes are between 500 and 750 m and the concentration reaches 1 mg/m^3. The next three maps show the vertical situation, on horizontal maps with a solid right line beginning with the lidar location close to Tzarigradsko chaussee. The first map (Fig. 10) alows us to assess the vertical size of the smoke trace from Fig. 9 that reaches 200 m in altitude and a concentration of 0,23-0,29 mg/m^3. In the second vertical section (Fig. 11), 10 minutes later the smoke trace has already dispersed. 10 minutes later (Fig. 12) this is even better underlined as the concentrations in the area are at the interval 0,14-0,2 mg/m^3 without any smoke formations. The meteorological measurements show an absence of temperature inversion layers up to 600 m where the concentration of particles would increase.

Some useful information for the periodic fluctuations of air pollutant contents is also obtained by mathematical Fourier-spectral analysis of the time ranges of concentrations, where the background of the determined fluctuations is superimposed on random fluctuations. The

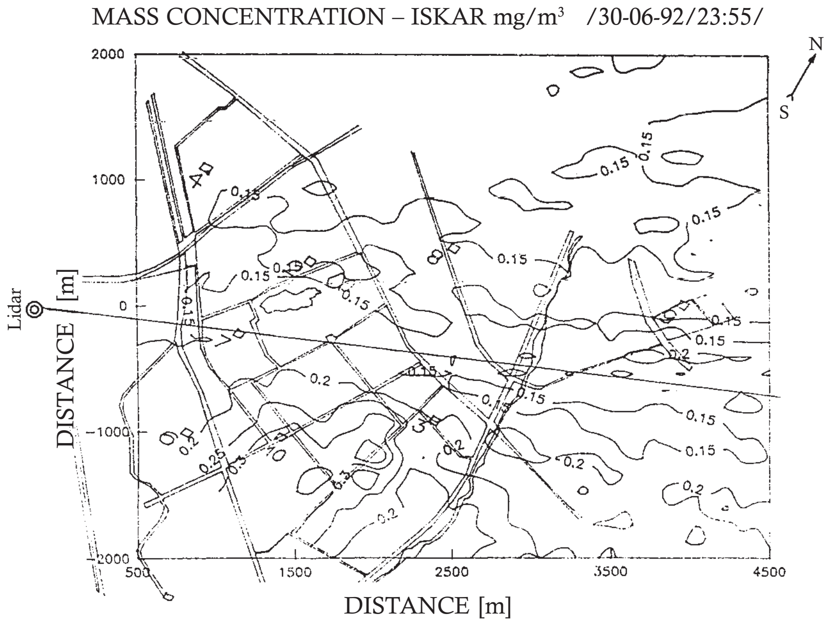

Fig. 8. A Horizontal Section of the Particles Mass Concentrations in the air (mg/m^3) of the district "Druj-ba" (Iskar) of Sofia, measured at 30.06.1992 – 23:55h.

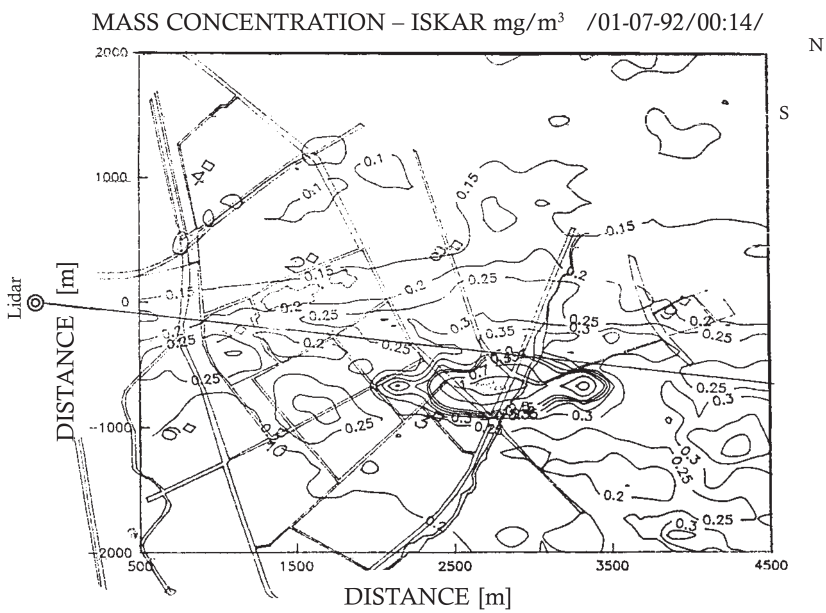

Fig. 9. The same as in Fig. 8 but for 1.07.1992 – 00:14h.

MASS CONCENTRATION mg/m³ /01-07-92/00:33/

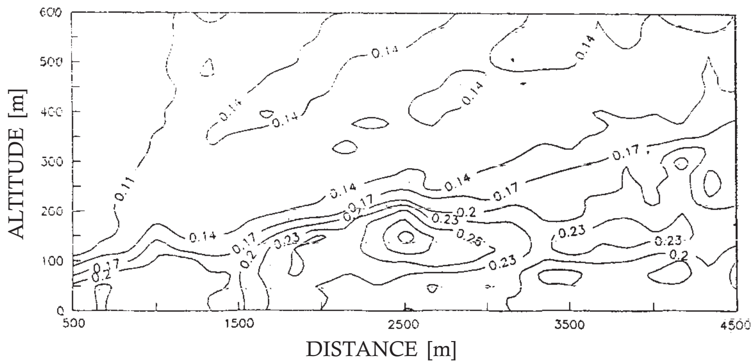

Fig. 10. A Vertical Section of the Particles Mass Concentrations into the air (mg/m³) of the "Drujba" (Iskar) district of Sofia, measured at 1.07.1992 – 00:33h.

MASS CONCENTRATION mg/m³ /01-07-92/00:43/

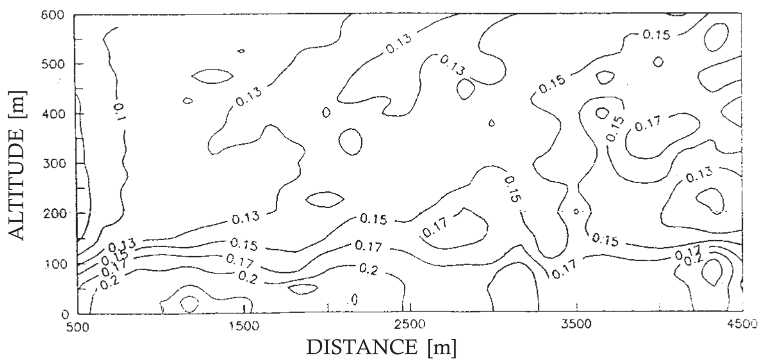

Fig. 11. The same as in Fig. 10, but for 1.07.1992 – 00:43h.

MASS CONCENTRATION mg/m³ /01-07-92/00:52/

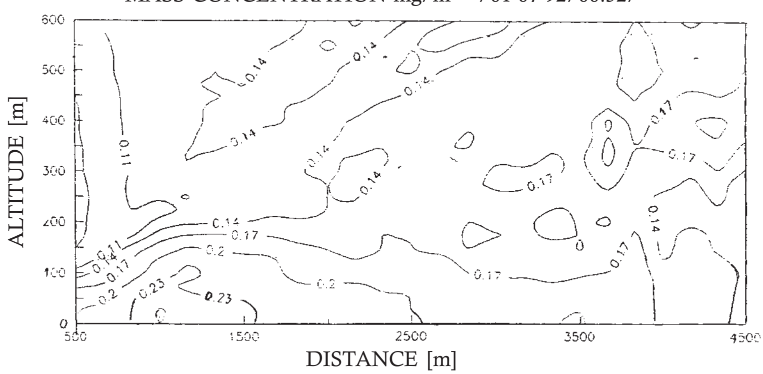

Fig. 12. The same as in Fig. 10, but for 1.07.1992 – 00:52h.

first study of this type in Bulgaria was presented in the publication of Donev *et al.* (1979). The spectral analysis is applied to data from simultaneous measurement in the Sofia'76 experiment of ground concentrations of SO_2, NO_2 and dust at a relatively large number of points in Sofia. This allows us to compare the individual fluctuations of concentrations at different parts of the city, and to see the general pattern of change in time. All autospectra render a notion of the distribution of the energy of a random process, because they are calculated in a normalized energetic type $S = f.S_{11}/s^2$, where S_{11} is an amplitude autospectrum, f - frequency, s^2 - dispersion. The series are treated, initially, with high-frequency filters having a permeability of T≤60h, T≤120h, T≤180h to extract any nonstationary trends. Assessments of the spectra obtained were made mainly by using the first of these filters because the other two shorten the already short series (100-200 terms at intervals of 3 hours).

The energetic auto-spectra of the three pollutants in air samples at different parts of the city show the presence of three energy maxima around periods of 24, 12 and 6-8 hours. Each of these are shown in a different way (expressed sharply, weakly or absent) depending on the season, the type of pollutant, the altitude and location of the air sampling point in the city (there were two points at 20m - on Levski sq. and Mladost 1 district-NIMH). The autospectra from different stations, according to the number of basic maxima, are divided into three groups: a) basic spectrum group with three shaped maxima; b) spectra where the 24 hour period is weakly expressed - spectra obtained during the summer measurement period; c) spectra where the 12-hour period is weakly expressed - mainly for NO_2. The explanations of these peculiarities of the fluctuations are given on the assumption that the concentrations of the pollutants are determined by two major factors - the parameters of the sources and the meteorological conditions. In the SO_2 and NO_2 spectra, for the greater part of the stations, there is a tendency for the establishment of a third characteristic energy maximum during the 6-8 hours period. This wave, of course, has a shorter amplitude than the 24 hours and 12 hours waves. It is probably due to fluctuations of the sources' regime because there is a minimum in the spectrum of the meteorological elements around these values. Some similar changes were detected for SO_2 in a range of cities like New York, Otawa, Sankt Petersburg where, alongside the basic fluctuations having synoptical (3.2 days) and 24 hours periods, some weak energetic maxima are observed for periods of 12-14 hours and about 6 (even 4) hours in winter and 7.5-8 hours in summer. These fluctuations of NO_2 in the cities are probably due to the three peaks in transport traffic - in the morning, around noon and in the evening. The dust auto-spectra in summer does not show a well expressed periodicity, i.e. it resembles random noise. The probable cause of this could be the dust from the earth surface being elevated by the vehicles and occasionally - by the stronger wind. In conclusion it is recommended that samples should be taken at smaller intervals (e.g., 1 hour) in order to obtain a more accurate assessments of the high-frequency part of the spectra where maxima obviously occur. The observations should not only be of equal intervals and continuous in time, but should also be extended to at least a month in order to improve the reliability of the assessments in different parts of the spectra, including the synoptic periods. The observations should also be done during different seasons for a few years in order to search for relationships with the long-periodical fluctuations of the meteorological elements - an essential part of the air pollution prognosis.

The space-time statistical structure of the air pollution field over residential and industrial regions provide valuable information for monitoring and to control strategy development. The structure of the two main urban pollutants – SO_2 and NO_2 have been studied in two field campaigns in 1976 and 1981-82 in Sofia (Syracov & Syracova, 1996). The first campaign consists of two measurement periods, named "winter" (Nov. 25-Dec. 9, 1976) and "summer" (June 10-25, 1976). Air samples were taken at 12 (respectively 10) sites in the town every 3 hours. The second campaign also had a winter (Nov. 20-Dec. 20, 1981; 16 sampling points) and a summer period (June 15-July 15, 1982; 15 points), and the time resolution of the measurements was 1,5 hours. Both experiments almost covered the same area including the center of the city. During the second campaign, a denser net of stations was used and the time lag was shorter and the campaign duration was longer compared to the first. The statistical structure of the field of the SO_2 and NO_2 concentrations in the air of Sofia is characterized by the space-time correlation and structure functions. As these functions represent two-dimensional surfaces, it is convenient to regard one of the variables (ρ-the distance between the stations and τ-the time lag) as an argument and the other as a parameter and vice versa. Thus, two sets of cross-sections are obtained of normalized functions, noted as $b^{\rho}(\tau)$ and $b^{\tau}(\rho)$. The results can only be treated qualitatively, but some basic features can be seen.

The most essential feature of the family of curves $b^{\rho}(\tau)$ for SO_2 (Fig. 13) is the rapid decrease in the correlation function with time. The time correlation functions $b^{0}(\tau)$ (i.e. $b^{\rho}(\tau)$ at $\rho=0$) reach

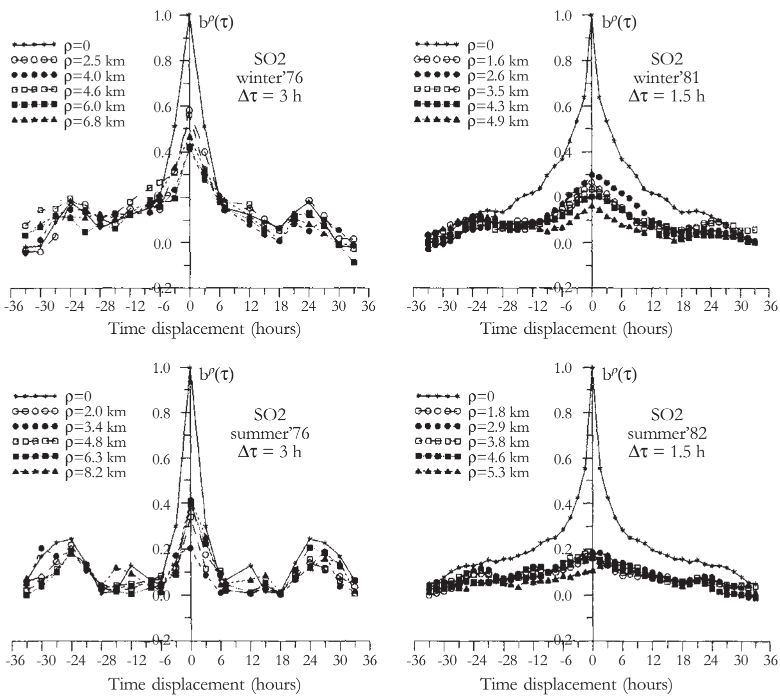

Fig. 13. Normalized space-time concentration functions for SO_2 as a function of τ at fixed ρ.

a value of 0.5 within time intervals of less than 3 hours, i.e. the time radius of correlation is less than 3 hours. Only in the winter period of the campaign (1981-1982) this radius is about 4 hours. At $\rho \neq 0$, the functions decrease more rapidly in summer than in winter. The time functions in the 1976 campaign possess a well-manifested secondary maximum at τ=24 hours that is related to the diurnal variation of the SO_2 concentrations. The analysis shows that after one time lag a new pollution field will be formed by multiple sources. That is why the maximum values for all the curves $b^{\rho}(\tau)$ turn out to be at $\tau=0$.

Fig. 14 presents the normalized space-time correlation functions for SO_2 as functions of distance ρ for fixed time lags τ i.e. $b^{\tau}(\rho)$. The space correlation functions (at $\tau=0$) also decrease very rapidly. The space radius of correlation ρ_c [$b^{\tau}(\rho_c)$= 0.5] is about 2 km for the first experiment and about 1 km for the second one.

Similar qualitative conclusions and values for orientation have been obtained for concentrations of NO_2 and dust (see Andreev, 1984) from data of the same campaigns.

The essential common result is that when the area is not very large, as in our case, the field of pollution can be considered locally homogeneous and isotropic.

The local wind field deformations over complex relief areas, considerably change the processes of transport and turbulent diffusion of pollutants and as a result, the air pollution distribution over these areas. On the basis of their laboratory modeling of the local flows over the Sofia valley, represented in the paper by Andreev *et al.* (this volume), Tucker (1989) has also

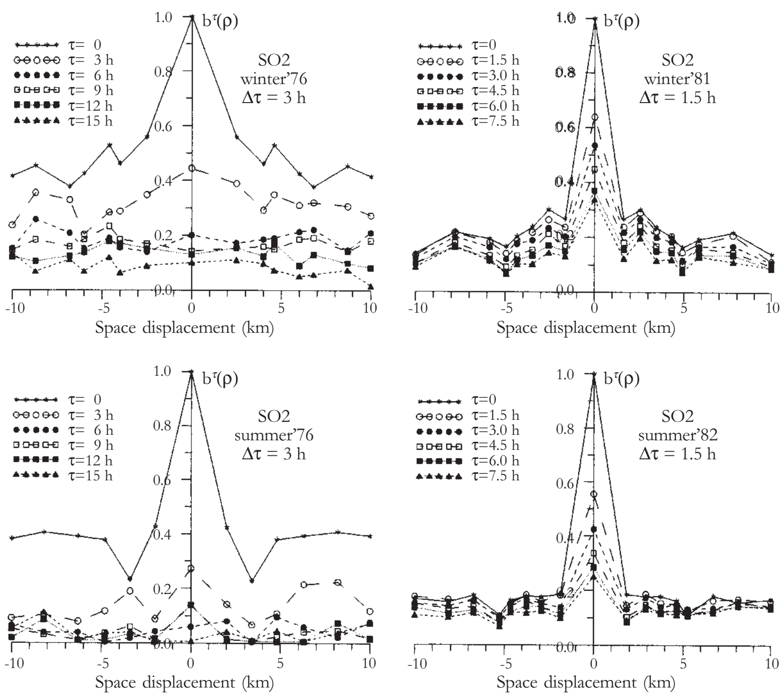

Fig. 14. Normalized space-time concentration functions for SO_2 as a function of ρ at fixed τ.

made conclusions on the distribution of the air pollutants in this valley during periods of the four cardinal wind directions.

When northerly winds occur, flow from sources to the east of the valley moves south-eastwards into the upper Maritza region. The eastern part of the Sofia valley is not affected by the city's pollution; however, these preliminary experiments had no dye source at the location of the industrial area of Kremikovtzi and this air probably drifts eastwards.

Air pollution episodes can occur over both Sofia and particularly Pernik during periods of easterly winds. Blocking occurs over Sofia, while an eddy in the lee of the Vitosha mountains causes a local circulation of air over Pernik, where local pollution sources are re-enforced by occasional insertions of air from Sofia.

During southerly winds, the western half of the Sofia valley, west of the Sofia, does not accumulate pollutants, and appears to be well swept with fluid moving northwards over the low hills and also northwestwards out of the valley. The eastern half of the valley, however, including Sofia, and the Looda Yana and Topolnitza valleys suffer from blocking of the circulation and transient lee eddies occur over this region. There is some indication of occasional northeasterly drift down into the Maritza valley.

During periods of westerly winds, the most interesting conclusion is that pollution from the Pernik area is likely to move northwards into the Sofia valley and to spread across the southern parts of the city of Sofia and along the north-facing slopes of the Vitosha mountains.

During the "winter" and "summer" periods of the air pollution field experiment in 1981-82 in Sofia, 62 and 104 air samples respectively were taken by a laboratory car at different distances on the lee side of the town. These measurements aimed at investigating the influence of this large city on the air pollution of the neighbouring areas (Andreev, 1996). Data processing started with a test in order to ascertain that a given sample had been taken on the lee side of the city. Wind data are a decisive factor for this test. Wind data analysis has shown significant changes in wind direction with height during observational periods. The largest ones are in the layer from the ground to a height of 500-700 m, reaching 45° during stronger wind, and even 180° when the speed is 2-3 m/s into the layer up to 500 m. Wind direction changes were more significant in the town periphery in comparison with the central parts. Correct information on the air pollution transport cannot be obtained from surface wind data, in most cases, with weak winds – up to 3-4 m/s. Only in cases of stronger winds (invasion type weather) there is coincidence between the surface wind and the wind within the 300 m layer. There are also days with significant wind changes not only in height but also in time. The time and height variability of the winds can be a cause for incorrectly determining the laboratory route for air sampling in such investigations. The route direction for air sampling during the experiment was selected operationally with the help of the surface and pilot-balloon wind measurements at Sofia's central meteorological station. Because of the incorrectly selected route, some air samples are defective. Special attention has been paid to cases with air pollution transport from the "Kremikovtzi" metallurgical plants, situated about 20 km North-East of Sofia's center. The cases with pilot-balloon wind at a level of 300-600 m from "Kremikovtsy" to the air sample points are included in a separate group. It is supposed that in these cases, "Kremikovtzi" plants contribute to air pollution at a given observation point. The large concentrations of SO_2 (Fig. 15) or other gases as NO and NO_2 at considerable wind speeds have led to the conclusion that a particular air sampling point has been placed under the direct influence of the Kremikovtzi plants' plume. The investigation shows that the "Kremikovtzi" metallurgical plants can considerably pollute the Sofia field with SO_2. NO and NO_2 pollution is more insignificant and their concentrations decrease more quickly with distance from the city center.

Mobile air samples taken westwards from Sofia when there is an easterly wind, is discussed separately because a health-recreation zone is situated into the mountain southwest of Sofia around the town of Bankja. The average SO_2 concentration increases in the direction of this mountain, the highest value (367,4 $\mu g/m^3$) was recorded in the village of Klissura on May 7, 1982 at 11 a.m. The average SO_2 concentration for this part of the Sofia valley, from mobile sampling, were about 1,5 times higher than that in the region under the influence of the metallurgical plants. This local maximum of SO_2 can be the result of either local air circulations (mountain and valley winds) or of the transport of pollutants from the neighbouring large towns of Sofia and Pernik. The latter is situated about 20 km south of the town Bankja. Tucker (1989) (see also Andreev, 1998) has shown, by laboratory modeling of air flow in the Sofia valley, that in the periods with easterly winds, blocking occurs over Sofia, while an eddy in the lee of the Vitosha mountains causes a local circulation of air over Pernik; occasional insertions of air from Sofia and Pernik into the air of Bankja can also be observed. Pollution from local sources can not be expected because there is no industry in the region of Bankja and no domestic heating during summer. This region requires a more detailed experiment on account of its importance as a health resort.

Some authors have shown an exponential decrease of SO_2 concentrations on the downwind side of big cities (see Landsberg, 1981). Andreev (1996) tried to verify this relationship by data from the air pollution field experiment in 1981-82 in Sofia. Acceptable results were obtained for SO_2 and NO_2 concentrations in the summer period (Fig. 16).

The dependence of concentration (*ln C*) on distance *r,* shown on Fig. 16, can be approximated by a linear equation in the form $\ln C = \ln C_0 - kr$, where C and C_0 are the SO_2 concentrations at the arbitrary distances of r and $r=0$, respectively, in the downwind side of the city of Sofia. The linear approximation of the dependence of *lnC* on distance enables us to get

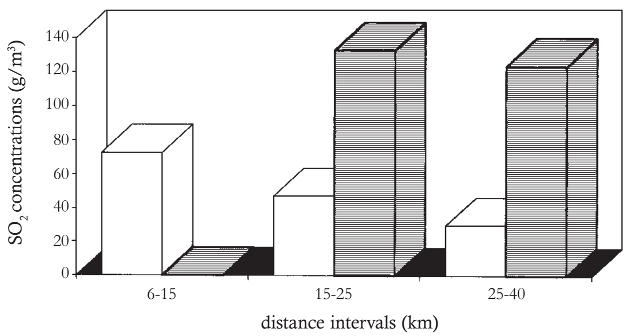

Fig. 15. Concentrations of SO_2 on the lee side of Sofia averaged for given distance intervals from the city center during the "summer" observation period in 1982. The concentrations under the influence of Sofia are plotted white and those of MP "Kremikovtsy" are in grey.

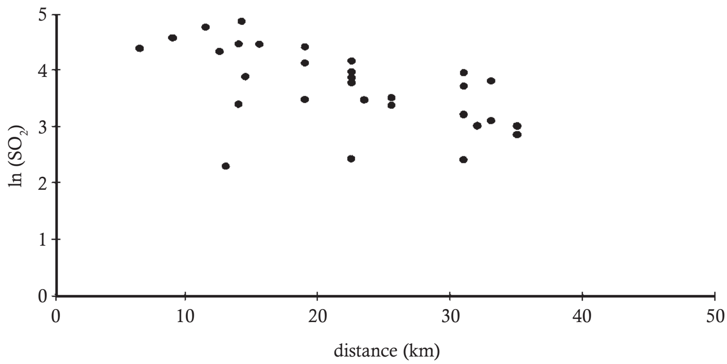

Fig. 16. The logarithm of SO_2 concentrations in the air – *ln* (SO_2) as a function of the distance from the city center on the lee side of the town for the summer period.

an idea of the values of the quantity "radius of influence" – r_{inf} i.e. that distance on the lee side after which no influence of the town is observed. For this purpose, the "concentration-distance" approximation equation has to take the form $r_{inf} = r / (1 - ln\ C/ln\ C_0)$. If the data from Fig. 16 are used and it is assumed that C_0 is equal to the average concentration at a distance of 6-15 km, then by the concentrations at distances r = 22 and r = 32 km, respectively, one can calculate that the radius of influence of Sofia is no more than 200-220 km for SO_2 and 60-80 km for NO_2. This distinction between the radius of influence of Sofia for SO_2 and NO_2 is probably due to the lower chemical activity and oxidation speed of SO_2 in comparison with nitrogen oxides. These assessments are intended for orientation only since they result from a formal extrapolation and many factors have not been taken into account such as the local pollution sources along the air transport trajectory; the chemical reactions with the participation of polluted gases; and the local orographical effect on air circulation, keeping in mind the presence of the high mountains around Sofia (see Tucker, 1989). In spite of this, the assessments appear reliable because similar values for the distribution of SO_2 were obtained by Zeferos *et al.* (2000). The authors explained the high values for SO_2 in Thessaloniki, Greece with the trans-boundary transport from the powerful sources in the region of the Steam Power Plant "Maritza-Iztok" with wind from east and north-east in the southeastern part of Bulgaria. Fig. 16 could be considered as an evaluation procedure of the accuracy of the data selection procedure. More precise empirical assessments could be obtained using a tracer experiment.

The other method for dealing with absences of direct observations in the atmosphere is the computer experiments with numerical models. Such experiments for the Sofia valley were made using a quasi-hydrostatic meso-scale model and an Eulerian dispersion model, created by the Geophysical Institute (Syrakov & Ganev, 1994; Dimitrova & Ganev, 2000; Dimitrova, 2001). The numerical experiments were conducted for an area of 105 to 75 km, a step of 1.5 km and 20 vertical levels at the following stationary meteorological conditions: a) calm weather or different directions of the given weak background wind; and b) stable or unstable stratification of air temperature. Real data for SO_2 emissions in Sofia for 1995 were used (Miloshev, 1997). The ground and vertically averaged (for the entire layer) concentration fields were obtained. In addition, the fields were obtained separately from high or low area (including domestic) sources because there are considerable differences in the distribution of emissions by them. The air pollution field depends considerably on the type of temperature stratification. These differences are also expressed in the absence of background winds as can be seen in Fig. 17 and Fig. 18.

The basic conclusion from the simulations in the conditions of high stability is that the meso-scale "slope wind" phenomenon is a dominant factor for the pollution field. The blocking effect of the mountain Vitosha affects the local circulation in such a way that it determines the accumulation of masses of polluted air at its northern slopes. The mountains around the field create a tendency for the retention and turning of the flow in a northern or southern wind and during a western or eastern influx – going around the obstacle. This is directly connected to the northwest-southeast orientation of the Sofia valley. The modeling results in the case of stable stratification correspond qualitatively well with the conclusions for the local air flows

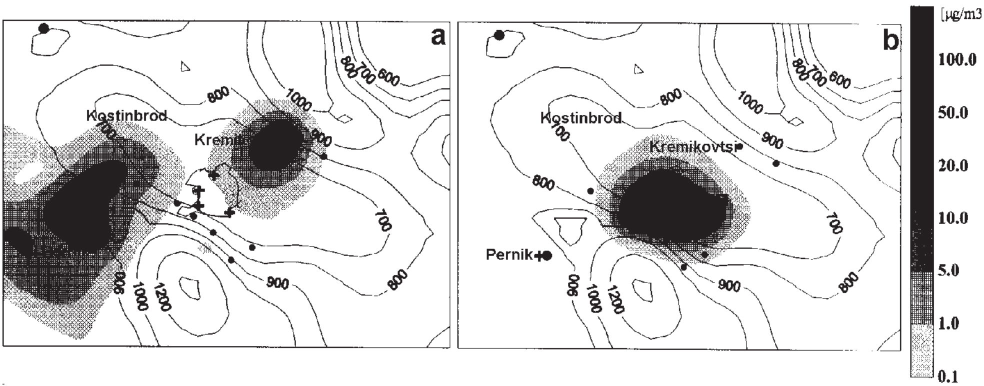

Fig. 17. Fields of the ground concentration of SO_2 formed by a) high and b) low area sources in a stable temperature stratification and an absence of background synoptic winds (Dimitrova, 2001).

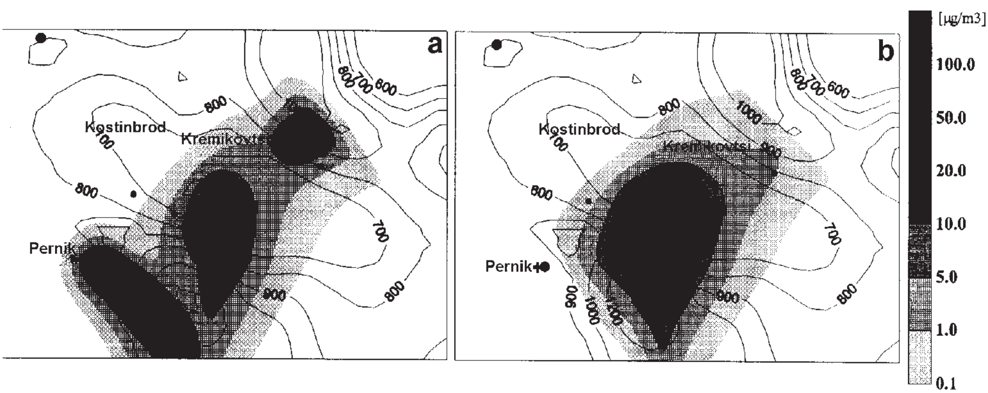

Fig. 18. Fields of the ground concentration of SO_2 formed by a) high and b) low area sources in an unstable temperature stratification and absence of synoptic winds (Dimitrova & Ganev, 2000).

and the distribution of air pollutants from laboratory water tank experiments (Tucker, 1989) and field campaigns (Andreev, 1998).

Pollution in the case of unstable temperature stratification in comparison with stable condition has the following peculiarities: a) pollution from low area sources reaches larger spatial scales; b) the high sources lead to pollution following by quantity the low ones unlike in a stable stratification; c) there is a tendency for the elevation of air masses and pollutants from Sofia up the northern slopes of Vitosha; d) no transport of pollutants is detected at high point sources from Pernik to Sofia as in a stable stratification; e) an additional increase in air pollution in Sofia from "Kremikovtzi" point sources under eastern winds and unstable stratification is obtained.

The general conclusion is that in all situations, air pollution with SO_2 is due to sources in Sofia and the city centre is most polluted.

A numerical modeling of air pollution at the local scale (for the urban part of Sofia or a separate segment of it) was completed by D. Syrakov and collaborators (see Batchvarova *et al.*, 2000; Tzenkova *et al.*, 2000). The versions of the original EPA (USA) Plume-model were used for the diffusion of gasses and aerosol particles and were developed into two groups. The one group - models working with climatic (mean) characteristics, use meteorological parameters from perennial data, representative for the region, like the rose wind, mean air temperature and precipitation quantity, mean duration of precipitation and the stability class typical for the respective period of the year. The input data for the other group of models are the measured values of the meteorological elements. One of the purposes was for the modeling results to compensate for the lack of representative data for the mean annual concentrations in a sufficiently dense network of points in Sofia City. Other necessary input information for the diffusion models is data for the emissions of harmful compounds into the air by different sources in the city. This is difficult because up to now no thorough inventory has been made on the number, type and emissions of sources in the city. In this case, modeling calculations were carried out for the complex pollution of the city by seven large point sources (mainly thermo-electric plants and MP "Kremikovtzi") and by some area pollutants - industrial plants in Gara Iskar and Gorubljane (the study was ordered for the projected "Sofia-Iztok" zone only), as well as the approximate emissions of NO_2 and lead by the city transport, on data for 1995.

In Fig. 19, the model fields of the mean annual concentrations of NO_2 in Sofia is presented as an example. The calculations are completed in regular network 37x25 km with a calculation step of 500 m. The climatic norms for the meteorological elements for the NIMH-Sofia station were used as input data. As a result of the positioning of the sources, some zones of a higher level of air pollution with NO_2 are formed in the areas of MP "Kremikovtzi" (a result of the combined action of industrial and transportation pollution) and over the city centre (a result of intensive road traffic). A third zone can be seen in the area of Gara Iskar and the northern parts of the Mladost district, as well as around the industrial zone Kazichene. These zones are a result of both the developed industry in the region and of considerable transportation flow. Such secondary maximuma are likely to occur in other parts of the city if the data for emissions by smaller industrial objects are entered. It should be noted that the map shows concentrations close to the mean annual MAC=60 $\mu g/m^3$ around MP "Kremikovtzi" only (the maximal calculated value is 43,6 $\mu g/m^3$). From this we can conclude that the level of NO_2, at least for these areas, can exceed MAC and for the city as a whole it can increase if all sources are considered.

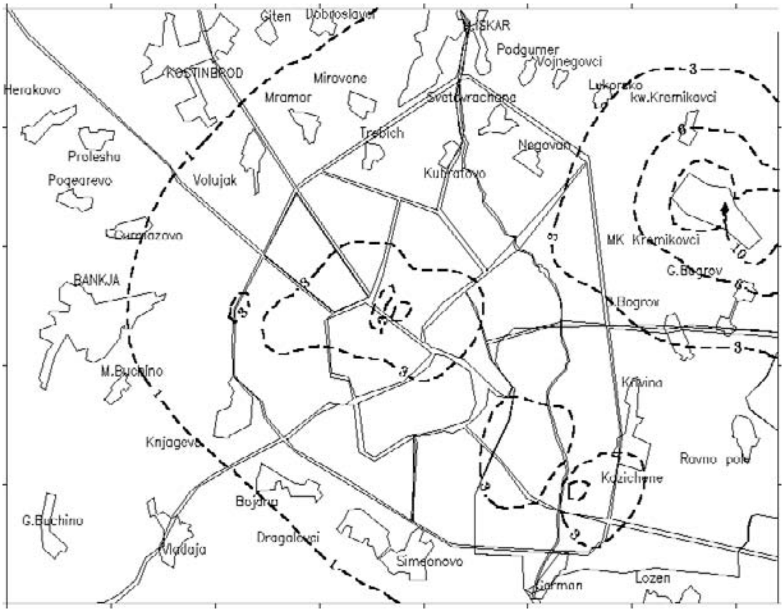

Fig. 19. Mean annual concentrations of NO_2 into the surface air in the city of Sofia, obtained by a variant of PLUME-models.

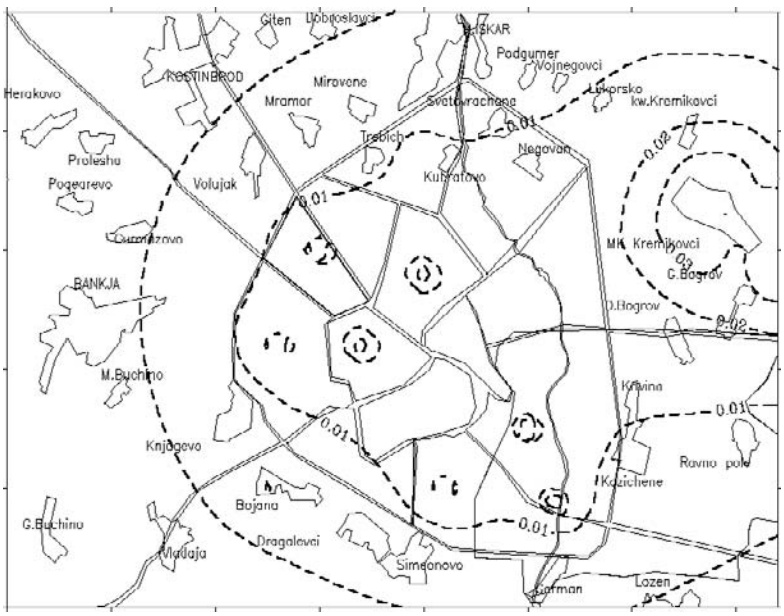

Fig. 20. Mean annual concentrations of Pb into the surface air in the city of Sofia, obtained by a variant of PLUME-models.

The mean annual modeling field in Fig. 20 does not show any concentrations of lead in the air above the norm in Sofia. The air in the eastern part of Sofia appears more polluted, probably due to a combination of powerful industrial sources (in MP "Kremikovtzi" particularly) and intensive road traffic. The maximal value 0,091 $\mu g/m^3$ is in the area of MP "Kremikovtzi" and is one order lower than the annual mean MAC=1 $\mu g/m^3$.

The concentration fields of cadmium and SO_2 in the air in Sofia were also calculated, as well as the mean annual deposition of the gasses and aerosol particles containing these metals. A separate calculation was carried out for the eco-zone "Sofia-Iztok". The modelling results are qualitatively similar to measurements from the short-term field experiments.

Calculation, by Gaussian plume models, of the climatic air pollution fields of SO_2, NO_2, Pb, and Cd in the eastern part of Sofia are published in Tzenkova *et al.* (2000). All calculations are made on a 9x6 km uniform grid, with 100 m steps. The pollution produced from the large point ("Kremikovtzi") and the linear sources (a set of 33 line elements with car traffic) in the region were studied. The meteorological and emission data from 1995 are used as input information. As a result of the model calculations, the average monthly ground fields of the concentrations of the considered air pollutants and their deposition in $\mu g/m^3$ and $\mu g/m^2$ respectively, are obtained. The ground field of NO_2 concentrations generated by traffic during May 1995 displays no MAC-exceeding values. The maximum model value is 17.7 $\mu g/m^3$. In principle, pollution is centered in large streets, the highest gradients being observed perpendicular to the street. The NO_2 field formed by the joint action of car traffic and point sources is shown in Fig. 21. The main road forms a secondary maximum southward of the Thermal Power Station "Sofia Iztok". The maximum model value [19.4 $\mu g/m^3$] remains an order of magnitude less than MPC – 100 $\mu g/m^3$.

The sources of lead in the air of the region are traffic and the Non-Ferrous Metal Plant (NFMP; now is called "Sofia Med") – Gara Iskar. The maximum model value of the pollution field concentrations caused by car traffic is only 0.089 $\mu g/m^3$ (MAC is 1$\mu g/m^3$). The contribution of the NFMP is centered around the plant, i.e. its influence on the city part is not noticeable. The calculated lead deposition field (Fig. 22) is similar to the air pollution concentration field. The deposition field has higher values compared to the concentration fields. Thus, for instance, the maximum model value is 239 $\mu g/m^2$, with a norm of 250 $\mu g/m^2$. Taking into account that the model yields mean diurnal deposition per month, we suppose that on particular days, the norm is exceeded. Considering that lead accumulates, the effect of car traffic on lead pollution is significant even if the NFMP pollution is not taken into account.

In the region considered, the NFMP is the only emitter of cadmium into the atmosphere. Maximum model values of Cd in the air of 0.026 $\mu g/m^3$ (MAC= 0.02 $\mu g/m^3$) is obtained at distance of about 250 m northwest and northeast of the plant. The NFMP generates an average diurnal cadmium deposition field exceeding the norm all over the territory of the Iskar Municipality, and the northern part of the Mladost district and the Gorublyane quarter. The norm is exceeded by 200% above parts of the Drujba district, Vrana Residence, Iskar Station, and partially, above the Gorublyane quarter. A maximum is identified in the vicinity of the NFMP, exceeding 8.8 times the norm (equal to 5 $\mu g/m^2$).

Fig. 21. The model mean monthly deposition of NO_2 [μg/m[3]].

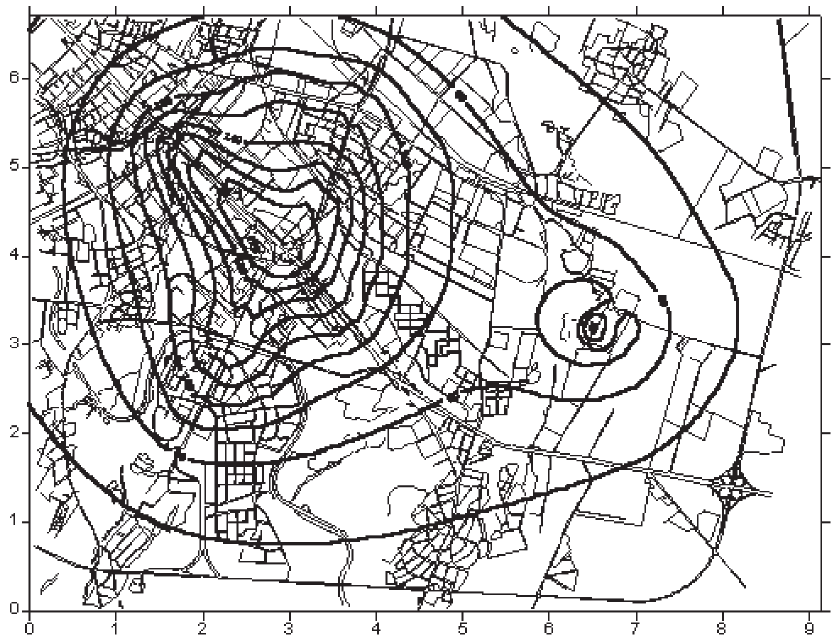

Fig. 22. The model mean monthly deposition of Pb per day [μg/m[2]].

The connection of air pollution with the synoptic situation and especially with the type of pressure started activities (see Andreev, 1984) for the creation of a method to determine the level of air pollution in Sofia. The idea of the synoptic-statistical approach was followed as suggested in 1971 by Sonkin (1991). Such a prognosis method was created and implemented in the operational work of NIMH. It is valid for the cold half-year period when air pollution reaches high values. The method is based on the classification of the synoptic situations at which, three levels of air pollution are observed – low, moderate and high. Experience has shown that for air quality assessment in the cities where the sources of pollutants are numerous and dispersed at random over the town, it is convenient to use a physical-statistical approach (see Sonkin, 1991; Sonkin *et al.*, 1999). The levels of air pollution can be defined by the integral indicator $p=m/n$ (see Sonkin, 1991), where n is the total number for a given measurement, and m – the number of cases when the concentration of the compound q is greater than 1.5 times the mean seasonal concentration of the compound q_m, i.e. $q>1,5q_m$ at all sampling points in the city. The term p can be calculated both for a single compound or a group of compounds. In cases when p is determined as a summary of the concentrations of a few compounds, the compounds that are specific for certain sources should be extracted, i.e. it is better to use measurements of compounds that are characteristic for urbanized regions. It is recommended to calculate this integral parameter p for cities that have at least 3 stationary points and the measurements for all compounds are no less than 20 for the separate days. The parameter p allows us to avoid one of the difficult factors of air pollution – the characteristics of emissions in the city and in this way to connect air pollution level only with meteorological conditions. It was shown that p is close to the first coefficient in the expansion of the concentration field by natural orthogonal functions; the coefficient of correlation between these values reaches 0.85-0.95 (Berlyand, 1985). The values of p vary from 0 to 1. The level of air pollution is usually classified into three gradations according to the p value: *low* ($p<0,20$), *moderate* (mean) ($0,20\leq p\leq 0,35$) and *high* ($p>0,35$). The dispersion of compounds in the atmosphere is different for different meteorological conditions. The meteorological conditions, which are represented by a complex of parameters, can be determined by different synoptic situations. So, if considerable repeatability of one of the three levels of air pollution is detected in certain synoptic situations, this will allow us to use the weather forecast as a prognosis of the air pollution level in the city as a whole.

The existence of this connection is logical since the synoptic situations reflect the effect of each meteorological parameter on the dispersion of compounds in the atmosphere. A similar approach was successfully used for the pointed type of prognosis in many cities in Russia (see Berlyand, 1985). It must be noted that the applicability of such an approach must be proved separately for each city. In some cases it is not possible to formulate a thorough method but only prognostic rules. In the publication of Vassilev *et al.* (1989), the first version of a method for a short-term prognosis of the level of air pollution in Sofia is presented for the cold half-year period. It was later specified in some works of I. Vassilev in the 1990s. The method is based on a specially prepared classification of the regional synoptic situations determining three levels of air pollution, defined by the values of the parameter p. The classification of the synoptic situations created for our region is presented in detail in Vassilev (1998). The statistical processing of the synoptical materials and the measurements of air pollution in Sofia for a

5-years period (1981-1986), detected three types of synoptic processes that create conditions for the formation of some of the three levels of air pollution during the cold half-year period. These types are the following: *type A* – synoptic situations for high levels of air pollution; *type B* – synoptic situations for moderate (medium) levels of air pollution; *type C* – synoptic situations for low levels of air pollution. From the pressure system point of view, such situations are: *type A* – anticyclones from the south, north-west or east; a warm sector of the cyclone, passing through Bulgaria; *type B* – non-gradient pressure fields; north-west, north-east or west high pressure ridges; *type C* – a cold atmospheric front passing through Bulgaria; at the rear of the cold front passage; a cyclone including Mediterranean cyclones or cyclo-genesis at the Balkan Peninsula region. Some prognostic rules obtained by statistical processing also appear useful for such a method. Thus the parameter p for a given day depends considerably on its value from the previous day. If a low level of air pollution was observed, then in only 10% of the cases is expected that it would rise considerably in the next day. It is also useful to consider the conditions that determine the pollution potential. In some cities the possibilities for such a prognosis are only the formulation of a certain number of prognostic rules. In other cases regression equations are used that connect the parameter p with some predictors such as wind speed, the atmosphere stability indicator and its enforcement, value of p for the previous day, the parameters of a ground or high inversion, radius of the isobaric curvature or Laplasian of pressure, etc. (see Berlyand, 1985). In our opinion, research should be conducted for obtaining such statistical relationships because they can make a prognosis on a synoptical approach more precise. At the present stage of development of knowledge on the processes and the development of measurements of the concentration fields, wind and other meteorological elements, it appears that in the urbanized regions or in areas with complex relief, it is correct to predict the level of air pollution in the region as a whole (i.e. by integral parameters), and not the concentrations that can be very different in different points of the region.

Table 3. Precipitation pH in the city of Sofia (district "Mladost I") for the period 1991-2001.

For years	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	All period
Number of samples	56	22	83	92	125	105	96	95	114	10	136	934
pH average	7,0	6,6	6,5	7,0	6,5	6,8	7,1	7,0	6,2	5,3	6,3	
Number of pH≤5,3	1	2	6	3	5	4	1	1	4	4	25	56
% pH≤5,3	1,8	9,1	7,2	3,3	4,0	3,8	1,0	1,0	3,5	40	5,4	7,2
Number of 5,3<pH<5,8	2	1	4	2	6	3	2	3	20	3	9	55
% 5,3<pH<5,8	3,6	4,5	4,8	2,2	4,8	2,9	2,1	3,2	17,5	30	15,1	8,2
Number of pH≥5,3	53	19	73	87	114	98	93	91	90	3	102	824
% pH≥5,3	94,6	86,4	88,0	94,5	91,2	93,3	96,9	95,8	78,9	30	75	77,4

The assessments of the chemical composition of precipitation must be included in the characteristics of the environmental quality in a region. *Acid Precipitation Measurement* has been conducted regularly in our country from the middle of the 1980's at half (20) of the NIMH synoptic stations. The chemical composition of the precipitation in Sofia is characterized here only by the *pH* indicator. Characteristics based on data from measurements of *pH* at the station NIMH in the district "Mladost I" during the 1991-2001 period are presented in Table 3. In particular, 934 samples were taken at times of precipitation. In 823 of these samples (88,1 %), $pH>5.8$, or there is an alkaline composition of precipitation; in 55 (5,9%) – $5.3< pH<5.8$, or neutral; in *56* (6,0 %) $pH<5,3$ or acidic precipitation. The prevailing alkaline composition of the precipitation is seen in the mean value for the period $pH=6.6$. The extreme values are $pH_{min}=2,4$ and $pH_{max}=8,0$ respectively. Such composition of precipitation is typical for big cities.

DISCUSSION

The level of air pollution in a certain region is determined by two major factors – the sources of harmful emissions and the meteorological conditions at regional and local scale. These factors determine the possibility for chemical transformations in the atmosphere. The air in Sofia has worsen due to the mutual action of these two major factors. One reason is the location of the city in a mountain valley. That is why the *meteorological conditions* during the greater part of the year are characterized by calm weather and temperature inversions, which can be very intensive in winter.

Another factor is the presence of various types of *sources of air pollutants* since the city is a big residential and industrial centre. About 27% of the territory of Sofia city are production areas and 34% of these areas are located no more than 4 km from city center. Many enterprises are within residential districts or in close proximity to them. The production zones in Sofia are combined into 3 large industrial complexes within the city (*Northern,* East*ern* and West*ern)* and 3 large industrial and transport complexes around the City (*Kremikovtsi-Gara Iana, Gara Elin Pelin-Ravno pole, along a direction Sofia-Slivnitsa)*. The *domestic (household) sources* in residential areas are also interesting in relation to air. The influence of these sources in Sofia decreased gradually over time. Domestic heating in combination of the inversions created heavy fog and high air pollution levels in the 1950's and 1960's. The town has grown considerably in size in the 1970's and 1980's. At that time, the central heating system was built and the effect was seen in the reduction of days with heavy fog and high air pollution levels in winter. The change of fuel from oil to gas in the late 1980's has decreased the concentrations of SO_2. The concentration of NO_2 in the city often exceed the accepted standards due to transport and new fuel. *Transport*, as an air pollutant, is a serious problem for all big cities around the world and especially for capitals where the majority of vehicles travel. This problem is even more serious for Sofia because the automobile park of the country consists mainly of old vehicles (mean age 14 years for cars and 8-10 for busses) traveling on roads with technical characteristics (sizes, coverings, radius, length slope etc.) that do not comply with normative requirements and are badly maintained. The result is a decreased traffic capacity, traffic jams and accidents. That is why automobile transport in Sofia has a low ecological index and is one of the most serious pollutants of the city.

To characterize the influence of the local meteorological conditions on air pollution in Sofia, the term “air pollution potential” was used. It allows us to obtain a notion of air pollution that can be formed under the influence of the climate and microclimate of the region assuming that the source parameters remain constant. According to this approach, the relative pollution potential in the city, calculated for low sources and cold emissions, is classified into 6 degrees, using data for the frequency of ground temperature inversions, of weak winds (up to 1m/s) and fog, as well as for cases of a combination of these factors. The air pollution potential in Sofia was presented form data for the NIMH-Sofia station and its mean monthly values were calculated for the three climatic terms of observation (02, 08 and 14h local time) and for the whole 24 hour period. The pollution potential calculated on data from 02h measurements throughout the year appears very high (V_A degree), and even in February-May it is exceptionally high – V_B degree. This means that throughout the year climatic conditions exist helping the detaining of compounds in the surface air. The potential at 08h in the morning is very high for the April-September period, and during the cold half-year period – high to very high. The conditions for dispersion of compounds are considerably better at 14h and during the greater part of the year the potential is moderate; only for the November-January period it is high.

Air quality in a certain region is characterized by different summary indicators of the concentration fields of the major air pollutants. The mean concentrations determined by perennial observations in a network of stationary points for air quality monitoring is an example. We already discussed the insufficient reliability of the mean concentrations of air pollutants for all cities in Bulgaria, including the capital. The reason for this is that in the national air quality monitoring system these values are calculated only on measurements for a part of the 24 hours period and a part of the days in a week. This limits the use of data in studies by Bulgarian experts, at least for the meteorological aspect of the air pollution problem. This is why only some characteristics of the concentration fields in Sofia are discussed, being calculated on measurements from the national air quality monitoring system. For example, it was shown that the annual concentration of SO_2 in the southeastern part of the city are lower than in the northern industrial zone and in the center of the city. The differences are bigger during morning hours and in winter than in the afternoon and in summer. The considerable influence of temperature inversions and the related fog on air pollution is also shown. These phenomena are due to the hollow character of the Sofia valley. Some interesting conclusions concerning the location of aerosol layers in relation to the temperature inversion layers were obtained with the help of lidar systems by assistants of the Institute of Electronics at BAS.

The defects of the data from the National air quality monitoring network make the notion of the concentration fields of air pollutants and its connection with the meteorological conditions more reliable. These are obtained through data from field experiments. Such experiments were conducted in Sofia for 20-30 days in typical summer and winter months as the density of the sampling points and the frequency of measurements all over the city (in 1976, 1982-1983) or in some city parts (1992-1993) were increased. Conclusions were specified by the data for Sofia with respect to the distribution of air pollutants and its connection to meteorological conditions, known from research for other cities. It was shown that there are two clearly expressed dangerous meteorological situations at present: a) stagnation of air usually combined with radiative inversions of temperature when a simultaneous increase of air pollution is observed in different parts of the city and; b) a stable wind directed from high pollutant sources (mainly for SO_2), so-called "critical wind speed" that lead to extremely high air pollution levels at the lee side of the sources. A well known fact was confirmed that in rainy conditions there is a local pollution minimum. A specific conclusion was made, however, that the concentrations of dangerous gasses and dust in surface air are relatively lower up to around 3 hours after the end of the precipitation. A correlation was established between the mean diurnal speed of surface winds and the SO_2 and NO_2 concentrations.

The regionalization of cities by air pollution levels represents an interest for some purposes and especially for correct planning. The best set of characteristics for this purpose are the mean seasonal and annual concentrations of pollutants. To look for such a representative empirical regionalization of the city, however, a large number of stations are needed, encompassing all microclimatic regions of the city. Only 7-8 such stations, working throughout the year are available in Sofia. The working regime of the stations does not allow us to correctly determine mean values for 24 hours, a month, a season or a year. That is why the regionalization was conducted on the spatial distribution of the basic gas pollutants (SO_2 and NO_2) and the quantity of lead and dust on data from one month experiments during the 1981-1982 period.

The regionalization of Sofia based on the distribution of the major air pollutant (SO_2, NO_2, NO) measurements from these experiments, coincided well with the microclimatic regionalization suggested by Blaskova *et al.* (1983) (see the article of Andreev *et al.* in this volume). Thus, for example, *the cleaner regions of the city* from the viewpoint of the mean monthly concentrations of gas pollutants are most frequently at the "Foot of the mountain" and the "Open hollow field". This is similar to the comparatively more favourable micrometeorological conditions of the dispersion of air pollutants, although some of the regions are situated in proximity with the northern industrial zone or powerful pollution sources such as MP"Kremikovtzi". Similary, *the most polluted* areas are the ones of the microclimatic region "City Centre". *The regionalization of Sofia using dust particle concentrations in the air* show that the most polluted areas appear to be the northeastern districts (mainly H. Dimitar), part of the main centre between the astronomical observatory in Borisovata gradina and the observatory in the district of Ivan Vazov, and around the Dianabad district. The cleanest areas are the foot of the mountain at Bankja and Bojana. During the summer period (15.6 - 15.7.1982), dust pollution is lower and more uniformly distributed. Only two points are distinguished: H.Dimitar with the highest and Bankja with the lowest dust concentrations. The pollution is of the diffusion type, i.e. the dust concentrations are weakly influenced by local sources and form after some time during which transport and diffusion occur. It should be noted that the dust sources are not only of anthropogenic origin; dust elevated and carried by wind also influences the process. This is probably why air pollution is relatively lower in the main city centre where the streets and squares have artificial coverings and are maintained better than in the outlying districts or where intensive construction work was under way during this period (for example in the Ivan Vazov district). The irregular distribution of lead content in dust particles during winter periods is noteworthy. The mean concentration of lead at the most polluted point HEA (39, Stambouliiski bld. close to Vazrajdane sq.) is almost 33 times greater than at the cleanest station in Bankja. The central city parts are most polluted, including the Astronomical observatory and the Krusta district. This can be explained by the greater concentration of transport vehicles in these areas. The high dust concentrations around the National observatory in the Ivan Vazov and Dianabad districts are probably not connected to automobile transport, because the lead content in dust is relatively low at these points. This is probably due to the influence of the nearby construction work. At the same time, the relatively low quantity of dust in the air in the Hladilnika district (point Krusta) contains considerable lead quantities, probably due to intensive road traffic. A very high lead concentration is shown in the Botunetz district that is due to its proximity to MP "Kremikovtzi".

The use of lidar systems in a range of cities in Bulgaria, including Sofia, shows that this is the best method to diagnose the distribution of aerosol particle layers in the atmosphere and the change in distribution over time. This allows us to document intensive emissions from local sources and to register smoke plumes. This is done by horizontal and vertical sections of the aerosol concentration fields with a lidar system at different altitudes in the atmosphere and periods of time. In our opinion a way should be found to compare lidar measurements of the absolute concentrations of aerosol particles in the air with data from direct measurements. The term "relative" concentration, used by some researchers of the Institute of Electronics during the 1994 measurements and later (see Donev *et al.*, 1995 or Kolev *et al.*, 2000), should also be clarified.

Periodical fluctuations in the concentrations of air pollutants are also a subject of research. The fluctuations are obtained by statistical processing of time series data. Donev *et al.* (1979). applied the mathematical Fourier-spectral analysis to time series data from simultaneous measurements of ground concentrations of SO_2, NO_2 and dust at a relatively large number of points in Sofia during the Sofia'76 experiment. This allows us to compare the individual fluctuations of concentrations at different parts of the city and to study on how these patterns change in time. The energetic autospectra of the three pollutants on air samples at different parts of the city show the presence of three energy maxima around periods of 24, 12 and 6-8 hours. Each maximum can appear in a different way (it is expressed sharply or weakly, or is absent) depending on the season, the type of pollutant, altitude and the location of the sampling point in the city. Similar changes were detected for SO_2 in a range of cities like New York, Otawa, and Sankt Petersburg where alongside the basic fluctuations having synoptical (3.2 days) and 24 hours periods, some weak energetic maxima are observed for periods of 12-14 hours and 6 (even 4) hours in winter and 7.5-8 hours in summer. The analogical fluctuations of NO_2 in the cities are probably due to the three peaks in traffic - in the morning, around noon and in the evening. The dust autospectrum in summer does not show a well expressed regularity. The cause for this could be the dust from the earth surface being elevated by the transport vehicles and, occasionally, by wind. It is recommended samples to be taken at smaller intervals (e.g., 1 hour) in order to obtain more accurate assessments for the high-frequency part of the spectra where obvious maxima occur. It would be preferable if observations last at least a month in order to improve the reliability of the assessments at the different parts of the spectra, including the synoptical periods. The observations should also be performed during different seasons for a few years in order to search for connections to long-period fluctuations of the meteorological elements; this is essential for the air pollution prognosis.

The space-time statistical structure of the two main urban pollutants-SO_2 and NO_2 have been studied by Syracov & Syracova (1996) on the basis of data from two field campaigns in 1976 and 1981-82 in Sofia. This structure has been characterized by the normalized space-time correlation and structure functions of SO_2 and NO_2 concentrations. As a result of the considerations above, a number of conclusions can be drawn. For instance, the curves $b^{\rho}(\tau)$ of the normalized space-time correlation functions for SO_2 or NO_2 as functions of time τ at fixed distance ρ, show well-pronounced diurnal variations. The correlation of gas-pollutant concentrations decreases rapidly both in space and time. The time correlation functions $b^{0}(\tau)$ (i.e. $b^{\rho}(\tau)$ at $\rho=0$) for SO_2 (Fig. 13) reach the value of 0.5 within time intervals of less than 3 hours i.e. the time radius of correlation is less than 3 hours. Only during the winter period of the 1981-1982 campaign this radius is about 4 hours. At $\rho\neq0$, the functions decrease more rapidly in summer than in winter. In some cases, the curves $b^{\tau}(\rho)$ – the correlation functions for SO_2 or NO_2 as functions of the distance ρ at fixed time lags τ, can give information on the characteristic scales of pollution field heterogeneities; when the area is not very large, as it is in our case, the field of pollution can be considered locally homogeneous and isotropic. The space correlation functions (at $\tau=0$) also decrease very rapidly. The space radius of correlation ρ_c [$b^{\tau}(\rho_c)= 0.5$] is about 2 km for the first experiment and about 1 km for the second one. Similar qualitative conclusions and assessments have been obtained for concentrations of NO_2 and dust, from data of the same campaigns (see Andreev, 1984).

The local wind field deformations over complex relief areas considerably change the processes of the transport and turbulent diffusion of pollutants and as a result, the air pollution distribution over these areas. On the basis of laboratory modeling of the local flows over the Sofia valley, Tucker (1989) has also made conclusions on the distribution of air pollutants in this valley during periods of each of the four wind directions i.e. northerly, easterly, southerly and westerly. However, the interesting conclusions described above are based on traces from dye emitted at a height which corresponds to 400 m above the valley floor, and for only one value of the dimensionless parameter Nh/U, corresponding to conditions of high stability, high obstacles and low wind speed in the real atmosphere. Fluid movement at this level may not be representative of that at the surface because, for this value of Nh/U, flow behaviour below and above the effective barrier height may be quite different. This is an aspect of the model that merits closer study. Also, the areas of preferred blocking and lee-eddy formation may be better revealed by flow regimes with lower values of Nh/U, corresponding to conditions of lower stability and obstacles, and high wind speed in the real atmosphere.

The continuation of these studies cannot be continued under current conditions on the basis of direct observations in the atmosphere or laboratory modeling, due to high costs. One possible approach is presented by computer experiments with numerical models. Such kinds of experiments for the Sofia valley were made by quasi-hydrostatic meso-scale models and Eulerian dispersion models, created at the Geophysical Institute. The numerical experiments were conducted in calm weather conditions or at different directions of the given weak background wind and at stable or unstable stratification of the air temperature. It appears that the air pollution field depends considerably on the type of temperature stratification, as the differences are evident in the absence of background wind. The modeling results in the case of stable stratification, coincide well with the conclusions for the local air flows and the distribution of air pollutants in the Sofia valley, obtained from laboratory water tank experiments (Tucker, 1989) and field campaigns (Andreev, 1998). The basic conclusion from the simulations in conditions of high stability is that the "slope wind" phenomenon is a dominant factor for the pollution field. The blocking effect of the mountain Vitosha affects the local circulation in such a way that it determines the accumulation of masses of polluted air at its northern slopes. The mountains enclosing the field create a tendency for deceleration and reversing of the flow in northern or southern wind conditions and during a western or eastern influx. The concentration fields during unstable temperature stratifications depend on the sources of emission into the air. Thus, for example, the pollution from low area sources diffuses into greater spatial scales; the high sources lead to pollution following by quantity the low ones unlike in a stable stratification; no transport of pollutants is detected by high point sources from Pernik to Sofia as it is in a stable stratification; an additional air pollution in Sofia is obtained by point sources of MP "Kremikovtzi". The general conclusion is that in all situations, air pollution with SO_2 is due to sources situated mainly in Sofia, and the centre is most polluted.

Air pollution in residential areas and industrial zones in the country, including Sofia, was also studied using two types of models (versions of the widely used EPA Plume-model). These models were applied to Sofia both for the entire city and for separate city parts. The one group of models give a notion of the mean characteristics of air pollution for longer periods of time (season, year) using meteorological information of the region. The other versions of models use air pollution data obtained during short periods. It is clear that the input data for this group of models are the measured values of the meteorological elements. A substantial difficulty in applying these models in Sofia, and also for all diffusion models, is the supply of the necessary input data for the emissions into the air of harmful compounds from different sources in the city. The reason for this is that up to now no thorough inventory has been performed on the number, type and emissions of sources in the city. That is why the modeling calculations are conducted for only a part, of the sources. It is an urgent task for environment protection agencies to complete an inventory of the emissions of harmful compounds into air for the residential areas in the country. This is extremely necessary not only for the model calculations but also for a range of other tasks. There is sufficient experience gathered in this regard (see BC-EMEP, 1994-1999; Miloshev, 1997; Ivantcheva *et al.*, 1997).

The availability of an air pollution prognosis method is of great interest for various applications and, above all, for the creation of informative-warning systems. In spite of the considerable experience in numerical modelling, up to now, no method for air pollution prognosis is available in Bulgaria on the basis of meteorological and diffusion models. The only successful attempt is based on the synoptic-statistical approach suggested in 1971 by Sonkin (1991). These studies started in the early 1980's (see Djolov *et al.*, 1980; Andreev, 1984; Vassilev, 1998). An operational method for short-term prognosis of the air pollution level in Sofia, based on Sonkin's idea, was created and implemented in NIMH only at the end of the 1980's. In the publication of Vassilev *et al.* (1989), the first version of this method is presented, which is valid for the cold half-year period. It was later (in the 1990's) specified in some studies by I. Vassilev. Because one of the basic components of this approach, the classification of the regional synoptic situations, is related to the entire territory of the country, the creation of one such prognosis method for different living areas in the country can be done quite fast. It is only necessary to obtain data for the concentrations of air pollutants in the area to calculate the integral parameter *p* and to study its connection with different synoptic situations included in the classification. If due to a lack of the needed number of sampling points, or a sufficient volume of air pollution information, than the prognosis method cannot be constructed for a certain city. It would be useful to obtain, by statistical processing, some prognostic rules.

The implementation of a thorough study on the chemical composition of precipitation for the country as a whole and Sofia in particular is important because a NIMH network for such observations has been functioning for over 15 years. At present, it consists of 20 points located in parts of the NIMH synoptic stations that are approximately uniformly distributed in the country. 14 stations functioned during the whole period but precipitation sampling is possible from all of the 30 NIMH synoptic stations.

ACKNOWLEDGMENTS

We thank the editors L. Penev, J. Niemela, D. J. Kotze and N. Chipev for the invitation to contribute to this volume. Special thanks are due again to D. J. Kotze and L. Penev for editing the text.

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Water Quality of the Sofia Region

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Abstract

We studied rivers flowing through the territory of the city of Sofia and surrounding towns and villages, groundwater in the region and the influence of the urbanized territory on surface and ground water quality. The development of the city of Sofia – the growth, and the setting up of new transport connections impose the actualization of the existing information, which was poor and partial.

The material collected during a three-year intensive investigation (1992-1995) and additional expeditions afterwards gave a possibility for the examination and assessment of the quality condition of water in the city of Sofia and surrounding regions. In the present paper, assessment of the condition of the rivers and the range of variation of the examined polluters are given. The rivers are categorized according to the Bulgarian legislation.

Key words

Water quality, surface and groundwater, urbanization, pollution, Sofia, Bulgaria.

A. SURFACE WATER QUALITY IN THE REGION OF THE CITY OF SOFIA

INTRODUCTION

We studied rivers that flow through Sofia City and the surrounding villages and the impact of the urbanized territory of this region on the river water quality.

Sofia is situated in the southwestern part of the Sofia Plain, which is bordered to the south by the Vitosha mountains, and to the north – by the Stara planina mountains. The largest river in the region is the Iskar (the basin catchment area from Pancharevo dam to the Novi Iskar town is 2365 km^2), which has five main tributaries – Slatinska river (catchment area – 106 km^2), Vladaiska river

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 129-163

(151 km^2), Bankyanska river (260,7 km^2), Lesnovska river (1096 km^2), and Blato river (774 km^2). Among them, only the Lesnovska river is a right tributary. With regard to the detailed examination of the impact of the town surroundings on the regime and the quality condition of the water, the river valleys of the two main tributaries of the rivers Slatinska and Vladayska are examined separately. These are the Perlovska river – left tributary of the Slatinska river and the Suhodolska river – left tributary of the Vladayska river (Fig. 1).

The development of the city of Sofia – the development of blocks of flats, industrial construction, river correction activities, and the setting up of new transport connections impose the actualization of the existing map information. For this purpose we made a special investigation and gathered information on the condition of the rivers of Sofia, their topographical situation, and the conditions of the river beds and banks. Suitable spots for monitoring stations were selected. Later, these spots were cleared and cleaned from mechanical waste, which disturbe the hydraulic regime. A temporary monitoring system was organized for the period of intensive investigation (1992-1995). Additionally, after this period several expeditions were carried out using the same monitoring system, which confirmed the results of the previous investigation, and the lack of any significant alterations in the water quality conditions after the period of intensive monitoring.

The Vladayska river takes its source from peats in the north of the line Cherni vrah-Sedloto, as its most eastern feeder is close to the sources of the Boyanska river. The length of the river

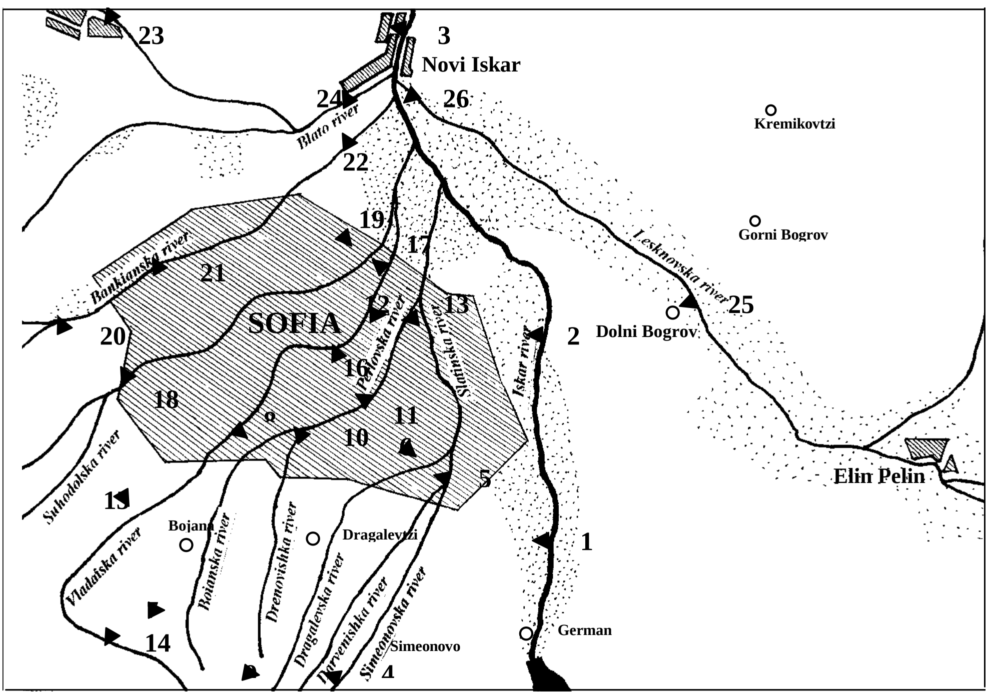

Fig. 1. Scheme of the surface water sampling stations.

is 37.2 km and its valley in the northwest is a border between the Vitosha and the Lulin mountains. Like most Vitosha rivers in their uppermost part, the Vladayska river flows down through the peat or under rocks. Above the Vladaya village, the river water is brought by a covered channel in Studena dam and thus near the village the bed is almost dry. Below Vladaya, the river changes its direction from northwest to northeast and runs through the Vladaya gorge, passes through the city of Sofia and joins the Suhodolska river a little before they flow together into the Iskar river.

The Boyanska river takes its source very close to the Vladayska river. It runs parallel with the Vladayska river, and at Momina skala hut the river turns northeast and the valley becomes extremely steep. In this section the Boyana waterfall is situated, as well as the main captation of the Sofia-Vitosha water supply system. In the past, this part of the Boyanska river was called Stara reka. After the river flows out of the narrowness above Boyana, surrounded by high rocks (the river in this section is known as Kriva river because of the topography), it passes through the foot of the mountain and the city of Sofia, crossing the center of the capital (Fig. 1). A little before the center, the Boyanska river receives water from the Drenovishka river in the region of the Southern park and continues under the name Perlovska river, which has an underground section in the region of the National Palace of Culture. The rivers Perlovska and Slatinska join in the City's outlines before their general inflowing into the Iskar river.

The Dragalevska river also takes its source from the peats. As the river leaves the peat-bogs, it flows in a deep, steep, rocky bed. The gorge ends under the Dragalevtsi monastery, where a large embankment starts. Recently, the water of the river was turned aside in the hollows of the famous Dragalevski water mills. Recently, the deserted inwash was turned into a park. The Dragalevska river inflows into the Darvenishka river at the Plovdiv road and here both rivers become the Slatinska river.

The Simeonovska (Stara) river had once been a small spring, drying during summer time. More than a 100 years ago some of the Iskar river water was turned aside into the Simeonovska river via channel called "Shikova vada". The river is a right tributary of the Darvenishka river.

The Suhodolska river springs from the Lulin mountain and after the river crosses the City at the residential district Lulin, it flows into the Vladayska river.

Bankyanska river (Kakatch) also takes its source from the Lulin mountain and after the river passes the northern suburbs of Sofia, it flows directly into the Iskar river.

One of the biggest and longest rivers in Bulgaria is the Iskar river. Its source area is situated in the central part of the Rila mountain. After the Iskar river leaves Samokovsko field, it enters the Pancharevo gorge between the mountains Plana, Lozenska and Vitosha. Between Pancharevo and the town Novi Iskar, the river flows across the Sofia Plain where several tributaries flow into it (the most important of which are: Lesnovska river and Blato river). The Lesnovska river is the only important right tributary of Iskar in the studied region. It flows through the industrial metallurgical zone Kremikovtsi, the basic collector of waste water. The river is the main collector of the surface water in the region of the city of Sofia and its surroundings.

MATERIAL AND METHODS

The existing regular hydrometrical network in the region is too poor and consists of only five hydrometrical stations – Vladayska river in the region of Kniajevo residential district (HMS 98), Bankyanska river – Republika residential district (HMS 100A), Lesnovska river – Dolni Bogrov village (HMS 97), Blato river – Petarch village (HMS 99) and Iskar river at Novi Iskar town (HMS 101). The station at Novi Iskar town represents a great interest as a locking section of the whole river system in the region of the city of Sofia. In this section, the influence of the whole investigated urbanized agglomeration of the Greater Sofia Area on the hydrological regime and the quality of the surface water can be noticed.

The quantity of the water in the examined river valleys can be judged by the average annual values of the amount of water. As an example of the examined region, we give data for: Vladayska river at the Kniajevo residential district (HMS 98) where Qav=0.82 m^3/s, Iskar river at Novi Iskar town (HMS 101) where Qav=22.80 m^3/s and Blato river – Petarch village (HMS 99) with Qav=1.02 m^3/s.

General characteristic of the annual changes of the river run-off for the Sofia rivers are the big run-off in spring and the small one at the end of the summer and the beginning of the autumn. This general regularity changes very little depending on the horizontal and vertical alteration of the physical and geographic conditions, the microclimate, the geological structure and the regulating features of the riverbeds. It should be remembered that in the City area, many of the rivers are corrected and flow in unnatural concrete beds with rectangular or double trapezium-shaped sections. Because of the increased permeability of the riverbeds after correction activities, the high water in the spring season does not cause any significant damages in the City. During spring, the rivers in the region have rain and snow inflow. Until the beginning of snow melting, the mountains usually accumulate thick snow cover. When the snow cover begins to melt in the beginning of spring, the maximum of the high water forms in April-May. Summer and autumn water discharge is very often comparatively small because of the decreased quantity of rain and the high infiltration ability of the soils, i.e. during the summer season there is quick evaporation of water. The rivers during these periods have mainly underground feeding. Only rare, intensive rainfall can cause a considerable increase of the flowing water quantity.

As an example, the monthly run-off (%) at the locking section of the river water system at Novi Iskar HMS is as follows: I – 6,4 %, II – 8,6 %, III – 12,9%, IV – 14,4 %, V – 16,6 %, VI – 13,9 %, VII – 6,5 %, VIII – 1,8%, IX – 1,8 %, X – 3,2 %, XI – 3,4 %, XII – 8,5 %.

Similarly, the monthly distribution in another hydrometrical stations, i.e. of Vladayska River at Kniajevo is: I- 4,3 %, II – 3,1 %, III – 10,7 %, IV – 9,7 %, V- 24,5 % VI – 19,2 %, VII – 4,8 %, VIII – 2,4 %, IX – 1,6%, X – 2,6 %, XI – 7,1 %, XII – 10,0 %.

The total number of the monitoring points of the temporarily created monitoring system is 26 (Table 1).

The observed points can be divided into four groups:

I group – background stations. Here hydrological measurements and examinations of the river water quality are taken in conditions of clean water and a lack of significant pollutants.

These points are situated in the upper most river sections, away from the built-up areas. Such points are N 4 above Simeonovo and N 7 above Boyana, N 9 above Dragalevtsi, N 14 above Vladaya, and N 23 close to Petarch village (Fig. 1, Table 1).

Table 1. Temporary Sofia water monitoring network and frequency of observation.

River, location of the monitoring point	Number of the monitoring point	Frequency of observation
Iskar river		
Camping Vrania	1	every two weeks
Vrajdebna	2	every two weeks
Novi Iskar town	3	every week
Slatinska river		
Simeonovo	4	every four weeks
Dragalevtsi	9	every four weeks
Tzarigradsko shaussee	5	every two weeks
4th km.	6	every two weeks
estuary	13	every week
Perlovska river		
Boiana	7	every four weeks
Rutchai square	8	every two weeks
National Palace of the Culture	10	every two weeks
Orlov most	11	every week
estuary	12	every week
Vladaiska river		
Vladaia village	14	every four weeks
Tchernia koss	15	every four weeks
Stotchna gara	16	every week
estuary	17	every week
Suhodolska river		
Orion station	18	every two weeks
estuary	19	every week
Bankianska river		
Pushkarov Institute	20	every four weeks
Evropa boulevard	21	every two weeks
estuary	22	every two weeks
Blato river		
Petarch village	23	every four weeks
estuary	24	every two weeks
Lesnovska river		
Dolni Bogrov	25	every two weeks
estuary	26	every two weeks

II group – stations, which are slightly polluted as a result of the impact of the city. In this group stations are included, in which the river water quality is slightly changed compared to the background stations. They are situated outside the city of Sofia and report on the river water quality before the intensive interference of the city. These are stations N1 Vrania, N15 above Knyajevo, N18 Orion, and N 20 above Pushkarov Institute.

III group – end stations at the mouths of the river systems situated within the city limits. At these stations the alterations, after the passing of the water through built-up territories, are registered. Such stations are – N3 above Novy Iskar – locking section of the river system, N5 river mouth of Darvenishka river, N8 river mouth of Boyanska, N10 river mouth of Darvenishka river, N12 river mouth of Perlovska river, N13 river mouth of Slatinska river, N17 river mouth of Vladayska river, N19 river mouth of Suhodolska river, N22 river mouth of Bankenska river, N24 river mouth of Blato river, and N26 river mouth of Lesnovska river.

IV group – basic observation stations at crucial points of the city's surroundings. They have an intermediate position between the background and the end estuary stations. The examinations record the condition of the river water in the core of the big City. Such crucial points are selected in the residential district Vrajdebna – N2, on river Slatinska – N6, Orlov most – N11, Stochna gara – N16, boul. Evropa – N21. N26 near Dolni Bogrov village is also included.

The frequency of observations at the different stations is different. Obviously, one point of observation is necessary for the background stations, where there are no pollutants, and another at both the basic and end stations, where more constant control for the water quality is necessary. The observation stations are divided into three groups – where samples are taken monthly, stations with weekly observations and stations where observations are taken every two weeks. The observation at some stations, with proven stability of the water quality, is more rare. The general observation scheme is presented in Table 1.

We studied the river water and the deposits at the bottoms of the riverbeds in the region of the city of Sofia. The natural water currants are a two-phase system: liquid and solid. A big part of the floating deposit fragments, because of their higher weight, precipitate on the bottom and form the upper layer of the riverbed. Because of the natural ability of the solid particles to absorb some pollutants (especially heavy metals), the bottom deposits are natural depots of these pollutants. Under given hydraulic and hydrological conditions, these fragments can turn into a floating condition and can lead to secondary pollution of the river flows. During the monitoring investigations, parallel with the water sampling, a deposit sampling was also taken.

The method of examination depends on the type, the character and the concentration of the hydrochemical parameters. The assessment of the water quality is made according to the published Ordinance N7 in the Official Gazette from 8.08.1986 "Ordinance for determination of the pollution of the surface flowing water". The results are compared with the active normative documents of the EU and the USA. The following parameters for water pollution are observed and are divided into five groups:

Group A – parameters for organic pollution and oxygen regime: permanganate oxidation – Ox, dissolved oxygen – O_2, biological oxygen demand on the fifth day – BOD5.

Group B – parameters for mineral composition: chlorides – Cl, sulfates – SO_4, hydrocarbonate – HCO_3, calcium – Ca, magnesium – Mg, total materialization, sodium – Na and potassium – K.

Group C – biogenic components: ammonium ions – NH_4, nitrite – NO_2, nitrates – NO_3, phosphate – PO_4.

Group D – toxic metals and other toxic microcomponents: chromium – Cr, nickel – Ni, copper – Cu, cobalt – Co, cadmium – Cd, lead – Pb, manganese – Mn, zinc – Zn, arsenic – As, selenium – Se, molybdenum – Mo, bismuth – Bi, iron – Fe, antimony – Sb, tungsten – W, aluminum- Al and tin – Sn.

Group E – special parameters: pH, phenols, turbidity, electrical conductivity and total hardness – (H).

Water and sediment analyses are elaborated at the chemical laboratory at the National Institute of Meteorology and Hydrology. The fixing of dissolved oxygen was done at the monitoring points in situ at the moment of sampling. The elements of group D were examined through atom-absorption analysis. Separately, the data were reanalyzed at the chemical laboratory of the Institute of Mining and Geology using the method of inductive-connected plasma (ICP). The process of mineralization of the sediment analyses is a necessary preliminary stage, in which the examined toxic elements were dissolved in a water solution; these analyses were performed in the chemical laboratory of the National Institute of Meteorology and Hydrology.

RESULTS

The obtained information includes three years of hydrological cycles, which allowed for statistical assessments. The hydrological measurements at the new system of monitoring stations are not enough to evaluate the hydrochemical and hydrological regime in the rivers, and in clearing the dynamic scheme of spreading of the pollutants. At present we give an assessment of the condition of the rivers, the range of variation of the examined polluters and the rivers are categorized according to the Bulgarian legislation.

1. Parameters of the organic pollution and oxygen regime (group A)

The examination of the main factors for the forming and seasonal dynamics of the organic substances in the rivers is impeded to a certain degree by the absence of reliable methods for their direct specification. The quantity content of the organic substances can be judged by the factors – the dissolved oxygen (O_2), the permanganate oxidation (Ox) and the biological demand of oxygen on the fifth day (BOD5). The doubled value of the permanent oxidation indicator, Ox is accepted as an approximation for assessing the content of the organic material in the water. The dynamics in the change of the oxygen regime and the quantity of the organic substances is in direct dependence on the hydrological and temperature peculiarities of the river flows, and depends on the regime of dropping of the waste water.

The range of alteration of the basic parameters for the organic pollution and oxygen regime of the examined river flows are shown in Table 2.

Table 2. Content of dissolved oxygen, BOD5 and permanganate oxidation in the water of the Sofia rivers.

River, monitoring point	N	O_2 mg/l			BOD5 mg/l			Oxidation mg/l		
		min	max	average	min	max	average	min	max	average
Iskar river										
Camping Vrania	1	7.8	10.6	9.5	3.5	5.7	4.4	2.6	8.3	5.3
Vrajdebna	2	2.7	8.1	5.2	8.8	21.4	12.8	3.7	27.6	11.4
Novi Iskar town	3	2.4	7.0	4.9	10.4	18.6	13.0	5.7	14.4	10.5
Slatinska river										
Simeonovo	4	8.9	10.2	9.4	2.2	4.3	3.7	3.2	4.4	3.9
Dragalevtzi	9	9.2	10.8	10.2	3.9	4.8	4.1	2.2	6.2	4.5
Tzarigradsko sh.	5	8.4	11.8	10.1	1.9	6.3	4.7	3.2	5.4	4.8
4th km.	6	8.4	13.4	9.8	1.9	5.1	3.9	2.9	4.8	3.9
estuary	13	6.1	7.8	7.1	2.5	8.0	5.1	4.1	8.0	6.6
Perlovska river										
Boiana	7	9.2	10.2	9.4	4.2	5.0	4.8	4.1	6.2	4.9
Rutchai square	8	8.4	10.6	9.2	3.0	9.2	5.8	4.5	13.0	5.9
Palace of Culture	10	9.5	12.3	11.1	2.7	8.7	5.9	2.7	4.8	4.2
Orlov most	11	5.2	10.3	7.5	4.1	13.5	8.5	4.2	9.8	7.8
estuary	12	4.9	10.8	7.4	3.0	12.5	8.6	2.9	13.3	8.6
Vladaiska river										
Vladaia village	14	8.9	10.5	9.5	4.1	5.8	5.0	3.0	6.9	5.5
Tchernia kos	15	8.4	9.9	9.2	3.6	7.9	5.3	3.0	8.0	5.6
Stotchna gara	16	6.7	10.8	8.7	3.0	12.4	7.4	3.7	11.8	7.9
estuary	17	5.0	10.2	7.4	4.1	13.4	9.2	5.0	28.8	16.1
Suhodolska river										
Orion str.	18	7.9	11.9	9.7	4.7	10.6	7.4	3.7	13.2	8.5
estuary	19	3.3	9.2	6.1	7.0	24.1	13.9	2.8	29.0	15.7
Bankianska river										
Pushkarov inst.	20	5.7	11.9	8.9	4.4	10.5	6.5	6.2	8.3	7.2
Evropa blv.	21	5.7	10.5	8.3	6.5	10.4	8.1	5.6	9.7	7.5
estuary	22	4.6	11.4	8.1	5.7	16.2	11.2	5.5	15.7	10.1
Blato river										
Petarch village	23	9.7	11.9	10.7	2.7	4.1	3.6	3.4	4.3	3.7
estuary	24	3.1	7.6	5.2	5.2	14.2	9.8	4.0	6.6	5.8
Lesnovska river										
Dolni Bogrov	25	7.7	11.2	9.2	3.5	6.7	5.3	2.4	6.4	4.8
estuary	26	4.3	7.6	6.1	4.6	12.2	8.4	4.5	13.8	8.9

The data show the existence of organic pollution and tends to increase along the examined river valley. At the background stations there are no pollution of organic character, with maximum values at the river mouth sections. Very high levels of pollution is found in the lower flows of the rivers Suhodolska, Bankianska, Perlovska and Iskar after the Vrajdebna residential district. For example – in the Iskar river for the section between Vrania and the Novi Iskar town, dissolved oxygen decreases almost two-fold, the biological need for oxygen increases three times and the permanganate oxidizing, which is an indicator of the content of organic matter, increases two-fold. A general trend exists for a doubling, and in places even more, of the organic pollution of the waters in the Sofia rivers after crossing the urbanized territory. To visualize the significant increase of the organic content in the water through the city, a graph for the Perlovska river (average values) is presented in Fig. 2. On the contrary, the content of dissolved oxygen decreases. Some improvement of the water quality is registered in the region after the South park at the inflow of the very clear Drenovishka river.

We categorized the water according to Ordinance N 7 from 1986, for indicators and norms for determining the quality of the surface water (Official gazette issue 96 from 12.12.1986). According to this categorization, the water quality in the Sofia rivers varies from category I to III. The rivers are mainly of category II. If the same results are comprised with the acting legislation in the EC, there would be mainly waters from category III, because of higher thresholds of values of some of the indicators. For example, BOD is assessed according to Bulgarian legislation for categories I, II and III as follows – 5, 15 and 25 mg/l. According to the norms of the EC, the comparative values are – 3, 5, and 7 mg/l. Obviously, the impact of the city on the organic content in the river water is very important and significant mainly because of municipal wastewater.

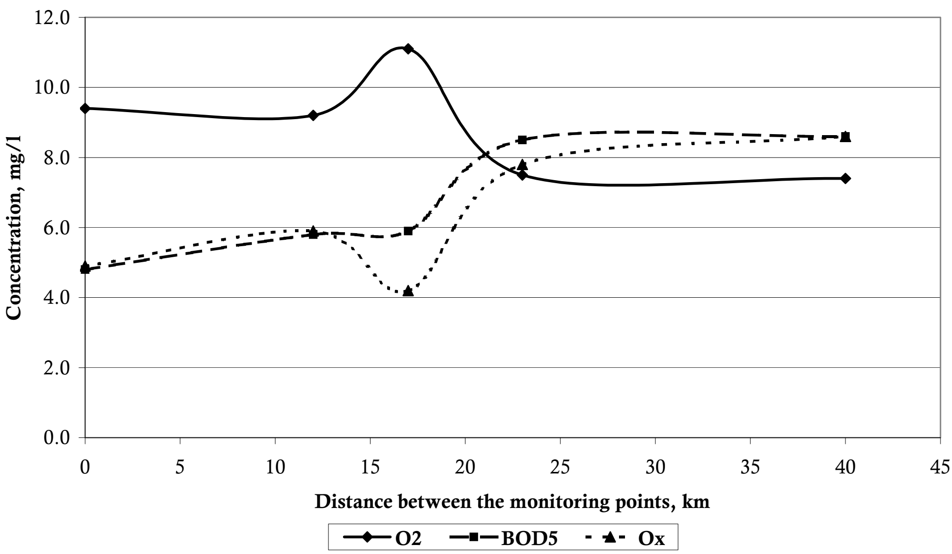

Fig. 2. Longitudinal distribution of the parameters of the oxygen regime and organic content in the water of the Perlovska river.

2. Parameters of the mineral composition (B Group)

Main ions, which characterize the mineral composition of the water, are: hydrocarbonate (HCO_3), sulfates (SO_4), chlorides (Cl), calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) ions. The results from the analyses are given in Table 3.

Table 3. Content of mineral components in the water of the Sofia rivers.

River, monitoring point	N	HCO_3 mg/l			SO_4 mg/l			Cl mg/l		
		min	max	average	min	max	average	min	max	average
Iskar river										
Camping Vrania	1	112.8	137.2	12.5	28.0	97.5	61.8	14.4	21.6	18.5
Vrajdebna	2	125.0	167.7	145.2	35.4	98.8	70.5	19.2	34.2	25.6
Novi Iskar town	3	137.2	183.0	162.0	41.6	147.3	92.3	24.0	37.2	31.2
Slatinska river										
Simeonovo	4	12.3	24.7	15.1	21.0	55.8	36.5	7.4	7.6	7.4
Dragalevtzi	9	15.0	33.5	26.3	4.5	50.6	25.3	4.0	5.6	4.7
Tzarigradsko sh.	5	88.4	131.1	99.2	21.0	127.2	67.5	11.8	26.0	15.0
4th km.	6	70.1	155.5	97.9	15.6	131.1	71.2	11.9	20.8	16.5
estuary	13	85.4	118.9	101.3	17.7	131.3	72.5	20.8	38.8	28.5
Perlovska river										
Boiana	7	15.0	24.4	19.5	4.5	11.1	7.6	4.0	7.2	5.8
Rutchai square	8	39.6	106.7	71.2	7.8	122.6	66.3	8.4	15.6	11.9
Palace of Culture	10	61.1	115.9	85.6	11.1	138.3	74.2	8.8	20.0	12.5
Orlov most	11	70.1	137.2	101.2	16.4	135.8	71.9	13.0	35.6	22.6
estuary	12	76.2	128.9	105.7	14.2	132.5	75.9	12.4	21.6	19.5
Vladaiska river										
Vladaia village	14	33.5	42.7	37.2	30.4	50.2	32.5	6.0	7.3	6.5
Tchernia kos	15	47.5	82.3	62.1	30.0	39.9	36.5	10.4	17.8	14.8
Stotchna gara	16	82.3	118.8	101.3	7.8	141.6	72.4	15.6	37.4	25.4
estuary	17	82.3	176.9	127.8	29.2	224.1	125.5	12.8	375.2	185.2
Suhodolska river										
Orion str.	18	134.2	222.6	169.5	30.0	148.9	83.1	22.0	26.4	22.4
estuary	19	82.3	268.4	177.5	19.3	154.3	85.5	17.2	30.4	22.6
Bankianska river										
Pushkarov inst.	20	70.8	192.1	98.6	47.7	92.2	61.0	15.2	39.6	25.9
Evropa blv.	21	76.2	193.2	135.4	34.5	90.1	61.2	15.4	26.6	22.3
estuary	22	170.8	320.0	244.1	50.9	76.9	63.5	21.6	30.0	25.7
Blato river										
Petarch village	23	225.7	259.1	240.2	32.5	59.3	44.5	17.4	47.0	31.4
estuary	24	170.0	341.6	254.1	53.5	219.7	137.5	26.4	87.0	55.6
Lesnovska river										
Dolni Bogrov	25	152.6	210.4	181.2	46.1	219.7	131.2	21.0	87.0	52.2
estuary	26	125.0	189.0	158.3	97.1	138.7	115.2	25.2	45.0	34.1

Table 3. Continued.

River, monitoring point	N	Ca mg/l			Mg mg/l			Na+K mg/l		
		min	max	average	min	max	average	min	max	average
Iskar river										
Camping Vrania	1	29.0	41.7	33.9	2.6	7.8	5.1	18.8	57.0	36.8
Vrajdebna	2	33.7	42.5	37.2	6.8	9.7	7.5	25.0	54.8	41.2
Novi Iskar town	3	40.9	53.7	46.5	7.3	21.4	12.9	12.5	77.3	43.5
Slatinska river										
Simeonovo	4	12.9	16.8	14.5	0.5	1.0	0.9	8.0	33.2	21.0
Dragalevtzi	9	5.9	15.2	10.2	0.5	0.6	0.8	3.2	22.8	12.5
Tzarigradsko sh.	5	29.1	40.9	29.6	2.4	8.3	5.2	25.2	76.5	50.8
4th km.	6	24.0	32.9	24.9	2.9	6.8	4.8	15.0	69.0	48.2
estuary	13	25.6	35.3	30.1	3.9	7.3	5.6	22.5	74.5	53.3
Perlovska river										
Boiana	7	5.6	8.8	7.9	0.2	0.5	0.5	3.2	16.5	9.5
Rutchai square	8	11.2	18.2	12.8	0.5	3.9	2.5	6.0	45.5	26.2
Palace of Culture	10	18.4	31.3	22.5	1.5	7.8	4.9	8.2	53.4	31.2
Orlov most	11	20.8	28.9	23.1	1.0	8.8	5.2	7.2	76.2	40.8
estuary	12	19.2	27.5	25.4	2.9	7.3	5.2	5.5	69.5	41.5
Vladaiska river										
Vladaia village	14	11.2	14.4	11.8	1.5	2.9	2.8	18.2	27.8	22.8
Tchernia kos	15	16.9	26.4	20.7	2.4	4.9	3.9	16.7	48.0	23.0
Stotchna gara	16	16.6	35.0	26.3	3.2	6.8	5.5	10.5	73.8	41.1
estuary	17	24.8	58.5	42.5	4.4	15.6	11.2	16.0	273.8	141.5
Suhodolska river										
Orion str.	18	40.9	55.3	49.3	8.3	28.1	15.9	25.8	81.0	52.6
estuary	19	24.1	46.5	33.2	1.1	20.8	12.4	13.5	79.5	44.5
Bankianska river										
Pushkarov inst.	20	44.1	53.7	37.5	9.7	12.6	12.5	27.8	54.5	40.2
Evropa blv.	21	25.6	53.7	38.5	3.4	27.3	14.8	18.8	53.2	35.8
estuary	22	45.7	83.4	62.5	9.7	17.0	14.9	10.2	47.0	36.0
Blato river										
Petarch village	23	68.1	77.8	71.2	2.3	14.5	8.5	16.0	71.0	42.5
estuary	24	76.2	136.3	103.2	16.5	40.9	29.6	19.3	93.2	55.3
Lesnovska river										
Dolni Bogrov	25	43.3	136.6	89.7	10.7	37.7	25.6	13.2	51.0	31.5
estuary	26	33.7	68.9	50.2	8.8	37.7	25.4	47.2	75.3	61.2

Table 3. Continued.

River, monitoring point	**N**	**Hardness °H** min	max	average	**SUM mg/l** min	max	average
Iskar river							
Camping Vrania	1	5.8	7.6	6.9	212.6	367.3	186.9
Vrajdebna	2	7.0	7.8	7.1	248.6	418.4	352.2
Novi Iskar town	3	8.2	11.0	9.5	279.0	537.8	401.3
Slatinska river							
Simeonovo	4	2.0	2.5	2.1	64.3	142.6	105.4
Dragalevtzi	9	0.9	2.2	1.8	33.3	128.9	82.5
Tzarigradsko sh.	5	5.6	7.3	6.6	185.1	413.0	291.2
4th km.	6	4.2	6.2	5.3	144.6	419.8	277.9
estuary	13	4.9	6.8	6.2	180.4	417.4	315.6
Perlovska river							
Boiana	7	0.9	1.3	1.5	33.1	71.1	55.4
Rutchai square	8	1.7	4.9	3.9	77.8	335.7	207.0
Palace of Culture	10	3.1	6.2	4.2	116.2	373.6	239.7
Orlov most	11	3.8	5.5	4.4	137.0	433.4	274.2
estuary	12	3.4	5.6	4.4	135.8	412.4	288.4
Vladaiska river							
Vladaia village	14	2.1	2.5	2.5	102.4	146.6	129.9
Tchernia kos	15	2.9	4.8	4.0	127.2	227.6	178.9
Stotchna gara	16	3.5	6.2	4.8	140.5	423.3	283.5
estuary	17	4.5	11.8	9.5	182.0	1134.5	647.0
Suhodolska river							
Orion str.	18	7.7	11.1	9.9	282.5	572.7	415.7
estuary	19	4.8	8.9	7.5	178.3	615.7	391.9
Bankianska river							
Pushkarov inst.	20	8.5	10.4	9.9	220.1	458.8	299.0
Evropa blv.	21	4.4	10.4	9.8	199.2	444.8	319.4
estuary	22	8.6	15.6	12.5	318.7	585.7	449.6
Blato river							
Petarch village	23	12.0	14.0	14.5	375.9	526.1	448.4
estuary	24	15.0	25.6	21.2	386.5	927.7	635.2
Lesnovska river							
Dolni Bogrov	25	8.5	25.6	15.9	316.1	754.9	513.0
estuary	26	6.7	13.6	12.0	367.9	563.4	480.1

Water of the Iskar river in the examined region shows its hydrocarbonate character. Water of the other rivers are of mixed hydrocarbonate sulfate character. However, while at the rivers Suhodolska, Bankianska, Blato and Lesnovska the hydrocarbonate ions predominates, at the rivers Slatinska, Perlovska and Vladaiska, i.e. all south tributaries taking their sources from Vitosha, sulfate ions predominate. In a weight ratio, the importance of chloride ions is comparatively small except for some river estuary regions, i.e. the river mouth of the Blato river. With a respect to the basic non-metal ionic composition, the water in the examined territory is always of category I. Regardless of this, there exists a tendency for increasing the content of the observed ions along the rivers. This increase varies between 2 and 5 times, but is always significant. In Figures 3 and 4 the average values of the main cations and anions along the Perlovska river are presented.

There seems to exists a relative balance between the calcium (Ca) and alkaline (Na and K) ions, as in the water of the rivers Suhodolska, Vladayska and Perlovska the alkaline (Na and K) predominates, whereas at Bankyanska, Blato and Lesnovska the calcium ions (Ca) predominate. For example, at Dolni Bogrov village the calcium ions exceeds alkaline by three times. The content of magnesium ions (Mg) is low everywhere.

The parameter total hardness (H) separates the observed rivers into two groups. The rivers taking their source from Vitosha – Slatinska, Perlovska and Vladaiska have "soft" waters and are of category I. The rest are "hard" water – categories II and III. There is no anthropogenic impact on the water hardness.

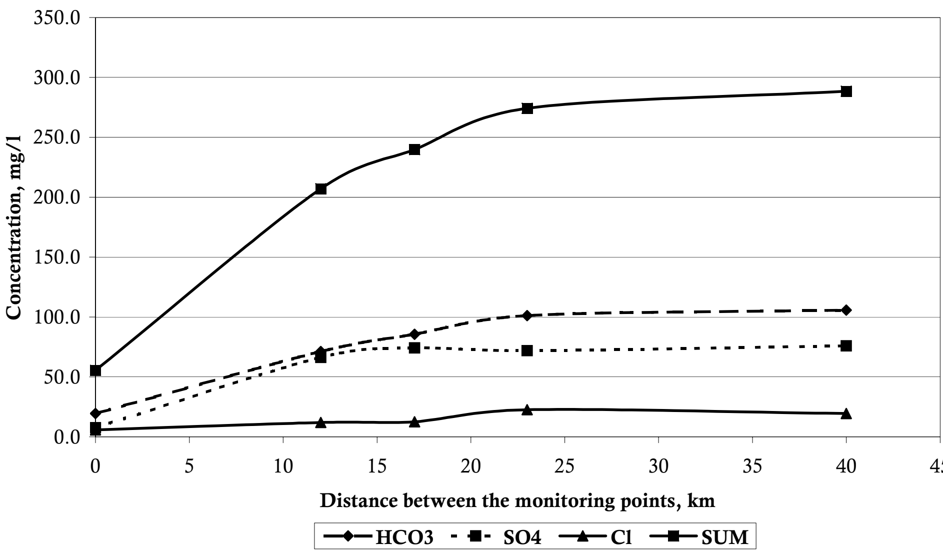

Fig. 3. Longitudinal distribution of the main anions and the total mineralization in the Perlovska river water.

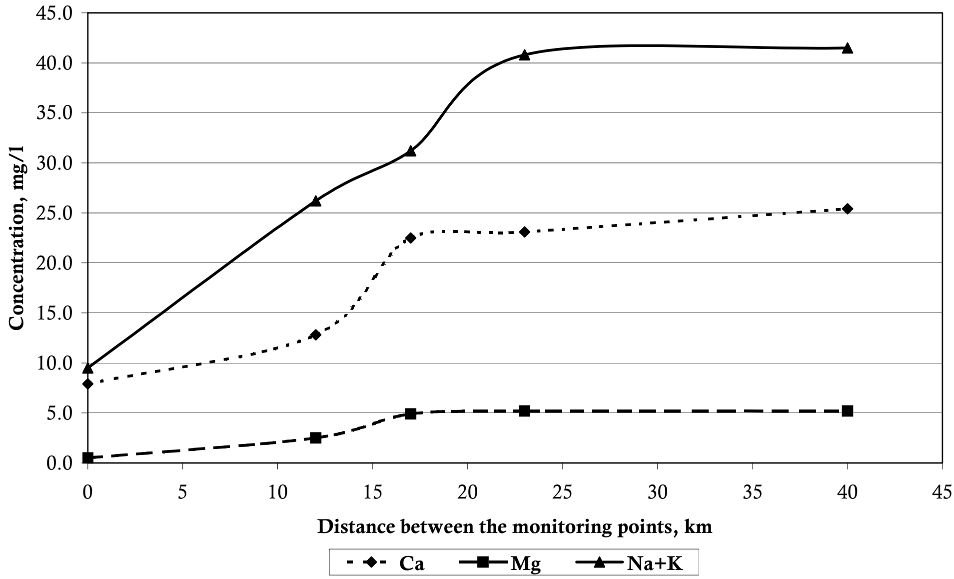

Fig. 4. Longitudinal distribution of the main cations in the Perlovska river water.

3. Parameters of pollution with biogenic components (Group C)

The quantity and the regime of the biogenic elements in the river flows is studied poorly. This is because of the complexity of their determination and their ability to be the first and the final product in the process of unfencing and the creating of organic matter. Sources of biogenic elements in the river flows are snow, rainwater, ground water and wastewater (sewerage water, animal farms and others). Quantity assessment of the biogenic elements is given as the nitrates (NO_3), nitrites (NO_2), ammonium (NH_4) and phosphate ions (PO_4).

With respect to the content of biogenic elements, water in the rivers of the Sofia region is distinguished having a considerable amount of pollution. In Table 4, we give the limits of change of the examined ions. The results show that only with regard to the nitrates (NO_3) the water satisfies the requirements for category I for all examined river valleys. As to their content of nitrites (NO_2) – main parameter for the sanitary and the hygiene condition of the water – considerable pollution is registered. The high content of the nitrites (NO_2) can be explained by wastewater discharge. Everywhere, the rivers in the Sofia region reach category III regarding this parameter. However, it is necessary to mention that the Bulgarian legislation allows very low degrees of nitrite (NO_2) content.

The content of ammonium (NH_4) and phosphate ions (PO_4) varies considerably and the content of these parameters is comparatively high in the urbanized area, as the quality of the river water reaches category III. The tendency for the increase in the concentration along the rivers is clearly seen, as the river estuary regions register maximum values. As an example, the longitudinal distribution of the average values of the biogenic parameters along the Perlovska river is shown (Fig. 5).

Table 4. Content of biogenic components in te water of the Sofia rivers.

River, monitoring point	**N**	**NO_3 mg/l**			**NO_2 mg/l**			**PO_4 mg/l**			**NH_4 mg/l**		
		min	**max**	**aver.**	**min**	**max**	**aver.**	**min**	**max**	**aver.**	**min**	**max**	**aver.**
Iskar river													
Camping Vrania	1	1.8	6.6	4.3	0.03	0.21	0.13	0.00	0.02	0.01	0.00	0.36	0.17
Vrajdebna	2	0.5	7.5	4.8	0.00	0.41	0.22	0.12	0.58	0.33	0.00	4.40	2.10
Novi Iskar town	3	1.2	18.0	9.5	0.00	1.60	0.40	0.12	0.98	0.50	0.12	5.80	2.85
Slatinska river													
Simeonovo	4	1.7	3.2	2.7	0.00	0.01	0.01	0.00	0.13	0.06	0.00	0.22	0.10
Dragalevtzi	9	0.1	0.3	0.3	0.00	0.01	0.01	0.00	0.04	0.01	0.00	0.01	0.01
Tzarigradsko sh.	5	1.2	5.3	3.5	0.00	0.31	0.15	0.09	0.22	0.16	0.00	0.28	0.12
4th km.	6	1.1	4.2	3.4	0.00	0.32	0.16	0.10	0.21	0.17	0.00	0.94	0.42
estuary	13	0.9	10.8	6.2	0.00	0.61	0.30	0.19	0.48	0.34	0.00	1.12	0.52
Perlovska river													
Boiana	7	0.3	2.5	1.9	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.08	0.03
Rutchai square	8	0.8	5.8	3.9	0.00	0.38	0.11	0.11	0.64	0.25	0.00	0.74	0.40
Palace of Culture	10	0.8	8.3	4.8	0.00	0.20	0.11	0.02	0.47	0.22	0.00	0.84	0.48
Orlov most	11	0.7	9.6	5.1	0.00	0.55	0.25	0.03	0.92	0.42	0.00	3.40	1.02
estuary	12	0.7	15.3	8.9	0.00	1.08	0.54	0.27	0.81	0.51	0.00	4.04	1.89
Vladaiska river													
Vladaia village	14	0.2	1.4	0.9	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.01	0.01
Tchernia kos	15	0.7	8.7	4.8	0.00	0.06	0.02	0.12	0.35	0.22	0.00	0.15	0.07
Stotchna gara	16	0.7	7.3	4.7	0.00	0.75	0.35	0.16	0.55	0.33	0.00	2.56	1.12
estuary	17	1.1	6.0	4.9	0.00	0.79	0.36	0.04	0.80	0.41	0.12	7.20	2.85
Suhodolska river													
Orion str.	18	1.2	19.1	11.2	0.01	0.76	0.30	0.24	0.61	0.41	0.00	2.16	1.11
estuary	19	0.8	14.6	10.3	0.01	1.20	0.58	0.27	0.44	0.33	0.04	8.00	3.92
Bankianska river													
Pushkarov inst.	20	1.0	10.6	5.9	0.02	0.87	0.44	0.38	0.72	0.40	0.50	1.96	1.23
Evropa blv.	21	1.1	9.0	5.2	0.00	0.97	0.49	0.24	0.67	0.42	0.04	2.60	1.32
estuary	22	2.0	6.9	4.2	0.00	0.97	0.44	0.42	1.08	0.74	0.08	4.52	2.22
Blato river													
Petarch village	23	1.6	2.8	2.3	0.00	0.01	0.01	0.07	0.15	0.10	0.00	0.44	0.21
estuary	24	0.1	14.9	7.8	0.00	1.20	0.50	0.12	0.86	0.47	0.00	3.30	1.45
Lesnovska river													
Dolni Bogrov	25	2.1	20.0	11.8	0.00	0.88	0.41	0.05	0.38	0.21	0.04	3.30	1.62
estuary	26	1.3	14.4	10.2	0.01	1.20	0.61	0.04	0.61	0.31	0.64	4.92	2.74

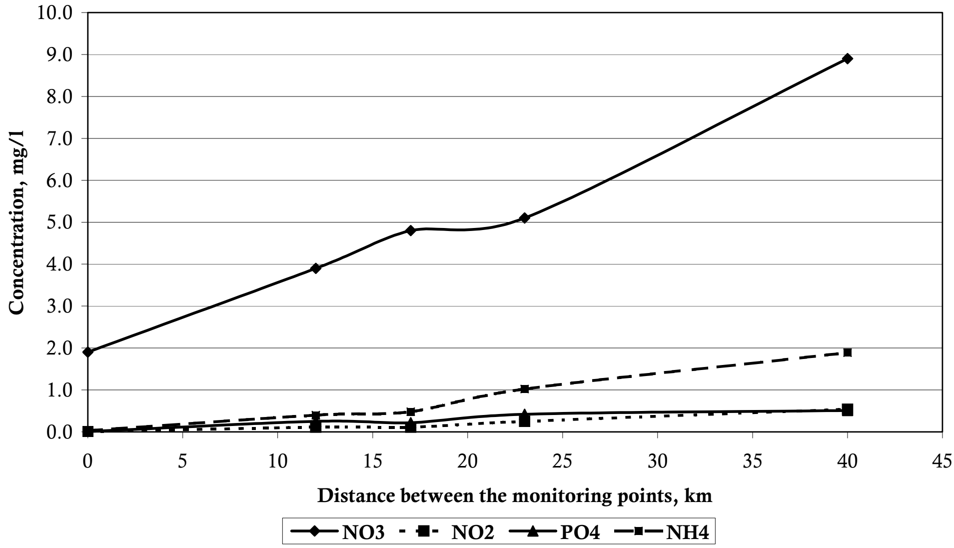

Fig. 5. Longitudinal distribution of the biogenic elements in the Perlovska river water.

The main reason for the variation and the increasing of the studied biogenic elements is the municipal wastewater and agricultural activity in the Sofia region. Some small contribution to natural origin is also possible.

4. Toxic elements and other microcomponents (Group D)

Micro-compounds, of high atomic weight (i.e. heavy elements), were also collected from the river water. Pollution with toxic elements is one of the most dangerous forms of infraction of the ecological condition of the environment. The development of industry and the low efficiency of wastewater treatment facilities lead to a considerable increase of their content. In Table 5 some results of our investigation concerning the toxic elements are presented.

Arsenic (As) is observed in separate sections of the rivers – Iskar (Novi Iskar town), Perlovska (River mouth), Suhodolska (Orion), Lesnovska (river mouth), as it reaches values corresponding to category II. The lowest concentrations of arsenic (As) are observed in the Vladayska river. The content of lead (Pb) varies between categories I and II, though at the river mouth of the rivers Blato and Lesnovska values correspond to category III. Only in the water of Bankyanska river lead (Pb) is not registered along the entire river. Pollution with cadmium (Cd) is most pronounced. Except for water of the Iskar river and the stations, pollution reaching to categories II and III is registered in all the other rivers.

For the rest of the examined micro components, there are no norms in the surface flowing water legislation, but a significant part of them are highly toxic and their observation is necessary. Comparatively high values are registered at different stations for selenium (Se), tungsten (W), tin (Sn) and bismuth (Bi).

Table 5. Content of heavy metals and some other toxic elements in the water of the Sofia rivers.

River, monitoring point	N	Ni 10^{-3} mg/l			Cu 10^{-3} mg/l			Co 10^{-3} mg/l			Cd 10^{-3} mg/l		
		min	max	aver.	min	max	aver.	min	max	aver.	min	max	aver.
Iskar river													
Camping Vrania	1	1	15	7	1	2	1	1	3	1	0.4	4	1
Vrajdebna	2	1	11	5	1	11	4	1	4	2	0.4	3	1
Novi Iskar town	3	1	27	12	1	13	5	1	9	5	0.4	5	2
Slatinska river													
Simeonovo	4	1	2	1	0	1	1	1	2	1	0.4	2	1
Dragalevtzi	9	1	11	5	0	1	1	0	1	0	0.4	4	1
Tzarigradsko sh.	5	1	15	6	1	8	3	1	2	1	0.4	7	1
4th km.	6	1	15	6	1	2	1	1	2	1	0.4	5	1
estuary	13	1	10	6	1	13	5	1	10	3	0.4	13	3
Perlovska river													
Boiana	7	1	2	1	0	1	1	1	1	1	0.4	2	1
Rutchai square	8	1	7	4	1	4	2	1	5	2	0.4	4	1
Palace of Culture	10	1	15	6	0	6	3	1	7	2	0.4	5	1
Orlov most	11	1	16	7	1	23	5	1	7	2	0.4	4	1
estuary	12	1	15	7	1	37	11	1	7	3	0.4	7	2
Vladaiska river													
Vladaia village	14	1	2	1	0	1	0	1	2	1	0.4	1	1
Tchernia kos	15	1	8	3	1	61	8	1	6	2	0.4	5	1
Stotchna gara	16	1	34	10	1	73	10	1	9	3	0.4	83	10
estuary	17	1	15	6	1	92	15	1	8	4	0.4	151	15
Suhodolska river													
Orion str.	18	1	6	2	1	6	2	1	3	1	0.4	17	10
estuary	19	1	15	6	1	33	7	1	6	2	0.4	24	11
Bankianska river													
Pushkarov inst.	20	1	2	1	1	2	1	0	1	0	1.0	7	2
Evropa blv.	21	1	2	1	1	5	2	1	2	1	1.0	6	2
estuary	22	1	7	2	0	23	9	1	2	1	1.0	20	7
Blato river													
Petarch village	23	1	2	1	1	1	1	1	5	1	0.4	1	1
estuary	24	1	2	1	1	20	5	1	6	2	1.0	13	3
Lesnovska river													
Dolni Bogrov	25	1	12	5	1	9	4	1	3	1	0.4	8	2
estuary	26	1	16	4	1	10	5	1	4	2	0.4	9	2

Table 5. Continued.

River, monitoring point	N	Pb 10^{-3} mg/l			Mn 10^{-3} mg/l			As 10^{-3} mg/l			Cr 10^{-3} mg/l		
		min	max	aver.	min	max	aver.	min	max	aver.	min	max	aver.
Iskar river													
Camping Vrania	1	1	2	1	1	298	114	1	16	6	0.3	5	2
Vrajdebna	2	1	2	1	1	282	112	1	16	6	1.0	16	5
Novi Iskar town	3	1	21	5	1	357	132	1	50	9	1.0	15	5
Slatinska river													
Simeonovo	4	1	5	1	1	39	11	1	11	4	0.1	1	0
Dragalevtzi	9	1	5	1	1	7	3	1	9	3	0.1	1	0
Tzarigradsko sh.	5	1	10	2	1	76	15	1	17	7	1.1	14	3
4th km.	6	1	5	2	1	101	23	1	14	7	0.4	11	3
estuary	13	1	35	6	1	130	25	1	19	7	0.1	1	0
Perlovska river													
Boiana	7	1	2	1	1	29	12	1	2	1	0.1	1	0
Rutchai square	8	1	12	2	1	48	23	1	16	6	0.1	2	1
Palace of Culture	10	1	21	5	1	178	56	1	14	5	1.0	2	1
Orlov most	11	1	32	5	1	170	52	1	14	6	0.1	3	1
estuary	12	1	30	5	1	218	114	1	22	9	0.1	2	1
Vladaiska river													
Vladaia village	14	1	20	3	1	47	20	1	4	1	0.1	1	0
Tchernia kos	15	1	20	3	1	63	26	1	19	6	0.1	4	0
Stotchna gara	16	1	24	4	1	240	109	1	19	6	0.3	6	2
estuary	17	1	48	4	1	457	212	1	15	5	0.1	11	3
Suhodolska river													
Orion str.	18	1	19	3	1	248	140	1	18	5	0.1	5	2
estuary	19	1	20	2	1	252	135	1	19	6	0.1	8	3
Bankianska river													
Pushkarov inst.	20	1	2	1	1	44	19	1	16	4	0.1	1	0
Evropa blv.	21	1	11	3	1	261	136	1	16	5	0.1	1	0
estuary	22	1	14	4	1	200	120	1	13	5	0.1	1	0
Blato river													
Petarch village	23	1	2	1	1	42	20	1	1	1	0.1	1	0
estuary	24	1	16	4	1	46	20	1	10	3	0.1	1	0
Lesnovska river													
Dolni Bogrov	25	1	9	2	1	127	65	1	18	6	0.1	1	0
estuary	26	1	23	4	1	338	119	1	25	9	0.1	1	0

Table 5. Continued.

River, monitoring point	N	Fe 10^{-3} mg/l			Mo 10^{-3} mg/l			Sb 10^{-3} mg/l			Zn 10^{-3} mg/l		
		min	max	aver.	min	max	aver.	min	max	aver.	min	max	aver.
Iskar river													
Camping Vrania	1	31	470	230	1	13	3	1	11	4	1	30	11
Vrajdebna	2	35	602	285	1	5	2	1	24	11	1	56	25
Novi Iskar town	3	48	2630	589	1	5	2	1	30	18	1	110	49
Slatinska river													
Simeonovo	4	10	210	45	1	2	1	1	4	1	1	12	3
Dragalevtzi	9	15	240	41	1	1	1	1	5	2	1	14	3
Tzarigradsko sh.	5	20	660	230	1	2	1	1	5	2	1	14	3
4th km.	6	22	820	289	1	4	1	1	8	3	1	5	2
estuary	13	26	830	200	1	2	1	1	17	4	1	11	3
Perlovska river													
Boiana	7	9	220	50	1	1	1	1	8	4	1	3	1
Rutchai square	8	11	649	111	1	1	1	1	11	3	1	45	18
Palace of Culture	10	14	451	120	1	2	1	1	17	4	1	38	18
Orlov most	11	15	353	145	1	2	1	1	18	4	1	42	21
estuary	12	23	870	254	1	2	1	1	19	4	1	47	23
Vladaiska river													
Vladaia village	14	5	201	48	1	1	1	1	8	2	1	3	1
Tchernia kos	15	9	350	56	1	3	1	1	10	3	1	230	88
Stotchna gara	16	16	466	145	1	5	1	1	24	11	1	100	66
estuary	17	24	1948	301	1	3	1	1	35	13	1	151	84
Suhodolska river													
Orion str.	18	8	488	98	1	7	2	1	53	16	1	32	12
estuary	19	19	693	125	1	5	1	1	24	13	1	230	89
Bankianska river													
Pushkarov inst.	20	10	514	130	1	2	1	1	12	5	1	3	1
Evropa blv.	21	11	942	287	1	3	1	1	13	5	1	96	32
estuary	22	16	865	291	1	5	2	1	9	4	1	88	41
Blato river													
Petarch village	23	12	720	230	1	2	1	1	4	2	1	12	3
estuary	24	18	510	258	1	2	1	1	15	5	1	25	5
Lesnovska river													
Dolni Bogrov	25	62	730	365	1	3	1	1	13	3	1	30	15
estuary	26	70	1140	411	1	5	2	1	8	3	1	234	67

Table 5. Continued.

River, monitoring point	**N**	**Se 10^{-3} mg/l**			**Bi 10^{-3} mg/l**		
		min	**max**	**aver.**	**min**	**max**	**aver.**
Iskar river							
Camping Vrania	1	1	28	6	1	18	6
Vrajdebna	2	1	20	5	1	38	12
Novi Iskar town	3	1	28	7	1	35	12
Slatinska river							
Simeonovo	4	1	20	4	1	14	3
Dragalevtzi	9	1	20	4	1	14	5
Tzarigradsko sh.	5	1	20	5	1	38	14
4th km.	6	1	20	5	1	14	10
estuary	13	1	20	5	1	32	14
Perlovska river							
Boiana	7	1	20	5	1	14	3
Rutchai square	8	1	29	5	1	14	5
Palace of Culture	10	1	19	5	1	31	11
Orlov most	11	1	20	6	1	45	15
estuary	12	1	20	6	1	35	14
Vladaiska river							
Vladaia village	14	1	20	3	1	20	5
Tchernia kos	15	1	5	2	1	14	5
Stotchna gara	16	1	17	3	1	25	6
estuary	17	1	27	6	1	69	33
Suhodolska river							
Orion str.	18	1	20	4	1	49	25
estuary	19	1	14	3	1	49	25
Bankianska river							
Pushkarov inst.	20	1	23	5	1	19	8
Evropa blv.	21	1	20	5	1	23	9
estuary	22	1	20	5	1	24	9
Blato river							
Petarch village	23	1	20	5	1	14	4
estuary	24	1	15	4	1	15	5
Lesnovska river							
Dolni Bogrov	25	1	20	5	1	60	24
estuary	26	1	20	5	1	31	15

In Figures 6 and 7 we present the average values of the most important toxic elements and their longitudinal distribution along the Perlovska river.

The average concentrations of the studied toxic elements increase towards the estuary (Figures 6, 7), but we cannot confirm a constant and a permanent tendency for increase along the observed river flows. This is due to their low concentrations, their origin and the ability to be

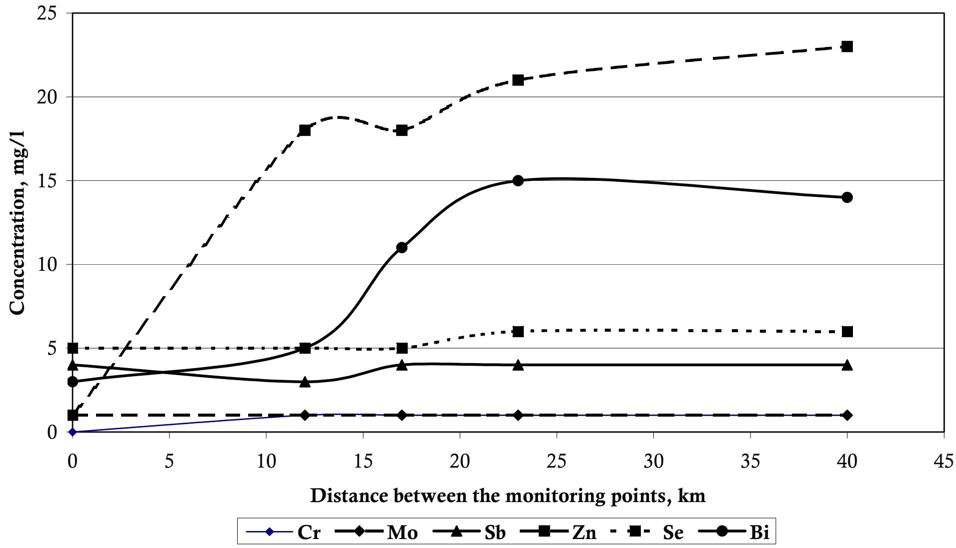

Fig. 6. Longitudinal distribution of some toxic elements in the Perlovska river water.

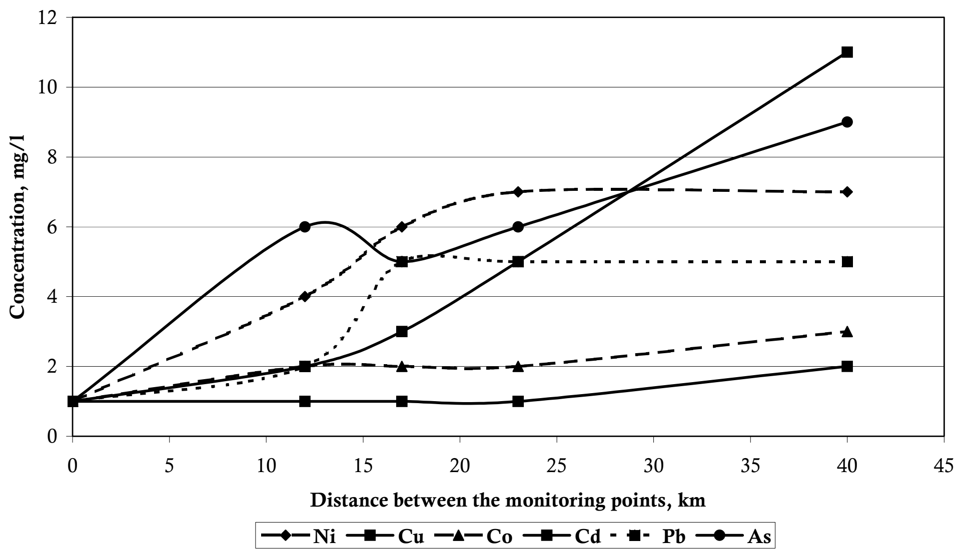

Fig. 7. Longitudinal distribution of some toxic elements (continuation) in the Perlovska river water.

adsorbed by suspended matter. Some of these elements can accumulate on the bottom. Therefore the toxic element contents in the bottom deposits need to be examined.

Finally, the increase in toxic element contents in some part of the studied rivers, above the natural background, could be a result of anthropogenic activities. The source for pollution with toxic elements is the industrial and municipal wastewater.

5. Content of toxic elements in the deposits

The bulk of the toxic elements in the rivers are adsorbed by the flowing deposits. Accumulated in the riverbed, the deposits, in special hydrological conditions, turn into flowing particles and become a source of secondary pollution. The pollution of the deposits in the Bulgarian rivers and the mechanism of secondary pollution are not studied thoroughly. It is known that most of the accumulated deposit pollutants are contained in the fine fraction, which is most easily brought into flowing condition. The samples from riverbed deposits are treated with granulometrical analyses where the weight of the separate fractions is estimated. A check sample is mineralized and brought to water solution, after which it is treated using atomic-absorption analyses. A parallel sample is treated with the method of inductive-connected plasma (ICP). The content of the toxic elements in the riverbed deposits in the Sofia rivers is given in Table 6. Because of the complexity of the examinations, legislation for assessment of the quality of the deposits does not exist. That is why the results are often compared and assessed according to the existing legislation for soils and the natural background in Bulgaria.

The examinations of the rivers in the Sofia region show that, in contrast to the flowing water where pollution with toxic elements is registered only in separate regions, the deposit pattern is quite different. In the bottom deposits, quantities of some of the examined elements accumulate, which can be potential sources of pollution. When the turbidity of the rivers is increased, because of the erosion of the river bottom and the banks, the content of the toxic elements in the water increases considerably. The process of vertical transmission of the suspended substances and the secondary pollution is an object of additional investigations.

From the point of view of their content in the deposits in the examined river valleys, the toxic elements can be separated into three groups: elements with lower quantity than the accepted standards for comparison; elements with observed pollution only at separate sections, and elements, for which a considerable pollution is registered. It can be assumed that in the deposits of the rivers in the Sofia region there is no registered pollution with chromium (Cr), cobalt (Co), aluminum (Al), molybdenum (Mo) and tungsten (W). Everywhere the samples show small background quantities of these elements.

The elements nickel (Ni), manganese (Mn), arsenic (As) and copper (Cu) is referred to as the second group. Considerably higher quantities of nickel (Ni) are found in the region of Vrajdebna residential district, Iskar river and the river estuary sections of the rivers Vladayska and Suhodolska. Generally, pollution with nickel (Ni) is not high. Increased quantities of manganese (Mn) is found at many places. Except for rivers Slatinska and Vladayska, pollution with manganese (Mn) is registered at the middle and in the estuary sections. More considerable content is found in Bankyanska, Lesnovska and some sections of the Perlovska and Suhodolska rivers. Pollution

Table 6. Content of heavy metals and some other toxic elements in the bed deposits of the Sofia rivers.

River, monitoring point	N	Ni mg/kg		Cu mg/kg		Co mg/kg		Cd mg/kg		Pb mg/kg	
		min	max	min	max	min	max	min	max	min	max
Iskar river											
Camping Vrania	1	2.9	26.0	6.8	75.0	1.4	11.5	0.0	10.5	2.6	119.0
Vrajdebna	2	8.2	69.4	26.5	401.0	3.9	9.6	0.0	44.9	0.3	165.0
Novi Iskar town	3	5.3	56.0	38.9	344.0	1.9	11.4	5.3	67.5	58.1	242.0
Slatinska river											
Simeonovo	4	4.0	30.5	34.5	50.0	8.5	13.9	0.8	3.0	5.0	60.0
Dragalevtzi	9	3.0	18.5	24.0	33.9	6.3	9.9	0.7	2.5	5.0	34.8
Tzarigradsko sh.	5	1.0	26.0	16.3	54.3	3.7	10.7	0.0	1.5	4.0	36.0
4th km.	6	12.5	34.6	73.0	516.0	5.3	18.2	0.0	7.5	60.4	141.0
estuary	13	7.2	41.5	31.1	100.0	5.7	14.5	0.0	19.7	21.3	126.0
Perlovska river											
Rutchai square	8	7.2	24.5	50.5	191.0	7.5	12.5	0.9	3.5	52.7	182.0
Palace of Culture	10	3.2	11.5	14.1	391.0	5.0	21.0	0.0	3.4	5.0	59.7
Orlov most	11	14.6	26.5	50.5	196.0	3.5	11.4	2.0	244.0	71.2	200.0
estuary	12	2.9	24.1	20.6	122.0	3.4	21.6	0.0	3.1	5.6	479.0
Vladaiska river											
Vladaia village	14	1.0	17.0	14.9	168.0	3.3	7.9	0.0	3.0	24.0	41.5
Stotchna gara	16	7.7	22.4	28.0	170.0	4.0	13.8	3.0	220.0	21.5	218.0
estuary	17	13.8	69.9	50.0	298.0	7.2	12.4	2.0	422.0	42.5	245.0
Suhodolska river											
Orion str.	18	7.0	15.0	24.3	61.0	9.0	21.2	0.1	2.0	7.5	26.6
estuary	19	8.0	61.4	23.0	195.0	5.0	11.0	1.0	247.0	1.0	146.2
Bankianska river											
Pushkarov inst.	20	10.7	20.5	41.3	79.3	13.3	23.3	1.5	3.5	2.0	54.2
Evropa blv.	21	5.5	19.5	19.5	50.8	9.5	19.7	1.0	2.5	7.0	37.1
estuary	22	7.4	27.0	24.4	108.0	7.6	15.0	0.3	3.0	7.0	33.0
Blato river											
Petarch village	23	11.0	41.5	14.6	45.5	3.5	12.6	0.4	3.0	18.1	144.0
estuary	24	11.7	27.5	27.3	141.0	8.6	13.5	0.2	3.5	9.9	58.3
Lesnovska river											
Dolni Bogrov	25	14.5	34.6	5.6	58.7	5.5	15.0	0.4	19.5	2.5	77.3
estuary	26	16.5	51.8	13.0	294.0	5.0	12.6	1.0	46.2	50.2	757.0

Table 6. Continued.

River, monitoring point	N	Mn mg/kg min	Mn mg/kg max	As mg/kg min	As mg/kg max	Sn mg/kg min	Sn mg/kg max	Fe mg/kg min	Fe mg/kg max	Mo mg/kg min	Mo mg/kg max
Iskar river											
Camping Vrania	1	268	5340	0.04	20.5	1.0	2.7	13889	29350	0.04	1.00
Vrajdebna	2	120	548	0.04	5.0	0.7	3.2	14950	32708	0.04	1.00
Novi Iskar town	3	111	820	0.04	24.5	1.0	5.8	48591	41273	0.04	1.00
Slatinska river											
Simeonovo	4	232	669	0.04	15.5	0.0	6.6	27943	33044	0.04	0.07
Dragalevtzi	9	426	594	0.04	8.5	0.0	4.9	17257	30066	0.04	0.06
Tzarigradsko sh.	5	293	566	0.04	7.0	0.0	3.5	10784	25550	0.04	1.00
4th km.	6	333	656	0.04	28.0	0.0	1.0	15257	13900	0.04	1.00
estuary	13	193	349	0.04	11.5	0.0	7.1	2323	41705	0.04	1.00
Perlovska river											
Rutchai square	8	275	1125	0.04	10.5	1.0	4.1	20750	275	0.04	1.00
Palace of Culture	10	321	967	0.04	5.0	0.0	4.8	13146	43167	0.04	1.00
Orlov most	11	333	1952	0.04	7.5	0.0	9.7	11915	30969	0.04	1.00
estuary	12	158	923	0.04	5.5	0.0	8.1	9800	27679	0.04	1.00
Vladaiska river											
Vladaia village	14	158	499	0.04	9.0	0.0	1.0	14647	32200	0.04	0.07
Stotchna gara	16	224	879	0.04	7.5	0.0	6.7	16188	33650	0.04	1.00
estuary	17	319	674	0.04	8.5	0.0	3.1	21391	33127	0.04	1.00
Suhodolska river											
Orion str.	18	572	1489	0.04	8.5	0.0	5.1	18677	32257	0.04	1.00
estuary	19	213	589	0.04	16.5	0.0	4.8	14250	33911	0.04	1.00
Bankianska river											
Pushkarov inst.	20	669	4863	0.04	15.5	1.0	4.2	30324	45741	0.04	1.40
Evropa blv.	21	665	1214	0.04	5.0	1.0	3.8	20201	34415	0.04	1.00
estuary	22	346	1231	0.04	14.0	1.0	2.1	20981	29794	0.04	1.00
Blato river											
Petarch village	23	340	995	0.04	14.0	1.0	2.7	8000	39212	1.00	1.40
estuary	24	142	1557	0.04	20.5	0.0	1.0	26358	32626	0.04	1.00
Lesnovska river											
Dolni Bogrov	25	363	1334	0.04	11.5	1.0	3.6	16400	42725	0.04	1.00
estuary	26	431	2913	0.04	21.5	0.5	7.4	12350	66215	0.04	1.00

Table 6. Continued.

River, monitoring point	**N**	**Sb mg/kg**		**Zn mg/kg**		**Se mg/kg**		**Bi mg/kg**	
		min	**max**	**min**	**max**	**min**	**max**	**min**	**max**
Iskar river									
Camping Vrania	1	1.0	2.7	29	164	0	5.0	1.4	29.7
Vrajdebna	2	0.7	3.2	106	1643	0	5.0	1.4	35.5
Novi Iskar town	3	1.0	5.8	197	1183	0	3.2	1.4	45.3
Slatinska river									
Simeonovo	4	6.4	6.6	34	740	0	1.0	1.4	21.2
Dragalevtzi	9	4.1	4.9	27	93	0	0.5	1.4	5.0
Tzarigradsko sh.	5	0.0	3.5	41	105	0	2.8	1.4	20.6
4th km.	6	0.0	1.0	188	496	0	1.7	1.4	25.5
estuary	13	0.0	7.1	150	467	0	2.1	1.4	46.7
Perlovska river									
Rutchai square	8	1.0	4.1	156	368	0	4.7	1.4	29.5
Palace of Culture	10	0.0	4.8	68	140	0	4.9	1.4	34.1
Orlov most	11	0.0	9.7	584	1284	0	6.5	1.4	34.9
estuary	12	0.0	8.1	108	1565	0	2.4	1.4	35.6
Vladaiska river									
Vladaia village	14	0.0	1.0	18	156	0	1.0	1.4	5.0
Stotchna gara	16	0.0	6.7	46	853	0	2.4	1.4	14.9
estuary	17	1.0	3.1	96	1905	0	5.0	1.4	38.2
Suhodolska river									
Orion str.	18	0.0	5.1	57	207	0	4.5	1.4	50.8
estuary	19	0.0	4.8	45	1651	0	5.0	1.4	68.5
Bankianska river									
Pushkarov inst.	20	1.0	4.2	94	407	0	14.4	1.4	31.2
Evropa blv.	21	1.0	3.8	39	121	0	5.0	1.4	24.9
estuary	22	1.0	2.1	82	613	0	5.0	1.4	39.3
Blato river									
Petarch village	23	1.0	1.7	61	119	0	2.0	1.4	26.1
estuary	24	0.0	1.0	58	372	0	18.4	1.4	19.4
Lesnovska river									
Dolni Bogrov	25	1.0	3.6	61	484	0	2.4	1.4	24.5
estuary	26	0.5	7.4	204	2486	0	6.3	1.4	46.4

with arsenic (As) is found only in the river mouth of the Perlovska river and some sections of the Bankyanska river (for example around Institute Pushkarov). Copper (Cu) pollution is observed at all the river mouth sections.

In general, accumulation of the elements cadmium (Cd), bismuth (Bi), lead (Pb), iron (Fe), zinc (Zn), selenium (Se), tin (Sn) and antimony (Sb) are observed. Of special interest is the comparatively high values of cadmium (Cd), one of the most dangerous toxic elements. Interesting are the higher values of bismuth (Bi), lead (Pb), selenium (Se) and zinc (Zn) as well. As for iron (Fe) and tin (Sn), they are not very toxic at low concentrations and their slightly increased values are not too dangerous. All elements from the third group are considerably accumulated in the deposits of the Sofia rivers.

However, the studied rivers are small with rocky beds in its upper most part and thin sediment layers downstream. Except for some small estuary sections, the deposit accumulations are not deep. Nevertheless, the higher content of some toxic elements in the deposits is not of significant danger for water quality because of the small quantity of the bottom sediments. However some additional studies are necessary in the sections just before the inflow of the Sofia river into the main collector – the Iskar river. In these short sections there are thicker sediments layers and some larger impact on the water quality can be expected.

CONCLUSIONS

On the basis of the systematic observations for three years (1992 -1994) and some additional investigations afterwards, the following conclusions can be drawn for the river water quality in the region of the city of Sofia:

1. As a result of urbanization in the region followed by the accelerated spreading of the City and the surrounding villages, industrialization, widening of the transport net and new technologies in agriculture, the surface river waters have changed considerably in quality in comparison to their natural background conditions.
2. The quality of the water differs from river to river, however a general trend of increasing of pollutant is observed in most river valleys, with few exceptions.
3. The indication of the category of the water, according to the different examined indicators, determine the aims for which it can be used according to the Ordinance N 7 from 1986.
4. The results can be used as evidence for the need to build new wastewater treatment plants.
5. The results show that pollution of the water has not reached its limits, which can ultimately prevent their use for watering and for technical water supply.
6. The water from the examined river valleys is not suitable for drinking, except at the background regions at the foot of the Vitosha mountain.
7. We found some heavy metals and toxic elements in the deposits on the river floor, which are potential sources of secondary pollution. Nevertheless, because of the small quantity of the bottom sediments, except for some short estuary sections, the danger of such secondary pollution is not that great at the moment.

B. GROUNDWATER QUALITY IN THE REGION OF THE CITY OF SOFIA

INTRODUCTION

As we know, groundwater fills the free spaces (pores, cracks, caverns) in previous geological bodies. When these free spaces are connected, their water-saturated part can be examined as an united water-bearing system (water-bearing horizon). The boundaries of this system are determined from the boundaries of the space-hydraulic connection between filled water pores, cracks and caverns and also from the unity of the recharging and discharging sources. So defined, these essential hydrodynamic boundaries exhibit themselves as hydrochemical ones in realization of the migratory processes of certain pollutants in particular water-bearing systems (horizon). The hydrodynamic (hydrochemical) boundaries, where the processes of forming, moving and draining of the groundwater are conditioned, depend on several factors, most important of which are: geology-tectonic structure, geomorphological shape of ground, hydrological and climatic elements.

The current investigation is concentrated on the Quaternary water-bearing horizon (aquifer) of the Sofia valley, whose chemical composition, ecological conditions and possibilities for use of groundwater had been an object of many examinations by the Hydrogeological and Engineering Geology departments of different institutions.

The Quaternary water-bearing horizon is represented by: fan cones $_{pr}Q$, fan and drift deposits – $_{pr\text{-}d}Q$, old terrace deposits – Q_3 and alluvial deposits $_{al}Q$, which have general spreading both in horizontal and vertical directions.

The alluvial deposits are represented by various gravel aggregates with a sandy fill and sandy clays.

Fan and Drift deposits are granular, bad rounded gravels with a clay-sandy fill.

The old alluvial terraces of the rivers Iskar, Lesnovska, Slatinska and Suhodolska are formed by gravels and valunes with sandy and clay-sandy fill.

The similar Quaternary deposit lithology composition and their spatial facial alterations are a reasonable reason for the lack of placing clear borders between them. The Quaternary deposits set up a general water-bearing horizon, represented mainly by valunes, gravel and sand containing thin clay and sandy clay ledges.

The mineral composition of the Quaternary horizon and the soils are tegumented by maroon forest and alluvial-meadow soils. They are characterized by low water permeability, comparatively high adsorption capacity (20-30mgq/100g) and high contents of hydromica, iron and manganese oxides and montmorillonite group minerals.

As a result of the dissolve, exsolution and ionic exchange processes, materials from the upper hydrodynamic zone become main incharging groundwater source of hydrocarbonate, sulfate, calcium, magnesium, potassium and sodium ions, as well as dissolved iron and manganese compounds. Because of these naturally formed conditions (quantity and chemical composition) the unconfined Quaternary aquifers are influenced by anthropological factors, such as urbanization, agriculture, industrial pollution and others.

MATERIAL AND METHODS

Hydrogeochemical characterization

Urbanisation, such as industry and agricultural activities, seem to be the most important anthropogenic factor, causing organic pollution of the Quarternery aquifer. As a whole, the hydrodynamic regime at the observation points during spring (predominately May) records a general increase of the permanganate oxidizing values ($_2O_{Mn}$), the appearance of nitrites, phosphates, ammonium and an increase in metal saturation mainly with Fe and Mg ions and in more rare cases, Zn.

In the investigated districts, water material composition during spring (heightened agricultural activity) is predetermined by the vertical seepage through the soil by different fertilizers. In this respect, nitrate pollution (village German – point 1, residential district Vrajdebna – point 2 and village Chelopechene – point 7, see Fig. 8), follows three stages:

nitrogen migration through soil layer;

movement across unsaturated zone;

circulation into saturated zone.

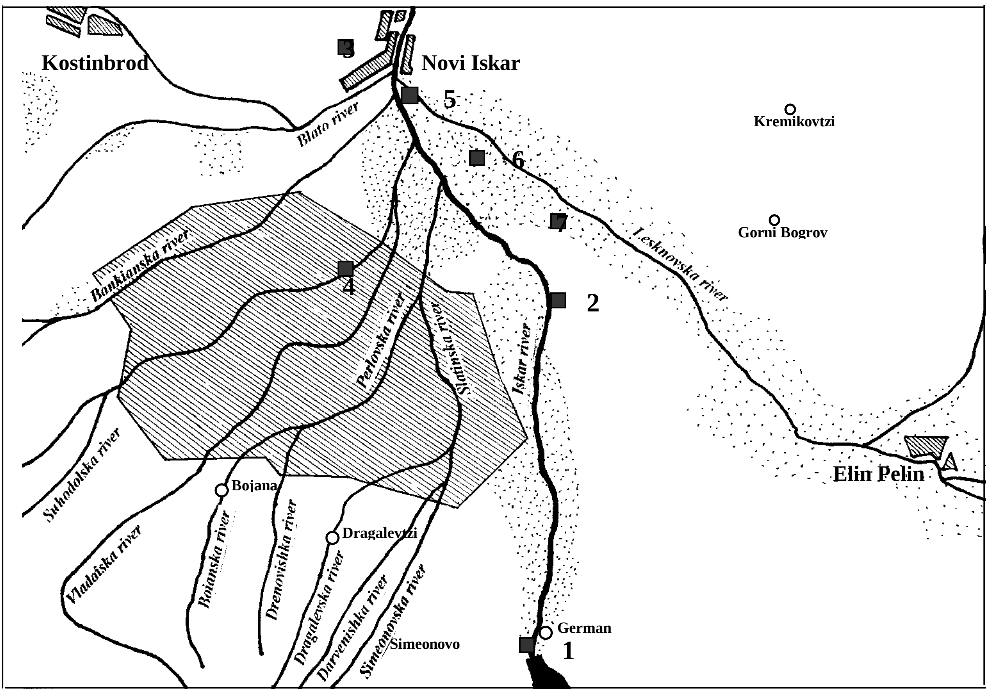

Fig. 8. Scheme of the groundwater sampling stations: 1 – German village; 2 – Vrajdebna district; 3 – Novi Iskar town; 4 – Levski district; 5 – Orlandovtzi district; 6 – Svetovrachane village; and 7 – Chelopechene village.

During every stage, specific processes (biological, physical, physical-chemical) are influenced by different factors, for example the heterogeneity of the surroundings, the layer active porosity, the water level alterations, indices of the convectional transfer, parameters of diffraction, etc. Furthermore, temperature is important during nitrate migration. It is directly connected with the activities of plants and microorganisms in the soil layer, creating a so called soil barrier.

The increased nitrate content during spring leads to a decrease in the oxygen concentration (increase of the permanganate oxidation $_2O_{Mn}$) and, respectively, a change in the Eh of the soil-rock system. This causes considerable volumes of divalent iron and Mn dissolved forms including the free cations of this metal and its complex compounds, to seep into the groundwater. This pattern, but only slightly expressed, also occurs during September. At the end of summer, because of the decreased water exchange and duration of the processes of dissolving, exolution and ionic exchange, the general mineralization of water increases. As a result of autumn rainfall, causing water levels to raise, groundwater again are enriched with organic substances, and heavy metals.

In addition, medical examinations connect disease with the combined presence of iron and nitrates in water. In humans, as in an alkaline medium, deoxidization occurs, i.e. the transition of NO3 to NO2. The released oxygen oxidizes the divalent iron – Fe_2 to Fe_3, which leads to the appearance of methahemoglobin, causing muscular exhaustion and widening of the vascular system.

The main aims of a groundwater hydrochemical classification system in each observation station is to obtain a generalized schematic view of water quality and its variation in time, to compare results of water composition at different points of the aquifer and to tentatively assess water suitability for different kinds of economic utilization.

Groundwater division into classes (depending on the predominant anions), groups (depending on the predominant cations) and types (depending on the particular ionic correlations) is made according to Alekin‘s classification. For each type, the typical salt forms are determined. The data illustrating water chemical composition are presented using Kurlov‘s formula.

In the sections with intensive agriculture, the classification is made seasonally. The rest of the samples, where the compositional data show an annual stability, generalized characteristics are prepared. An exception is the station in the town of Novi Iskar, where fast flowing water refreshment is observed. In this case, the relatively high pump capacity of the factory, cause the surface water influx from the Iskar river.

The different groundwater classes, groups and types and their corresponding salt composition are given in Table 7.

The material composition is given in Table 8.

The following peculiarities should be noticed:

Waters is from hydrocarbonate and sulfate classes, and calcium group.

The first type is characterized by an ionic correlation $HCO_3 > Ca + Mg$ and is observed only in the station near the town of Novy Iskar. The water from this type is fresh, alkaline and soft. The specific salts, determining the name of this type is $NaHCO_3$.

Table 7. Groundwater classes, groups and types and their corresponding salt composition.

Observed stations - No	Months	Class	Group	Type	Salt composition (form)
1	04	hydrocarbonate	calcium	II- B	$Ca(HCO_3)_2$, $CaSO_4$, $MgSO_4$, Na_2SO_4, NaCl
1	05-06	hydrocarbonate	calcium	II- A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$CaSO_4$, $MgSO_4$, $MgCl_2$, NaCl
1	07	hydrocarbonate	calcium	II- A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$CaSO_4$, $MgSO_4$, $MgCl_2$, NaCl
1	08-09	hydrocarbonate	calcium	II- A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$CaSO_4$, $MgSO_4$, $MgCl_2$, NaCl
2	04	sulfate	calcium	II-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$, $MgSO_4$, Na_2SO_4, NaCl
2	05-06	hydrocarbonate	calcium	III-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$Ca(SO_4)$, $MgSO_4$, $MgCl_2$,NaCl
2	07	hydrocarbonate	calcium	III-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$Ca(SO_4)$, $MgSO_4$, $MgCl_2$,NaCl
2	08-09	sulfate	calcium	III-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$Ca(SO_4)$, $MgSO_4$, $MgCl_2$,NaCl
3	04-09	sulfate	calcium	II- B	$Ca(HCO_3)_2$, $CaSO_4$, $MgSO_4$, Na_2SO_4, NaCl
3	07	hydrocarbonate	calcium	I	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,Na_2SO_4, $NaHCO_3$, NaCl
4	04-09	sulfate	calcium	II- B	$Ca(HCO_3)_2$, $CaSO_4$, $MgSO_4$, Na_2SO_4, NaCl
5	04-09	hydrocarbonate	calcium	III-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$Ca(SO_4)$, $MgSO_4$, $MgCl_2$,NaCl
6	04-09	hydrocarbonate	sodium	II- A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$, $MgSO_4$, Na_2SO_4, NaCl
7	04	hydrocarbonate	calcium	III-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$Ca(SO_4)$, $MgSO_4$, $MgCl_2$,NaCl
7	05-06	hydrocarbonate	calcium	III-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$Ca(SO_4)$, $MgSO_4$, $MgCl_2$,NaCl
7	07	hydrocarbonate	calcium	II-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$, $MgSO_4$, Na_2SO_4, NaCl
7	08-09	hydrocarbonate	calcium	III-A	$Ca(HCO_3)_2$, $Mg(HCO_3)_2$,$Ca(SO_4)$, $MgSO_4$, $MgCl_2$,NaCl

The second type is characterized by an ionic correlation $HCO_3 < Ca + Mg < HCO_3 + SO_4$. It is distinguished by the most significant sulfates – $CaSO_4$, $MgSO_4$, Na_2SO_4. Two genetic modifications of salts are differentiated: Subtype II-a containing $Mg(HCO_3)_2$ – its forming is determined by means of complex processes of interaction between soils and waters, and Subtype II-b containing $CaSO_4$ – salt, usually combined with the dissolution of gypsum lenses.

The third type is characterized by an ionic correlation $HCO_3 + SO_4 < Ca + Mg$ or $Cl > Na$. Water of this type are mixed and metamorphosed. The specific salt for the subtype III-a is $MgCl_2$.

Table 8. Groundwater material composition.

Observed stations - No	Month	Material (substance) water composition according the Kurlov`s formula
1	04	$M_{0.86}\dfrac{HCO_3 51 SO_4 32 Cl 14}{Ca 60 Na 24 Mg 16} pH 7.5 T^0 9.3_2 O_{Mn} 1.44$
1	05-06	$M_{077}\dfrac{HCO_3 40 SO_4 26 NO_3 21 Cl 13}{Ca 55 Na 20 Mg 10} pH 7.4 T^0 9.8_2 O_{Mn} 3.6 Zn 0.62 Fe 0.13$
1	07	$M_{0.63}\dfrac{HCO_3 62 SO_4 21 Cl 13}{Ca 57 Mg 35} pH 7.4 T^0 10.3_2 O_{Mn} 2.3$
1	08-09	$M_{0.86}\dfrac{HCO_3 41 SO_4 23 NO_3 19 Cl 17}{Ca 59 Mg 25 Na 16} pH 7.6 T^0 11.0_2 O_{Mn} 6.4$
2	04	$M_{0.56}\dfrac{SO_4 43 HCO_3 36 Cl 18}{Ca 31 Mg 25 Na 24} pH 7.6 T^0 9.1_2 O_{Mn} 0.92$
2	05-06	$M_{0.58}\dfrac{HCO_3 37 NO_3 22 SO_4 21 Cl 20}{Ca 54 Mg 30 Na 16} pH 7.4 T^0 9.3_2 O_{Mn} 3.75 Zn 2.85 Fe 0.35$
2	07	$M_{0.48}\dfrac{HCO_3 41 SO_4 27 Cl 19 NO_3 13}{Ca 60 Mg 27 Na 13} pH 7.5 T^0 9.7_2 O_{Mn} 1.56$
2	08-09	$M_{0.95}\dfrac{NO_3 33 SO_4 27 HCO_3 23 Cl}{Ca 43 Na 30 Mg 27} pH 7.6 T^0 10.2_2 O_{Mn} 13.2$
3	04-09	$M_{0.786}\dfrac{SO_4 45 HCO_3 36 Cl 16}{Ca 45 Mg 28 Na 27} pH 7.2 T^0 9.2_2 O_{Mn} 5.0$
3	07	$M_{0.14}\dfrac{HCO_3 51 SO_4 23 NO_3 18}{Ca 32 Mg 15} pH 7.6 T^0 8.0_2 O_{Mn} 2.96$
4	04-09	$M_{0.42}\dfrac{SO_4 48 HCO_3 39 Cl 11}{Ca 47 Mg 35} pH 7.5 T^0 9.6_2 O_{Mn} 2.009 Fe 0.22$
5	04-09	$M_{0.29}\dfrac{HCO_3 45 Cl 38 SO_4 15}{Ca 56 Mg 28} pH 7.2 T^0 10_2 O_{Mn} 2.8 Fe 0.89 Mn 0.26$
6	04-09	$M_{0.43}\dfrac{HCO_3 60 SO_4 28 Cl 11}{Na 38 Ca 37 Mg 25} pH 7.5 T^0 9.0_2 O_{Mn} 3.2 Fe 3.94 Mn 1.14-1.19$
7	04	$M_{0.67}\dfrac{HCO_3 54 SO_4 25 Cl 18}{Ca 50 Mg 38 Na 12} pH 7.6 T^0 9.3_2 O_{Mn} 1.3$

Table 8. Continued.

Observed stations - No	Month	Material (substance) water composition according the Kurlov`s formula
7	05-06	$M_{0.69}\frac{HCO_3 54 SO_4 22 Cl 15 NO_3 9}{Ca 56 Mg 28 Na 16} pH 7.6 T^0 9.5 {}_2O_{Mn} 1.8$
7	07	$M_{0.4}\frac{HCO_3 58 SO_4 26 Cl 12}{Ca 51 Mg 28 Na 21} pH 7.6 T^0 9.5 {}_2O_{Mn} 1.8$
7	08-09	$M_{0.63}\frac{HCO_3 52 SO_4 24 Cl 12 NO_3 12}{Ca 56 Mg 34 Na 10} pH 7.6 T^0 9.4 {}_2O_{Mn} 4.8$

At each station, differences between classes, types, salt compounds and material water contents (Tables 7, 8) are due to the specific special features of the active factors (natural and anthropological ones), which jointly form the chemical water composition.

RESULTS

Water for agriculture

In agriculture, groundwater is mainly used for irrigation. In the assessment of water suitability hydrogeological, agrochemical and climatic peculiarities of the examined territory should be taken into account. Such general assessments are connected with the danger of salting and subsequent ion exchange replacement (Ca and Mg), with sodium. However the soil structure is becoming worse and its filter capacity decreases.

For purposes of accomplishing hydrochemical water suitability assessment four basic characteristics are used:

a) Temperature. Low water temperatures restrict plant growth and as a optimum temperatures between 12-18 degrees are considered. According to this index, the water in the stations 1, 2, and 3 is suitable (see Fig. 8).
b) Mineralization. So far, with respect to mineralization, maximum values do not exist because it depends on many local factors: soil type, concentration of the pore solution, dissolved water salt composition and the character of the cultures. Seasonally, water mineralization does not exceed 1 g/dm^3, and can be considered as fresh and harmless for the cultures (Table 8). Mineralization values increase during summer (August – beginning of September) and it is recommended irrigation to be divided into small portions, but at high frequency. That will prevent accumulation of additional quantities of salt and pore solution concentrations.
c) Salt composition. In irrigated water, sodium salts appear to be most harmful. For soils with a high coefficient of filtration, accepted admissible maximum levels are: Na_2CO_3 – 1g/dm^3, NaCl – 2g/dm^3, Na_2SO_4 – 5 g/dm^3. In case of joint presences of these salts, these values are

reduced. For example, the groundwater at station 1 and 2 during the irrigation season contained NaCl, $MgCl_2$ and $MgSO_4$. At the station Chelopechene village (except the listed salts), Na_2SO_4 can be found (Table 7).
This fact is of great importance, because Mg and Na adsorb soil colloids and causes soil structure and its filtration properties to worsen.

d) According to the irrigation coefficient SAR, this index provides quantitative view of the potential danger caused by replacement of calcium and magnesium adsorbed in the soil with sodium. In accordance with the seasonally examined values, groundwater in the region can be considered excellent (Table 9).

Water for industry

The requirements for groundwater utilization by industry correspond to the special features of industrial production. When steam-boilers operate, requirements are especially high (stations 3, 4, 5, 6) and almost all water components might be considered as harmful. According to the values of this index, water is middle hard to hard. Predominant are water with thin and hard incrustation mass (coating) (Table 10). The presence of $CaSO_4$ in the water leads to the formation of so-called gypsum incrustations.

Table 9. Groundwater irrigation coefficient – SAR.

Observed Stations No	Months	Irrigation coefficient (SAR)	Classification according SAR
1	04	1.28	excellent
1	05-06	0.61	excellent
1	07	0.36	excellent
1	08-09	0.84	excellent
2	04	0.51	excellent
2	05-06	1.84	excellent
2	07	1.08	excellent
2	08-09	0.74	excellent
3	04	0.56	excellent
3	05-06	0.74	excellent
3	07	0.89	excellent
3	08-09	0.44	excellent

Table 10. Groundwater hardness and incrustation mass (coating).

Observed Stations No	Categorization according hardness indicator	Categorization according incrustation mass
3	hard	water with thick hard coating
3 (07)	very soft	water with thin hard coating
4	middle hard	water with thin hard coating
5	middle hard	water with thin hard coating
6	middle hard	water with thin soft coating

Table 11. Groundwater foam forming and corrosive activity.

Observed Stations No	Categorization according foam forming indicator	Categorization according corrosive activity
3	semi-foam forming	corrosive
3 (07)	foam- free forming	corrosive
4	semi- foam forming	corrosive
5	foam- free forming	corrosive
6	semi- foam forming	corrosive

When steam boilers operate, the usage of water forming incrustations is quite uneconomical – even 1-mm layer incrustation cause heat over expenditure of up to 5%, and under the incrustation layer additional corrosion processes operate. As in this particular case, groundwater are characterized with having corrosive activity and semi-foam and foam-free forming (Table 11). This is why it is advisable before each water usage, to soften the water, i.e. to treat the water with processes that lower the Ca and Mg salt concentrations.

For this purpose, different kind of methods are suitable: thermal, chemical, cation and others.

CONCLUSIONS

In the Sofia Plain groundwater, quantity and quality formations are determined by interactions between basic natural and anthropological factors. Concerning natural (basic water composition factors), climatic, geological, geomorphological and hydrogeological factors are investigated. The anthropogenic influences appear to be: urbanization, industry, and agriculture. These influences are expressed in the sharp increase in permanganate oxidization values ($_2O_{Mn}$), the appearance of nitrite, phosphates and ammonium predestining Eh alterations into the system soils-rocks. These alterations cause groundwater enrichment with heavy metals harmful to humans: Fe, Mn and Zn.

In the agricultural regions, the water regime is distinct and the above-mentioned characteristic appears during spring months (pre-vegetative period). Generally, the values are stable (obtained substances and salt compositions). Repeated enrichment with organic substances is observed during the autumn months when the water levels is increasing – secondary pollution of the groundwater aquifer (due to non-assimilation of soil nitrogen by plants and microorganisms).

Water utilization is appointed mainly into two directions: agriculture and industry. As a whole, groundwater can be used for irrigation. Taking into account the increasing mineralization and their salt composition, we recommended the use of low irrigation norms with high frequency. With respect to industry it should be taken into account that the water are: mainly middle hard to hard; with thin hard incrustation forming; semi and foam-free; corrosive, i.e. requiring preliminary softening.

With respect to examining the anthropogenic impact assessment of groundwater quality, it is recommended to clarify surface-groundwater relations and to support their model provision. In this respect, the updated observation stations, considered with actual hydrogeological situation, will contribute in the creation of real estimations of pollution types, its sources and its impact on surface and groundwater quality deterioration.

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Urban Planning and Ecological Problems of the Green Systems of Large Cities in Bulgaria: Sofia as a Case Study

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Abstract

The green system of a large city supports the biological balance of the human – society – environment ecological system.

In order to improve all urban territories, it is important not only to introduce an optimum amount of green spaces of different functional purposes, but also to appropriately place the park elements within the territory of the city.

The interrelation of the interior and exterior spaces and the green areas form the green system at all levels of the urban formation; the penetration of forests, situated outside the city, into the built up areas, is one of the major conditions for an organic development of a large modern city.

The creation of an integrated green system in a city is a complex and long process and it is related to a number of architectural, urban planning, construction, environmental, visual, and economic decisions.

Key words

Green system, park, urban, urbanization, Sofia, Bulgaria.

DEFINITION AND FUNCTIONS OF THE GREEN SYSTEM

In general, the green system is designed to improve the environment of a large city, creating optimum conditions for the development of all functional systems.

The green system of a large city has diverse functions:

- **Urban planning functions** – organises and distributes the green spaces, which, coupled with the surrounding architectural and landscape groupings, forms the appearance of the streets, squares, districts, and functional zones (housing, public services, industry, communication, transport);

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 165-170

- **Amelioration** - improves the air quality and microclimate of the city;
- **Recreation** - creates a favorable environment for public recreation;
- **Aesthetic** - presents a remembered image of the city and its structural elements;
- **Ecological** - generally improves the environment of a city with respect to biodiversity conservation (Naidenova, 1982; Puhalev, 1994; Kovachev, 1999).

In order to display and analyze the current urban ecological problems of parks and green spaces it is necessary to define the green system of the city as a whole. Based on numerous work and continuous research of the Bulgarian and foreign urban planning practices in the field of green system development, we reached the following definition:

The green system is all planned, designed, and built green spaces for public and special purpose use in the building boundaries of the inner city and the suburban zone, which, depending on the size and significance of the city and the particular environmental and social conditions and, regarding the quantitative and qualitative standards, maintain the biologically active part of the living environment of the population, participate in the formation of the functional and spatial composition of the city, and connect its separate structural elements, functional zones with the external environment (Kovachev, 2000).

CLASSIFICATION OF GREEN SPACES

Until the beginning of the 1990s, the green spaces in Bulgaria were classified into:

- green spaces for wide public use;
- green spaces for limited public use;
- green spaces with special purposes for wide or limited use.

Regulations concerning landscaping of settlements currently in force in Bulgaria, further classify green spaces into two types:

- **Public green spaces** - urban parks, gardens, squares (i.e. areas with a recreational function). They are public property (state or municipal) and comprise the backbone of the green system of the city. The standards for green spaces *per capita* in square meters applied only to this type, *i.e.* the public green spaces are subject to *per capita* calculation.
- **Service green spaces** - green spaces in the residential areas and districts; industrial zones; child, education, hospital, sports, and research centers; botanical and zoological exhibition parks etc. They can be either public or private property, as well as mixed property (public and private).

A serious problem in the new social and economic conditions in Bulgaria, in terms of the transition from a centralized to a market economy after 1989, is the lagging in development of green systems in the large cities and the capital. Many years are required for the creation of a garden or a park. Practice shows that the vegetation elements and groupings reach proper shape at least 15–20 years after planting. This means that special attention is necessary to preserve the already matured green spaces.

Some 10 years ago, many parks of various functions were still designed and constructed, but this is impossible today as a result of many obstacles. One is the severe financial shortage during the period of economic transition. There is neither funding to maintain the existing green spaces, nor to develop new ones, in spite of provisions made available for urban development programs.

During the last decades of the 20th century, a number of restitution acts were adopted in Bulgaria. Restitution is the process of giving back land and real estate property, taken away for the benefit of the state on the basis of various acts, such as the Scheduled Urban Development Act and the Regional Development Act, in the event of nationalization in 1946 and the following decades, to its former owners.

Sofia, as the capital and the largest city of the country is an example where the problems of the present condition and the future development of the green system are progressively gaining attention these days.

THE GREEN SYSTEM OF SOFIA: PRESENT CONDITIONS

The green system of Sofia has been formed on the basis of several large green wedges originating at the rim of the city and reaching out to its central areas. This system of green wedges, which are, at the same time, axes or rays from the city center to the suburban zone, was incorporated into the urban development plan before World War II (the plan of 1938 known as Musman's plan after its creator, the German professor of architecture Adolf Musman) and into all subsequent urban development plans from 1945, 1961, and the 80s. Nowadays, the basis of the green wedges system of the capital are still the large public parks (Southern park, Western park, Northern park; King Boris' Garden).

Fig. 1. Sofia – park of residence Vrana.

The present condition of the green system of the capital is characterized by partial completeness and delay of the realization of the large urban parks (Southern park part IV, Eastern park, etc.) which is favourable for the negative restitution process, the construction of temporary structures in the park territories, and the destruction of the existing vegetation.

Currently, the green system of Sofia has the following structure:

a) 44,98 % - green spaces for wide public use;

b) 41,10 % - green spaces for limited public use;

c) 13,92 % - green spaces with special purposes for wide or limited use.

Current regulations set a minimum necessity of public green spaces of 35.0 sq. m *per capita*. In reality, however, at the end of the 20th century, the *per capita* supply with green spaces was about 15.0 - 16.0 sq. m, which is less than half the requirement (Kulliliev *et al.*, 1999-2000).

The situation becomes even more complicated in the present period of economic crisis and transition of the country's and society's development, as the population of the capital is not decreasing. The official statistical data shows that the population of the capital is more than 1/7 of the population of the country. On 31.12.1998 the population of Sofia accounted for 1 199 708, while the population of Bulgaria was 8 230 371. Moreover, in recent years the number of cars have increased sharply, which have had seriously deteriorated the environmental conditions. At the same time, park territories have decreased in size.

Experience showed that at the end of the 20th century, 10 to 80 % of the territories planned to be developed as parks in Sofia had been restituted. This created huge problems of how to pre-

Fig. 2. Sofia – South Park, part 3.

serve the significant and famous parks of the capital and how to further develop the spatial structure of the green system of the million-strong city. Some measures on the modification of the urban development plan at different levels will have to be worked out regarding land ownership changes.

The problem with restitution concerns not only the public green space, but also those for special purposes. More than 60 % of the green spaces for limited use, occupy spaces in residential areas and districts, which have been built over four decades, applying industrialized technologies. In recent times, restituted land appears quite frequently in-between houses in the housing areas. How did all this happen? Here is one of the important background characteristics: Bulgaria is one of the few countries in the world where a large percentage of residential fund is private property. Currently, more than 93 % (other sources give 94-95 %) of the residential fund in the country, and more than 85 % for Sofia, is private property. Even within the former planned economy (1944-1989), the state used to build dwellings and than sell them to the people. These were mainly concrete panel blocks of flats, which require serious reconstruction at present. This is another urgent topic connected to the upgrading of the panel-built residential fund, which for the scale of Bulgaria is huge and add to the complex and pressing issues of the agenda problems. In other words, the inhabited flats in the buildings in residential districts are privately owned, however, the land on which the buildings stand and that between the buildings (the inner-district space) is municipal or state property.

POLITICS FOR THE DEVELOPMENT OF THE GREEN SYSTEM OF SOFIA

In order to keep the spatial borders of the elements of the green system of the city, it is necessary to pursue a policy of preserving the character of the park territories with the following objectives:

a) Preservation of the public character of the green spaces (parks and gardens);
b) Implementation of measures for compensation - reimbursing the land owners with municipal land of the same quantity and quality lying beyond the boundaries of the parks;
c) Allowing construction of objects and structures on restituted land, which are compatible with the functions of the park;
d) Joint participation of land-owners and the municipality in the management of the territory for a certain period of time with the objective to achieve higher economic efficiency and investment returns.

In order to effectively implement these measure, it is necessary to develop, adopt, and implement urban development standards, regulations, and mechanisms regarding the green spaces.

However, there are difficult and complicated problems to face:

a) The city administration should preserve the public character of the park territories, providing opportunities for recreation for the population;
b) The land-owners, who have had their land returned as a result of the restitution act have their own interests, which very frequently not only diverge with those of society, but also rise contradictions with the provisions in some other acts (Kovachev, 2000).

To find the balance between private and public interests (between the interests of land-owners and the municipality) is perhaps, by itself, the most difficult, but also the only correct way to solve the task of preserving the green system of the city for present and future generations. Land owners, whose land is within the boundaries of existing green spaces or such designated for construction under the urban development plan (but not fulfilled yet) should understand that they can not build anything they want or like (for example, they have no right to build houses), but only facilities for recreation and entertainment. They still refuse to realize, that they can profit by investing money in the organization sites, which are compatible with the functions of the green spaces, for instance entertainment facilities.

The integration of investors and their interests is necessary for the fulfillment of the building programs on the territories of the parks following one important rule: any buildings, constructions and various activities should not deteriorate the ecological, recreational, and aesthetic qualities of the park territory.

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Plants

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Bryophytes in the city of Sofia

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Summary

In order to determine the species composition of bryophytes, samples were collected from parks, gardens and meadows in the central and southern parts of the city, growing on different substrata: stones, bare soil, brick walls, at the base of tree trunks, and along streets and pavements. Nineteen bryophyte species inhabit the park territories and gardens in Sofia. Diversity of bryophyte species is higher in the old city parks. Bryophytes can thrive on suitable microhabitats, such as stones, decaying wood, bare soil, and in humid grassy areas. The absence of epiphytic bryophytes on deciduous trees and shrubs is explained by insufficient air humidity and the polluted atmosphere of the city.

Key words

Bryophytes, Sofia, bryoflora, urban environment.

INTRODUCTION

The first investigations on the bryoflora of Bulgaria date back to the beginning of the twentieth century. They were carried out by the Czech botanists Velenovsky and Podpéra, and by the Bulgarian explorers Arnaudoff, Petkov and Kovačev. These researchers described the distribution of some bryophyte species, mainly in the mountainous regions. Even nowadays the paper of Podpéra (1911) is of particular interest. Three hundred taxa were included in it, 13 of which were collected in the rock garden of the Royal Botanical Garden in Sofia. In his inventory of the bryoflora of Mt Vitosha, Arnaudoff (1909, 1914) mentioned five species, collected in Sofia. Ade & Koppe (1955) recorded the distribution of *Grimmia pulvinata* Smith in the city. The species grew on stones and occasionally on rocks. More recent publications did not contain any data on the species composition of the bryoflora in Sofia, probably because scientific effort and interest were mainly directed towards the still anthropogenically unaffected countryside, lowlands and mountains in Bulgaria.

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This study does not strive to present a detailed description of the bryophyte flora in Sofia but to throw light on some areas in the city, important from the viewpoint of a bryologist.

MATERIAL AND METHODS

In order to determine the species composition of bryophytes, samples were collected from parks, gardens and meadows in the central and southern parts of the city. Bryophytes grow on different substrata, i.e. stones, bare soil, brick walls, at the base of tree trunks, and along streets and pavements.

The names of the species collected follow the nomenclature of Corley *et al.* (1981) and the ecological types follow Boros *et al.* (1993).

RESULTS AND DISCUSSION

Nineteen bryophyte species from eleven families inhabit the park territories and gardens in Sofia (Table 1). Most are mesophytes. Some are widespread in Bulgaria: *Hypnum cupressiforme* Hedw., *Bryum argenteum* Hedw., and *Ceratodon purpureus* (Hedw.) Brid. The first species often occurs in parks, at the base of oak trees, sometimes together with *Dicranum tauricum* Sap. The two remaining species grow on stones and pavements covered with a thin layer of soil, or on degraded soils. *Funaria hygrometrica* Hedw. is a pioneer species inhabiting bare soil, dugout and scorched terrains. *Bryum capillare* Hedw. var. *flaccidum* (Brid.) B., S. et G., *Tortula muralis* Hedw., and *Tortula subulata* Hedw. grow on humid, shady brick walls covered with a thin layer of soil. Species like *Brachythecium rutabulum* (Hedw.) B., S. et G., *Brachythecium salebrosum* (Web. et Mohr) B., S. et G., *Eurhynchium hians* (Hedw.) Sande Lac., *Dicranella heteromalla* (Hedw.) Schimp., *Bryum elegans* Nees ex Brid., and *Fissidens taxifolius* Hedw. were found as components of meadow herb vegetation, together with various grass species. The above mentioned bryophytes prefer intact meadows. *Plagiomnium undulatum* (Hedw.) T. Kop. was collected in ever more humid places in parks and gardens. This species is widespread in Bulgaria and prefers humid and shady forest habitats and soils along springs and rivers. *Brachythecium velutinum* (Hedw.) B., S. et G. is another widespread species in Bulgaria. In Sofia it was found on soil, stones and brick walls, sometimes with *Amblystegium serpens (*Hedw.) B., S. et G. Dry, exposed stones and walls serve as a substrate for *Schistidium apocarpum* (Hedw.) B., S. et G., a species distributed all over the country on calcareous and siliceous rocks. *Atrichum undulatum* (Hedw.) P. Beauv. is a terricolous species and often forms dark-green patches around trees in the oak park-forests in Sofia. It is also typical for natural oak and beech forests, where it grows on clayey and sandy soils.

Diversity of bryophyte species is highest in the old city parks. These parks cover large areas and the plant communities are more or less undisturbed. Bryophytes thrive in these specific environments and on diverse suitable microhabitats, such as stones, decaying wood, bare soil, and in humid grassy areas. Only a few bryophyte species were found in ray-grass meadows or in places where flowering plants are often planted and re-planted in accordance with the park landscaping.

Table 1. List of bryophytes collected in the city of Sofia and their ecological types.

No.	Taxa	Ecological types
	Bryopsida	
	***Polytrichaceae* Schwaegr.**	
1.	*Atrichum undulatum* (Hedw.) P. Beauv.	mesophyte
	***Fissidentaceae* Schimp.**	
2.	*Fissidens taxifolius* Hedw.	mesophyte
	***Dicranaceae* Schimp.**	
3.	*Dicranum tauricum* Sap.	mesophyte
4.	*Dicranella heteromalla* (Hedw.) Schimp.	mesophyte
5.	*Ceratodon purpureus* (Hedw.) Brid.	xerophyte
	***Pottiaceae* Schimp., nom. cons.**	
6.	*Tortula subulata* Hedw.	xero-mesophyte
7.	*T. muralis* Hedw.	xerophyte
	***Grimmiaceae* Arnott**	
8.	*Schistidium apocarpum* (Hedw.) B., S. et G.	xerophyte
	***Funariaceae* Schwaegr.**	
9.	*Funaria hygrometrica* Hedw.	xero-mesophyte
	***Bryaceae* Schwaegr.**	
10.	*Bryum capillare* Hedw. var. *flaccidum* (Brid.) B., S. et G.	mesophyte
11.	*B. elegans* Nees ex Brid.	mesophyte
12.	*B. argenteum* Hedw.	meso-xerophyte
	***Mniaceae* Schwaegr.**	
13.	*Plagiomnium undulatum* (Hedw.) T. Kop.	meso-hygrophyte
	***Amblystegiaceae* (Broth.) Fleisch.**	
14.	*Amblystegium serpens* (Hedw.) B., S. et G.	mesophyte
	***Brachytheciaceae* Schimp.**	
15.	*Brachythecium salebrosum* (Web, et Mohr) B., S. et G.	mesophyte
16.	*B. rutabulum* (Hedw.) B., S. et G.	mesophyte
17.	*B. velutinum* (Hedw.) B., S. et G.	mesophyte
18.	*Eurhynchium hians* (Hedw.) Sande Lac.	mesophyte
	***Hypnaceae* Schimp.**	
19.	*Hypnum cupressiforme* Hedw.	meso-xerophyte

The absence of epiphytic bryophytes on deciduous trees and shrubs is explained by insufficient air humidity and the polluted atmosphere of the city. Species like *Bryum argenteum* and *Ceratodon purpureus* are pollution-resistant and often grow along pavements and on walls, even in the central parts of Sofia. They could be successfully used as biomonitors of air pollution. Concentrations of some chemical elements in the moss samples from polluted and unpolluted areas could be compared, so as to obtain data on environmental conditions.

As part of the urban flora, bryophytes are an important component of urban ecosystems. The bryophyte layer creates favourable conditions for seed germination of tree and herb species, preserving moisture and decreasing temperature fluctuations (Ipatov & Tarhova 1982; Raimolt 1986). Bryophytes are the first settlers on open, bare soils and devastated areas. These plants are also aesthetically important. Their green carpets could be used as elements of the park landscaping, together with flowering plants, small shrubs and in-between rocks in rock gardens.

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Mapping Air Quality Using a Lichen Diversity Index in Northeastern Sofia

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Summary

Air pollution patterns were mapped near the town of Sofia, Bulgaria. For the first time in Bulgaria the Index of Atmospheric Purity (IAP) was used for this purpose. IAP was calculated using lichen frequency. Twenty eight sampling stations were studied. At each sampling station, lichen frequency was registered on 10 trees. A contour map, showing air quality zones, was drawn on the basis of the mean IAP value from each station. Forty-three epiphytic lichen species were found in the area.

Key words

Air quality, bioindication, mapping, lichens, urban environment, IAP, Bulgaria.

INTRODUCTION

Data on environmental conditions are important in the decision making process. Air pollution monitoring in Bulgaria is traditionally carried out by means of recording gauges. However, high costs limit the possibilities for having enough and constantly working stations, with a subsequent lack of comprehensive data on temporal and spatial changes in air pollution patterns. In addition, technical data do not give information on synergic and antagonistic effects of pollution on organisms (Loppi *et al.*, 1995). The use of biomonitors can aid in solving these problems.

Lichens are established bioindicators and biomonitors. Most lichen species are extremely sensitive to a wide range of air pollutants and get easily damaged and perish (Gilbert, 1973; Hawksworth, 1973; Laundon, 1973; Hawksworth & Rose, 1976; Shouman, 1988). Because of this sensitivity, lichens are widely used for assessing air quality by means of various morphological, floristic and population characteristics. Such studies will allow investigators to reveal spatial and temporal changes in air pollution patterns. Plotting of contour maps showing different lichen zones is the most common result from lichen bioindication studies. Despite the obvious advantages of

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using lichens as bioindicators and biomonitors only a few mapping studies (Filipova, 1962; Ivanov & Ivanova, 1995) have so far been carried out in Bulgaria. Here, the Index of Atmospheric Purity (IAP), proposed as an indicator by De Sloover (1964) and Le Blank & De Sloover (1970), was used as a method providing fast and statistical information on air quality for the first time in Bulgaria. The aim of the study was to obtain information on air pollution patterns in the north-eastern part of Sofia. The data were used in a public campaign of a Bulgarian non-governmental environmental organization "ECO-CLUB 2000".

STUDY AREA

The study area is situated in Western Bulgaria, northeast of Sofia and southwest of the "Kremikovtzi" metallurgic plant. A 79 km^2 area was investigated and mapped in detail. The area is situated in the Sofia plain at 500-630 meters above sea level. Agricultural lands and damp meadows predominate the area, but small villages, industrial estates and artificial lakes are also present. The climate in the region is moderate and continental (Stanev, 1991) with an average annual temperature of 10.5°C and an annual rainfall of 621mm. Westerly winds predominate during eight months of the year (January - April, June - August and December) and easterly winds during four months (May and September - November). The main sources of air pollution in the area and its surroundings are the city of Sofia, the "Gara Iskur" industrial zone, Sofia Airport, "Kremikovtzi" metallurgic plant with a big industrial waste landfill and coal burning used for heating in suburbs and small villages.

Six atmospheric pollutants (dust, SO_2, NO_2, H_2S, Pb and phenol) were monitored in the town of Sofia and in a few surrounding villages. According to these data, the most important pollutant in Sofia is NO_2 and its concentrations are often higher than the national air quality standards, whereas SO_2 exceeds standards only during the winter season. There are no monitoring stations, providing technical data on air pollution concentrations in the mapped area.

MATERIALS AND METHODS

The study was carried out in 1997-1998. Twenty-eight randomly selected sampling stations were studied. At each station, 10 poplar trees (268 were *Populus euramericana* (Dode) Guinier and 12 were *Populus nigra* L.) were used for collecting the field data. In order to standardize field data collecting procedures, the following conditions were followed: use of trunks with circumference between 100 and 300 cm.; use of trunks with inclination of primarily 90° (upright trees), or as an exception between 70° and 100°; trees growing in dense and shady forests were not chosen; trees with visible damage on the bark surface were not used.

The Index of Atmospheric Purity (IAP) was used to estimate air quality. In our study IAP was calculated on the basis of the frequency of lichen species according to the modified formula of IAP (Ammann *et al.*, 1987; Liebendorfer *et al.*, 1988; Urech *et al.*, 1988; Herzig *et al.*, 1989; Ammann *et al.*, 1991): $IAP = \Sigma F$, where F represents the frequency of each lichen species on each tree. Lichen species frequency was registered with a grid rectangle (50 cm long and 30 cm wide).

The grid was placed at a height of 1.10-1.70 meters, on the side of the tree trunk with the highest lichen diversity. The frequency of each lichen species was calculated as the number of grid units in which the species occurs. Species found outside the grid, on the same tree were also registered. All species found in the grid were used to calculate IAP values. Some species could only be correctly identified in the laboratory.

The mean, standard deviation and standard error of the IAP values are given. Based on the mean IAP values of each sampling station, a contour map illustrating air quality changes was plotted using the plotting program SURFER (Golden Software Inc., Colorado), and Kriging was used as an interpolation algorithm. The width and limits, distinguishing the significantly different lichen zones, were determined by the standard deviation of 28 mean IAP values of all sampling stations. However, the width of the first zone was twice as small as the standard deviation and its lower value was set to zero (Liebendorfer *et al.*, 1988; Urech *et al.*, 1988).

RESULTS

Forty-three epiphytic lichen species were collected in the investigated area (Table 1). Due to difficulties in distinguishing eight species in the field, these were grouped into four groups of two species each. Both species of the *Lecanora carpinea* / *L. leptirodes* and *L. rugosella* /*L. subrugosa* pairs were almost equally abundant and widespread in the field. Only the first species of the *Lecanora hagenii* / *L. subfusca* pair was present in the most polluted areas. In the fourth pair, *Buellia punctata* was more common and often collected, while *Buellia disciformis* was collected only three times.

Physcia adcsendens, Lecanora hagenii, Buellia punctata, Rinodina sophodes, Phaeophyscia orbicularis, Physcia stellaris, Candelariella vitellina, Lecanora rugosella, Lecanora subrugosa and *Xanthoria parietina* were the most frequently collected species in this study. These species are relatively insensitive to air pollu-

Table 1. Epiphytic lichen species found on the 280 investigated poplar trees. The number of trees on which the species were found in the lichenological grid is shown for each species (species without numbers are established on the same trees but never in the grid).

Species	No	Species	No	Species	No
Physcia adcsendens	192	*Scoliciosporum umbrinum*	22	*Lecanora intumescens*	3
Lecanora subfusca × *Lecanora hagenii*	162	*Melanelia glabra*	20	*Parmelina quercina*	3
Buellia punctata × *Buellia disciformis*	116	*Caloplaca cerina*	19	*Physconia grisea*	3
Rinodina sophodes	116	*Parmelia sulcata*	18	*Anaptychia ciliaris*	1
Physcia stellaris	97	*Evernia prunastri*	16	*Melanelia acetabulum*	1
Phaeophyscia orbicularis	93	*Xanthoria candelaria*	14	*Melanelia exasperata*	1
Candelariella vitellina	83	*Caloplaca holocarpa*	10	*Micoarea nitschkeana*	1
Lecanora rugosella × *Lecanora subrugosa*	63	*Melanelia exasperatula*	9	*Physcia aipolia*	1
Lecanora carpinea × *Lecanora leptirodes*	51	*Hypogymnia physodes*	7	*Physconia enteroxantha*	1
Xanthoria parietina	47	*Caloplaca lobulata*	6	*Buellia erubescens*	
Ramalina pollinaria	28	*Caloplaca aurantiaca*	5	*Lecanora muralis*	
Phaeophyscia nigricans	27	*Melanelia fuliginosa*	5	*Neofuscelia verruculifera*	
Lecidella olaeochroma	26	*Pseudevernia furfuracea*	4	*Physconia distorta*	

tion and are nitrophilous. Even at the least polluted sampling station, nitrophilous species predominated, while sensitive species were absent. The lichen vegetation found here was therefore very different from the primeval expected assemblage.

It is not possible to compare our findings with previous studies in Sofia (Popnikolov, 1931; Filipova, 1962). These authors investigated different areas, did not fully describe all epiphytic lichen flora, and did not objectively estimate lichen abundance. In summary, most abundant lichens reported from the early 1930's are the same nitrophilous species reported now. Comparing these observations with that of the present day, it is clear that lichens have suffered impoverishment within the city in recent times.

The sum of frequencies per tree and mean IAP values per station are given in Table 2. The lowest IAP value was 0 and the highest 70. The mean IAP value per sampling site varied between 0.1 and 54.2. The lowest IAP values were found in the vicinity of Sofia Airport, and the highest values in

Table 2. Mean IAP values, standard deviations (STDEV) and standard errors (STE).

Station	**Sum of frequencies on individual trees**										**IAP**	**STDEV**	**STE**
No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
1	0	6	0	3	0	0	0	0	0	1	1.0	2.0	0.6
2	9	8	11	1	1	8	1	0	5	7	5.1	4.0	1.3
3	4	17	5	0	0	3	0	3	1	5	3.8	5.1	1.6
4	0	0	0	0	0	0	0	0	0	1	0.1	0.3	0.1
5	0	0	0	0	2	1	0	0	11	0	1.4	3.4	1.1
6	7	11	0	0	1	3	7	17	6	23	7.5	7.6	2.4
7	0	0	0	0	0	0	0	0	1	0	0.1	0.3	0.1
8	0	0	0	0	0	0	6	0	0	0	0.6	1.9	0.6
9	44	17	11	32	13	14	19	23	25	11	20.9	10.6	3.3
10	0	0	0	0	0	13	13	7	15	18	6.6	7.5	2.4
11	5	5	9	0	1	3	1	0	16	0	4.0	5.1	1.6
12	35	17	11	7	30	24	22	13	3	9	17.1	10.4	3.3
13	33	35	46	19	14	11	0	0	0	28	18.6	16.4	5.2
14	6	29	44	13	9	19	16	13	2	24	17.5	12.3	3.9
15	29	43	32	16	31	33	44	41	24	28	32.1	8.8	2.8
16	21	15	5	19	20	28	22	31	16	27	20.4	7.5	2.4
17	60	58	57	70	64	37	54	46	67	29	54.2	13.2	4.2
18	58	29	21	41	54	1	35	41	16	54	35.0	18.5	5.8
19	14	10	15	23	19	23	15	15	17	16	16.7	4.0	1.3
20	39	44	35	48	17	25	16	17	17	44	30.2	13.1	4.2
21	25	11	16	32	21	15	5	7	13	0	14.5	9.6	3.0
22	37	19	30	17	33	11	37	19	30	17	25.0	9.4	3.0
23	5	11	69	11	30	35	30	17	1	15	22.4	19.9	6.3
24	25	12	20	17	16	24	29	0	12	0	15.5	9.9	3.1
25	35	48	43	47	57	53	37	58	30	33	44.1	10.1	3.2
26	6	3	22	15	0	17	3	15	7	3	9.1	7.5	2.4
27	0	3	2	13	5	7	7	3	2	1	4.3	3.9	1.2
28	7	19	1	7	0	5	1	0	0	0	4.0	6.0	1.9

the northern part at a greater distance from the city and probably influenced by the southern slopes of the Balkan mountains. The average IAP value was 15.4 with a standard deviation of 14.04.

The most important contribution of this study is the objective evaluation of lichen diversity, based on a quantitative index and then to use this to construct air quality zones (Fig. 1). Five distinctive zones were identified and are briefly described as follows:

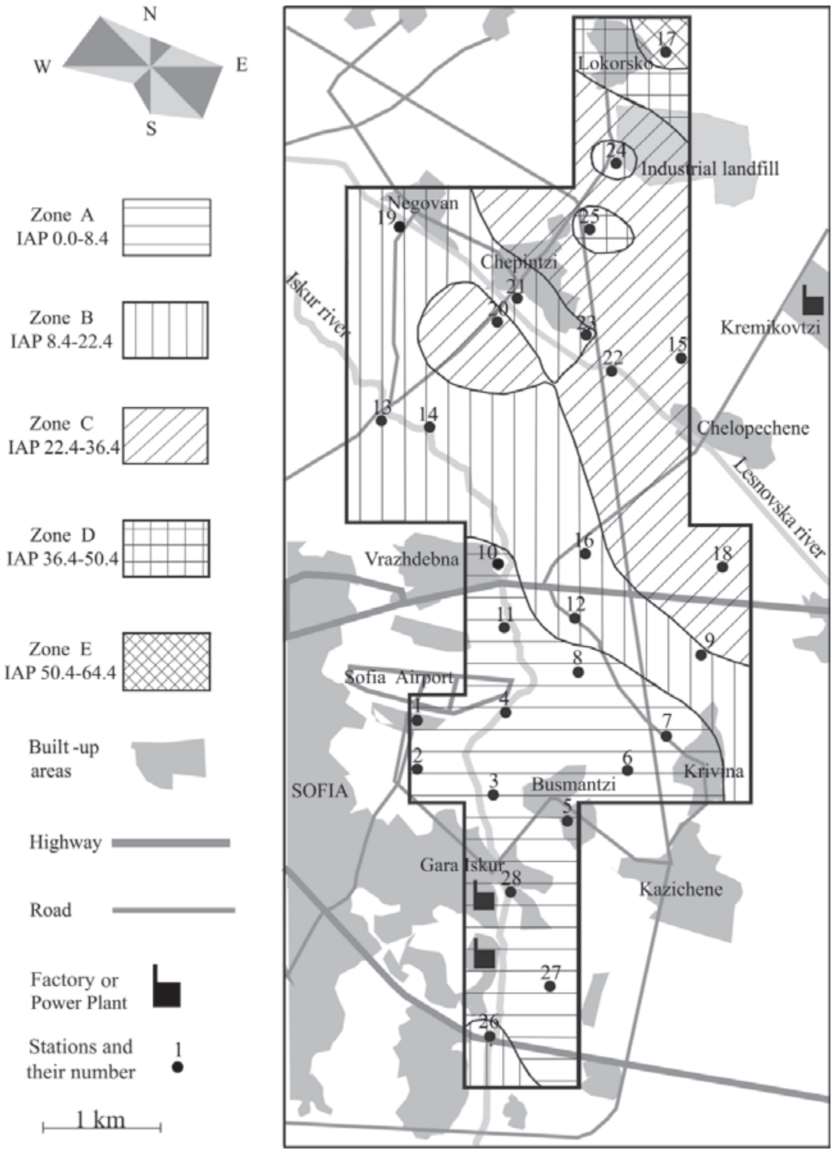

Fig. 1. Contour map of lichen zones.

a) Zone A (highly polluted zone: IAP ranging between 0 and 8.4) is situated in the "Gara Iskur" industrial area, Sofia Airport and adjacent suburbs. Twelve sampling stations were located in this zone and 16 species were found in the grids.
b) Zone B (high pollution: IAP ranging between 8.4 and 22.4) bordering Zone A to the northeast. A small section of this zone was situated in the southern part of the mapped area. This zone also appeared in some places with local pollution sources, like the small villages of Negovan and Chepintzi and the Kremikovtzi landfills. Ten sampling stations were included in this zone and 29 species were found here.
c) Zone C (moderate pollution: IAP ranging between 22.4 and 36.4) surrounding Zone B to the northeast. Only four sampling stations were included in this zone and 28 species were found in the grids.
d) Zone D (low pollution: IAP ranging between 36.4 and 50.4). This zone included only one sampling station with 21 lichen species. It shows the general tendency for air quality improvement towards the northeast.
e) Zone E (the lowest pollution: IAP more than 50.4) included one sampling station situated at the foothills of the Stara Planina mountain. Twenty-nine species were identified at this sampling station which makes it the richest station in the investigated area.

DISCUSSION

An important issue is weather this study is comparable with other studies carried out in other countries and regions using IAP based on frequency.

The design of our survey was similar to others in other countries (Ammann *et al.*, 1987; Liebendorfer *et al.*, 1988; Urech *et al.*, 1988; Loppi *et al.*, 1992; Loppi *et al.*, 1995; Monaci *et al.*, 1997). There were, however some differences. First, poplars used here are not commonly used in lichen mapping studies. Lichen vegetation on poplars often varies strongly from tree to tree (see Table 2). This is probably due to the variety in bark properties, and the high variation in IAP values at each sampling station is likely because of these poplars features. However poplars were the only species providing enough suitable trees for mapping purposes. Furthermore, poplars had the most basic bark in comparison to other species found in the study area. A preliminary field investigation showed that poplars were the only suitable trees with lichen flora in strongly polluted places. PH differences in the bark prevented us from using different tree species, as lichens are PH and tree specific, which influences the IAP values.

Second, the lichen flora in Bulgaria is to some extent different from that of other regions. For example, a widespread, pollution tolerant species found in western Europe (*Lecanora conizeoides*) was not recorded in our mapped region. Finally, lichens change their response to air pollution depending on environmental conditions.

In addition, different to other studies in the calculation of IAP values, we used all species found in the grid rectangle. We did not use a simplified and uniform list of indicator species, because the calibration of IAP values to physical measurements of air pollutants had not been conducted before in Bulgaria. Despite the similarity of our IAP values to those obtained in other studies (Ammann *et al.*, 1987; Liebendorfer *et al.*, 1988; Urech *et al.*, 1988; Loppi *et al.*, 1992; Loppi *et al*., 1995; Monaci *et al*., 1997), close parallels between these are not yet possible. Such comparisons will be possible after a calibration of IAP to technical air quality data and standardization of IAP procedures in Bulgaria and after comparison of these results to calibrations carried out in other regions of Europe.

Another difference is in the choice of sampling stations here. We tried to select stations randomly, but in the future a standardized approach to the choice of sampling stations, related to the geographical grid system should be used.

What do the IAP zones reflect then? Calibration of IAP with eight different pollutants carried out in Switzerland (Ammann *et al*., 1987; Liebendorfer *et al*., 1988; Urech *et al*., 1988) showed that IAP values closely follow air pollution data obtained through technical measurements, and the best correlation between these criteria are made if all available pollution data are used in a regression model. Climatic factors (rain, humidity, temperature) did not have an essential impact on the IAP values. Loppi *et al.* (1995) concluded that the influence of environmental factors other than the atmospheric pollution on the IAP values becomes essential only in pollution-free areas. In our investigation IAP values were obtained within a small area with uniform natural conditions. Air polltuion appears to be the only factor to be different from one sampling station to the next. Micro-climatic and micro-habitat conditions such as lighting, tree age and trunk inclination are also important factors which can reflect lichen vegetation and therefore IAP values (Hawksworth, 1973; Hawksworth & Rose, 1976). These factors were standardised as best as possible and only a simple tree species was used here. Therefore, the zones established with the help of lichens should reflect mainly air pollution influences on lichen diversity. As was expected, lichen zones followed the distribution of air pollutant sources in Sofia (Sofia Airport, industrial waste landfill, small villages) and they were distinguished on a zone map.

It is important to evaluate the accuracy of the mean IAP values at the sampling station. Many stations showed high variation (SD and SE values) in IAP values. This is possibly because the chosen standardization used here was not sufficiently accurate. Part of the variation can be the result of the high variability in bark properties of poplars. The accuracy of the lowest mean IAP values is directly related to the number of units in the grid rectangle used. However, even in stations with the highest variation of IAP values, the standard error was always smaller than the width of the lichen zones.

The main conclusion of this study is that the IAP method as a basic measure of air quality mapping in Bulgaria, requires calibration to technical measurements of air quality and standardization of data collecting procedures. Such a unified lichen bioindication method should be used in future lichen biomonitoring studies in Bulgaria so that comparable results can be obtained and data integrated in databases for future mapping in Europe.

ACKNOWLEDGMENTS

We are very grateful to Dr. Trayko Lidanski from the Institute of Genetics, Bulgarian Academy of Sciences and Dr. Anton Filipov from the Geology and Geography Faculty of Sofia University for consultations; to Dr. Ivan Pisut, Dr. Anna Lackovicova and Dr. Anna Guttova from the Institute of Botany in Bratislava and to Dr. Martin Backor from the Department of Plant Physiology of the Comenius University in Bratislava for assistance and reference materials.

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The Vascular Flora of the city of Sofia

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Abstract

This paper summarises the results of 18 years of collecting vascular plants in the city of Sofia.. A total of 755 species and 7 varietes belonging to 432 genera and 100 families are listed. Data on local distribution and biological type of each species, as well as proportions of biological types and higher taxa in the local flora are presented.

Key words

Flora, vascular plants, urban, Sofia, Bulgaria.

INTRODUCTION

The first study on the vascular flora of the city of Sofia dates back to the end of the nineteenth century. Pančič (1883) recorded approximately 150 species from Sofia and its surroundings during his travels to the Rila Mountains. Similar data are found in the work of Skorpil (1897) for the flora of Plovdiv. Later on, Avramova (1939), Ganev (1942) and Vakarelov and Delkov (1988) studied the species composition of trees of the parks and gardens of Sofia, while Bondev and Ljubenova (1984) studied the artificial and grass plantations in the city.

This study lists the vascular flora of Sofia, collected over a period of 18 years (1984-2001). The material was collected from all the parks, grass areas, streets, riverbeds, railway tracks, artificial lakes in the city, etc. An atlas of the city of Sofia was used as a map base at a scale of 1:20 000 (Smilenova, 1996).

The map of Sofia was divided into 25 quadrants, each of an area of 4900 m². The total number of species of the flora of the city of Sofia include both wild and decorative species.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 185-207

RESULTS

A total number of 755 species and 7 varieties of vascular plants were collected, belonging to 100 families and 432 genera (Appendix). The most numerous families in the Bulgarian flora also dominated the flora of Sofia:

Asteraceae 94; Poaceae 60; Rosaceae 52; Fabaceae 47; Brassicaceae 34; Caryophyllaceae 31; Apiaceae 28; Scrophulariaceae 24; Lamiaceae 22; Chenopodiaceae 16; Ranunculaceae 16; Caprifoliaceae 14; Cyperaceae 13; Polygonaceae 13; Pinaceae 12; Liliaceae 12; Euphorbiaceae 12; Onagraceae 10; etc.

Weed species represented 30.9% of the entire flora of the city. The therophytes in the city invaded mainly through the railways and the riverbeds from the Vitosha, the Ljulin and the Stara planina mountains, as well as through motorways. The weed species belong to the following families: Amaranthaceae, Asteraceae, Polygonaceae, Brassicaceae, Convolvulaceae, Dipsacaceae, Euphorbiaceae, Fabaceae, Geraniaceae, Caryophyllaceae, Lamiaceae, Malvaceae, Phytolaccaceae, Papaveraceae, Poaceae, Portulacaceae, Ranunculaceae, Resedaceae, Solanaceae, Scrophulariaceae, Urticaceae, Valerianaceae, Zygophyllaceae.

The majority of the ruderal species are annual herbs (therophytes) – 99 species (45.4%), perennial herbs – 70 species (32.1%), annual-perennial[1] – 44 species (15.6%) and one species of bush (*Solanum dulcamara* L.).

The flora of the city of Sofia is similar to that of the Sofia Plain. On the other hand, several mountainous species typical of the surrounding mountains were collected in Sofia, i.e. *Euonymus europaeaus* L., *Trifolium* medium L., *Fagus sylvatica* L., *Quercus sessilis* Ehrh., *Geranium robertianum* L., *Calamintha nepeta* (L.) Savi, *Malva sylvestris* L., *Circaea lutetiana* L., *Platanthera chlorantha* (Custer) Rchb. in Mössl., *Cephalanthera damasonium* (Mill.) Druce, *Brachypodium sylvaticum* (Huds.) Beauv., *Calamagrostis arundinaceae* (L.) Roth, *Festuca heterophylla* Lam., *Melica uniflora* Retz., *Trisetum flavescens* (L.) Beauv., *Poa nemoralis* L., *Aremonia agrimonoides* (L.) DC., *Fragaria vesca* L., *Filipendula ulmaria* (L.) Maxim., *Lathraea squamaria* L., *Sanicula europaea* L., *Angelica pancici* Vand., *Teucrium chamaedrys* L.

Only three species of the Division *Pteridophyta* were collected. These are: *Asplenium ruta-muraria* L., *Equisetum arvense* L., *Equisetum ramosissimum* Desf.

In compliance with moisture requirements, the flora of the city of Sofia is classified as follows: mesophytes, 385 (55%); meso-xerophtytes, 242 (34.5%); xerophytes, 26 (3.7%); hygrophytes, 21 (3%) and hydrophytes, 5 (0.7%).

Four historically rare species of the flora of Sofia were found: the aquatic plants – *Acorus calamus* L. and *Hottonia palustris* L., (as subsequently extinct during the drainage of the swamps surrounding the Iskar river and Kazichene village), and *Merendera sobolifera* C. A. Mey, found in Poduene. It was recently collected near Ravno pole, district of Sofia. *Stachys milanii* Petrov had been found next to the railway track near Nadezhda village in the 1920's and was recently collected near Bozhurishte village, district of Sofia.

[1] The annual-perennial plant species are represented by those, which can be both annual and perennial in terms of environmental conditions.

Seventy (10%) herb species were collected in Sofia city. These are:

Equisetum arvense L., *Angelica pancicii* Vand., *A. sylvestris* L., *Eryngium campestre* L., *Heracleum sibiricum* L., *Sanicula europaea* L., *Hedera helix* L., *Achillea millefolium* L., *Artemisia absinthium* L.,*A. vulgaris* L., *Cichorium intybus* L., *Silybum marianum* (L.) Gaertn., *Betula pendula* Roth, *Corylus avellana* L., *Buglossoides arvensis* (L.) M. Jonston, *Symphytum officinale* L., *Humulus lupulus* L., *Sambucus ebulus* L., *S. nigra* L., *Viburnum opulus* L., *Herniaria hirsuta* L., *Saponaria officinalis* L., *Chenopodium botrys* L., *Bryonia alba* L., *Astragalus glycyphyllos* L., *Melilotus officinalis* (L.) Pall., *Ononis arvensis* L., *Erysimum diffusum* Ehrh., *Geranuim macrorrhizum* L., *Hypericum perforatum* L., *Leonurus cardiaca* L., *Melissa officinalis* L., *Mentha spicata* L., *Teucrium chamaedrys* L., *Convallaria majalis* L., *Colchicum autumnale* L., *Galega officinalis* L., *Malva sylvestris* L., *Chelidonium majus* L., *Plantago lanceolata* L., *P. major* L., *Polygala anatolica* Boiss. & Heldr., *Polygonum aviculare* L., *Rumex acetosella* L., *Agrimonia eupatoria* L., *Grataegus monogyna* Jacq., *Fragaria vesca* L. *Filipendula vulgaris* Moench., *F. ulmaria* (L.) Maxim., *Geum urbanum* L., *Laurocerasus officinalis* M. J., *Sorbus aucuparia* L., *Sanguisorba officinalis* L., *Galium verum* L., *Populus nigra* L., *P. tremula* L., *Linaria vulgaris* Mill., *Gratiola officinalis* l., *Physalis alkekengi* L., *Solanum dulcamara* L., *S. nigrum* L., *Tilia cordata* Mill., *Verbena officinalis* L., *Viola odorata* L., *Tribulus terrestris* L., *Leucojum aestivum* L.

The following species new to Bulgaria were collected: *Acalypha virginica* L., *Ambrosia artemisiifolia* L. and *Nasturtium barbareoides* (Tausch.) Čelak. Furthermore, a number of decorative species, present in the Red Data Book, are found in the city parks. These are: *Taxus baccata* L., *Cercis siliquastrum* L., *Laurocerasus officinalis* M. J. Roemer., *Castanea sativa* Mill., *Pyracantha coccinea* Roem., *Ficus carica* L.

During the spring of 1994 some of the tree species were harmed seriously while others were completely eradicated due to unfavorable weather conditions. These were *Acer palmatum* Thunb., *Betula pendula* Roth, *Salix fragilis* L., *Populus nigra* L.

At the end of winter (February, March), snowfall harms many park tree species. These are *Aesculus hippocastanum* L., *Acer platanoides* L., *Acer pseudoplatanus* L., *Quercus cerris* L., *Q. pedunculiflora* C. Koch.

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APPENDIX. Vascular plants* collected in the city of Sofia.

SPECIES NAME	Biol. type	Quadrant*	Weed**
Div. EQUISETOPHYTA			
I. Equisetaceae			
1. *Equisetum arvense* L.	H[1]		
2. *E. ramosissimum* Desf.	H	17	+
Div. POLYPODIOPHYTA			
II. Aspleniaceae			
3. *Asplenium ruta-muraria* L.	H		
Div. PINOPHYTA			
III. Cupressaceae			
4. *Chamaecyparis lawsoniana* Parl.	Ph[2]	15, 20	
5. *Cupressus sempervirens* L.	Ph	15	
6. *Juniperus pygmaea* C. Koch	Ph	20	
7. *J. sabina* L.	Ph		
8. *J. virginiana* L.	Ph	33	
9. *Thuja gigantea* Nutt.	Ph	21	
10. *Th. occidentalis* L.	Ph		
IV. Pinaceae			
11. *Abies cephalonica* Loudi	Ph	33	
12. *Abies concolor* Lind. et Cord.	Ph	20, 21	
13. *Cedrus libani* Laws.	Ph	21	
14. *Larix sibirica* Ldb.	Ph	20	
15. *Picea abies* (L.) Karst.	Ph	19, 20	
16. *P. pungens* Engelm.	Ph	15	
17. *Pinus excelsa* Wahll.	Ph	15, 33	
18. *Pinus mugo* Turra	Ph	15	
19. *P. nigra* Arn.	Ph	15	
20. *P. silvestris* L.	Ph	15, 33	
21. *P. strobus* L.	Ph	16, 19	
22. *Pseudotsuga glauca* Mayr.	Ph	15	
23. *Sequoja sempervirens* Endl.	Ph	15, 20, 33	
V. Taxodiaceae			
24. *Taxodium distichum* Rich.	Ph	33	
VI. Ginkoaceae			
25. *Gingko biloba* L.	Ph	15, 33	
VII. Taxaceae			
26. *Taxus baccata* L.	Ph	15, 33	
Div. MAGNOLIOPHYTA			
VIII. Aceraceae			
27. *Acer campestre* L.	Ph	15, 33	
28. *A. ginnala* Maxim.	Ph	14, 15	
29. *A. monspessulanum* L.	Ph	15	
30. *A. negundo* L.	Ph		
31. *A. platanoides* L.	Ph		

SPECIES NAME	Biol. type	Quadrant*	Weed**
32. *A. pseudoplatanus* L.	Ph		
33. *A. palmatum* Thunb.	Ph	33	
34. *A. tataricum* L.	Ph	33	
35. *A. saccharatum* L.	Ph	15	
IX. Alismataceae			
36. *Alisma plantago-aquatica* L.	H	25	
X. Amaranthaceae			
37. *Amaranthus albus* L.	Th[3]	15	+
38. *A. deflexus* L.	Th	16	+
39. *A. gangeticus* Hort	Th	16	
40. *A. hybridus* L.	Th	15, 21	
41. *A. hypochon driacus* L.	Th	15, 33, 21	
42. *A. lividus* L.	Th		
43. *A. retroflexus* L.	Th	25	+
XI. Amaryllidaceae			
44. *Leucojum aeustivum* L.	G	26, 30	
XII. Anacardiaceae			
45. *Cotinus coggygria* Scop.	Ph	19	
46. *Rhus coriaria* L.	Ph	17	
XIII. Apiaceae			
47. *Aegopodium podagraria* L.	H	20	
48. *Anetum graveolens* L.	H		
49. *Angelica pancicii* Vand.	Th-H		
50. *A. sylvestris* L.	H		
51. *Anthriscus caucalis* M. B.	Th	16, 21	
52. *A. cerefolium* (L.) Hoffm. var. *longirosris* (Bertol.) Cannon	Th	33	
53. *A. nemorosa* (M. B.) Spreng	H	16	
54. *A. nitida* (Wallenb.) Garcke	Th-H	16	
55. *A. sylvestris* (L.) Hoffm. var. *sylvestris*	H		
56. *Bifora radians* Bieb.	Th	16, 21	
57. *Caucalis platicarpos* L.	Th		
58. *Chaerophyllum aureum* L.	H		
59. *Ch. hirsutum* L.	H		
60. *Conium maculatum* L.	Th-H		
61. *Coriandrum sativum* L.	Th	15	
62. *Daucus carota* L.	Th-H		
63. *Eryngium campestre* L.	H		
64. *Falcaria vulgaris* Bernh.	Th-H	21	
65. *Foeniculum vulgare* Mill.	H	33	
66. *Heracleum sibiricum* L.	Th-H	15	
67. *Myrrhoides nodosa* (L.) Cannon	Th	15	
68. *Pastinaca hirsuta* Panc.	H	25	
69. *P. sativa* L.	H	16	
70. *Peucedanum aegopodioides* (Boiss.) Vand.	H	10, 21	
71. *Sanicula europaea* L.	H	10	
72. *Smyrnium perfoliatum* L.	Th-H	14	

SPECIES NAME	Biol. type	Quadrant*	Weed**
73. *Torilis arvensis* (Huds.) Link. ssp. *arvensis*	Th		
74. *T. japonica* (Houtt.) DC.	Th-H		
XIV. Apocynaceae			
75. *Vinca herbacea* W. K.	Ph	33	
XV. Aquifoliaceae			
76. *Ilex aquifolium* L.	Ph	33	
XVI. Araliaceae			
77. *Hedera helix* L.	Ph	33	
XVII. Asclepiadaceae			
78. *Periploca graeca* L.	Ph	15	
XVIII. Asteraceae			
79. *Achillea crithmifolia* W. et K.	H	14, 15	
80. *A. filipendulina*	H	19	
81. *A. millefolium* L.	H	16	
82. *A. nobilis* L. ssp. *neilreichii* (A. Kern.) Vel.	H	20, 21, 33	
83. *A. pannonica* Scheele	H	33	
84. *Ambrosia artemisiifolia* L.	Th	16	
85. *Anthemis arvensis* L.	Th	15	
86. *A. ruthenica* Bieb.	Th	16	
87. *Arctium lappa* L.	Th-H	16	
88. *A. tomentosum* Mill.	Th-H	10	+
89. *Artemisia absinthium* L.	H	16	
90. *A. annua* L.	Th		
91. *A. scoparia* W. K.	Th-H		
92. *A. vulgaris* L.	H		
93. *Aster novi-belgii* L.	H	16	
94. *A. salignus* Willd.	H	16	
95. *Bidens tripartita* L.	Th		
96. *Carduus acanthoides* L.	Th-H		+
97. *C. nutans* L.	Th-H		
98. *Centaurea affinis* Friv. ssp. *candida* (Vel.) Dost	Th		
99. *C. biebersteinii* DC.	Th		
100. *C. calcitrapa* L.	H	10	
101. *C. cyanus* L.	Th-H	25	
102. *C. diffusa* Lam.	Th-H		
103. *C jacea* L.ssp. *angustifolia* (Sch.) Gugl.	H	21	+
104. *C. phrygia* L. ssp. *phrygia*	H		+
105. *C scabiosa* L.	H	15	+
106. *C. rutifolia* S.S.	Th		
107. *C. solstitialis* L.f. *solsticialis*	Th		+
108. *C. rhenana* Boreau	Th-H		+
109. *C.uniflora* Turra ssp. *nervosa* (Willd.) Bonn. et Layens	H	25	
110. *Chamomilla recutita* (L.) Rausch.	Th		+
111. *Chondrilla juncea* L.	Th-H		+
112. *Cirsium arvense* (L.) Scop.	H		+
113. *C. candelabrum* Grsb.	Th-H		

SPECIES NAME	Biol. type	Quadrant*	Weed**
114. *C. canum* (L.) All.	H	10, 21	
115. *C. creticum* (Lam.) D'Urv.	Th	25	
116. *C. ligulare* Boiss.	Th-H	25	
117. *Cichorium intybus* L.	H		+
118. *Conyza canadensis* (L.) Cronq.	Th		
119. *Cosmos bipinatus* L.	Th	19	
120. *Crepis biennis* L.	Th-H	33	
121. *C. foetida* L.ssp. *foetida*	Th	20	
122. *C. pulchra* L.	Th		+
123. *C. sancta* (L.) Babck	Th	16	
124. *C. setosa* Hall.	Th	33	
125. *Echinops banaticus* Roch. ex Schrad.	H	25	
126. *E. sphaerocephalus* L.	H		
127. *Erigeron annuus* (L.) Pers.	Th-H		+
128. *E. acer* L.	Th-H		
129. *Eupatorium cannabinum* L.	H	25	
130. *Galinsoga ciliata* (Rf.) S. F. Blake	Th	16, 21, 33	+
131. *G. parviflora* Cav.	Th	33	+
132. *Helianthus tuberosus* L.	Th-H		
133. *Hieracium hoppeanum* Schult	H	21	
134. *H. murorum* L.var. *medianum* (Grsb.) H. Zahn	H		
135. *H. praealtum* Vill. ssp. *bauchinii* (Bieb) Pet	H		
136. *Inula bifrons* (L.) L.	H	16, 21	
137. I. *brittanica* L.	H	20	
138. *I. helenium* L.	H	25	
139. *I. thapsoides* (Bieb.ex.Willd.) Spem.ssp.*urumoffii* (Deg.) Hay.	H	19, 25	
140. *Lactuca saligna* L.	Th-H	15	+
141. *L. serriola* L.	Th	33	+
142. *Lapsana communis* L.	Th		
143. *Leucanthemum vulgare* Lam.	H		
144. *Leontodon autumnalis* L.	H	20	
145. *L. crispus* Vill. ssp. *asperrimus* (Willd.) Finch. & P.Sell	*H*	*25*	
146. *L. hispidus* L. ssp. *danubialis* (Jacq.) Simonk.	H		
147. *Matricaria perforata* Merat	Th-H		
148. *M. trichophilla* (Boiss.) Boiss.	Th		
149. *Mycelis muralis* (L.) Dum.	H		
150. *Picris hieracioides* L.ssp. *hieracioides*	H	21	
151. *Pulicaria vulgaris* Gaertn.	Th		+
152. *Onopordum acanthium* L.	Th-H		+
153. *Santolina chamaecyparissias* L.	H	21	
154. *Scolymus hispanicus* L.	Th-H	16, 17	
155. *Scorzonera cana* (C. A. Mey.) Hoffm.	H		
156. *Senecio bicolor* (Willd.) Tod.ssp. *cineraria* (DC.)Chater	H		
157. *S. vernalis* W. K.	Th		+
158. *S. viscosus* L.	Th		
159. *S. vulgaris* L.	Th-H	16, 21	+

SPECIES NAME	Biol. type	Quadrant*	Weed**
160. *Silybum marianum* (L.) Gaertn.	Th-H		+
161. *Solidago canadensis* L.	H	15, 16, 21	
162. *Sonchus arvensis* L.	H		+
163. *S. oleraceus* L.	Th		+
164. *Tanacetum macrophyllum* (Waldst. et Kit.) Schultz – Bib.	H	15	
165. *T. parthenium* (L.) Schultz-Bip.	H		
166. *T. vulgare* L.	H		
167. *Tarxacum officinale* Web.	H		
168. *Teleckia speciosa* (Schreb.) Baumg.	H		
169. *Tragopogon pratensis* L.	H	15, 16	
170. *Tussilago farfara* L.	H		+
171. *Xanthium strumarium* L.	Th		+
172. *Xeranthemum cylindraceum* S.&S.	Th	21	
XIX. Berberidaceae			
173. *Berberis vulgaris* L.	Ph		
174. *Mahonia japonica* (Thunb.) DC.	Ph		
XX. Betulaceae			
175. *Alnus glutinosa* (L.) Gaertn.	Ph	20	
176. *Betula pendula* Roth	Ph		
177. *Carpinus betulus* L.	Ph		
178. *Corylus avellana* L.	Ph		
179. *C. maxima* Mill.var. *atropurpurea* Beau	Ph	15	
180. *Ostrya carpinifolia* Scop.	Ph	15	
XXI. Bignoniaceae			
181. *Catalpa bignonioides* Walt.	Ph		
XXII. Boraginaceae			
182. *Anchusa procera* Bess.	H		
183. *Asperugo procumbens* L.	Th		+
184. *Buglosoides arvensis* (L.) M. Joston	Th-H		
185. *Cynoglosum hungaricum* Simonkai	Th	16	+
186. Echim vulgare L.	Th		+
187. *Lappula squarrosa* (Retz.) Dumort.	Th	16, 17	+
188. *Myosotis arvensis* (L.) Hill.	Th-H	33	+
189. *M. ramosissima* Rochel in Schultes	Th		
190. *Pulmonaria mollis* Wulfen ex Horn.	H		
191. *P. officinalis* L.	H	10	
192. *Symphytum officinale* L.	H		
XXIII. Brassicaceae			
193. *Alliaria petiolata* (M.B.) Cavara et Grande	Th-H	33	+
194. *Alyssum alyssoides* L.	Th		
195. *A. desertorum* Stapf.	Th		
196. *A. strigosum* Banks et Soland.	Th	21	
197. *Armoracia rusticana* (Lam.) P. Gaertn.	H	33	+
198. *Barbarea vulgaris* R. Br.var. *vulgaris*	Th-H	19	
199. *Berteroa incana* (L.) DC.	Th-H		+
200. *Brassica juncea* (L.) Czern.	Th		+

SPECIES NAME	Biol. type	Quadrant*	Weed**
201. *B. napus* L.	Th	16	+
202. *B. nigra* (L.) Koch	Th	15, 33	
203. *B. oleraceae* L.	Th-H		
204. *Camelina microcarpa* Andrz. ex DC.	Th-H		
205. *Capsella bursa-pastoris* (L.) Medic.	Th-H		+
206. *Cardamine hirsuta* L.	Th		
207. *Coronopus procumbens* Gilib.	Th-H	26	
208. *Erophylla verna* (L.) Bess.	Th		
209. *Erysimum diffusum* Ehrh.var. *diffusum*	H	21	
210. *Hesperis matronalis* L.	H		
211. *Lepidium campestre* (L.) R.Br.	Th-H		+
212. *L. ruderale* L.	Th-H		+
213. *Myagrum perfoliatum* L.	Th-H		+
214. *Nasturcium barbareoides* (Tausch.) Celak.	H	15	
215. *Neslia paniculata* (L.) Desv.	Th-H		+
216. *Raphanus raphanistrum* L.ssp. *raphanistrum*	H	21	+
217. *R. sativus* L.var.*radicula* Pen.	Th-H	17	
218. *Rorippa austriaca* (Crantz) Bess.var.*angustifolia*(Schur.)Nyar.	H	19	
219. *R. austriaca* (Crantz) Bess.var.*austriaca*	H	15, 33	
220. *R. prolifera* (Heuff.) Neilr.	Th-H	33	
221. *R. sylvestris* (L.) Bess.ssp. *sylvestris*	H		
222. *Sinapis alba* L. ssp. *alba*	Th	15, 33	+
223. *S. arvensis* L.	Th	16	+
224. *Sisymbrium altissimum* L.	Th-H	15	+
225. *S. loeseli* L.	Th-H	15	+
226. *S. officinale* (L.) Scop.	Th-H	19	+
227. *Thlaspi arvense* L.	Th	16, 26	+
XXIV. Buxaceae			
228. *Buxus sempervirens* L.	Ph	15, 33	
XXV. Calycanthaceae			
229. *Calycanthus occidentalis* Hook. et Arn.	Ph	15	
230. *Chimonanthus praecox* (L.) Link	Ph	15, 33	
XXVI. Campanulaceae			
231. *Campanula bononiensis* L.	H	16	
232. *C. rapunculus* L.	H		
233. *C. rapunculoides* L.	H		
234. *Leguozia pentagonia* (L.) Thell.	Th		+
235. *L. speculum* (L.) Fisch	Th		
XXVII. Cannabaceae			
236. *Cannabis sativa* L.	Th	21	+
237. H*umulus lupulus* L.	H		
XXVIII. Caprifoliaceae			
238. *Abelia grandiflora* (Andre) Rehd.	Ph	33	
239. *Kolkwitzia amabilis* Graebn.	Ph	15, 26	
240. *Lonicera etrusca* G. Santi	Ph		
241. *L. maackii* Maxim.	Ph	16, 19, 20	

SPECIES NAME	Biol. type	Quadrant*	Weed**
242. *L. tatarica* L.	Ph	15	
243. *Sambucus ebulus* L.	H		
244. *S. nigra* L.	Ph		
245. *Symphoricarpus albus* (L.) Blanke	Ph		
246. *S. chenaultii* Rehd.	Ph		
247. *S. orbiculatus* Moench.	Ph	21, 33	
248. *Viburnum lantana* Hemsl.	Ph	14	
249. *V. opulus* L.	Ph		
250. *V. rhytidophyllum* Hemsl.	Ph		
251. *Weigela japonica* Thunb.	Ph		
XXIX. Cannaceae			
252. *Canna indica* L.	H		
XXX. Caryophyllaceae			
253. *Arenaria serpyllifolia* L. var. *serpyllifolia*	Th-H	16	+
254. *Cerastium biebersteinii* DC.	H	10, 16	
255. *C. caespitosum* Gilib.ssp.*glandulosum* Aschers.et Graegn.	H	33	
256. *C. dubium* (Bast.) Schwartz	Th		
257. *C. fontanum* Baumg.ssp.*vulgare* Greut.&Burd.	H	21	
258. *C. pumilum* Curt.	Th-H	20	
259. *C. semidecandrum* L. var. *semidecandrum*	Th		
260. *C. tomentosum* L.	H	17	
261. *Cucubalus baccife*r L.	H	15	
262. *Gypsophila muralis* L.	H	16	
263. *Herniaria hirsuta* L.f.*leiophylla* Griseb.	Th-H	16, 26, 33	
264. *Holosteum umbellatum* L.	Th-H		+
265. *Lychnis flos-cucculi* L. sp. *flos-cucculi*	H	21	
266. *Moehringia trinervia* (L.) Clairv.	Th-H		
267. *Myosoton aquaticum* (L.) Moenh	H	16, 17	
268. *Petrorhagia prolifera* (L.) P. W. Ball et Heywood	Th	15	
269. *P. saxifraga* (L.) Link	H		
270. *Polycarpon tetraphyllum* (L.) L.	Th-H	21	
271. *Sagina apetala* Ard.	Th		
272. *S. procumbens* L. var. *procumbens*	H		
273. *S.procumbens* var.*ciliata* Neilr.	H	16	
274. *Saponaria officinalis* L.	H		+
275. *Scleranthus polycarpos* L.	Th-H	33	
276. *Silene alba* (Mill.) E. Krause in Sturm	Th		
277. *S. vulgaris* (Moench.) Garcke ssp. *vulgaris*	H	20	
278. *S. noctiflora* L.	Th		+
279. *S. pendula* L.	H		+
280. *Spergularia rubra* J. et C. Presl.	Th-H	33	
281. *Stellaria graminea* L.	H		
282. *S. holostea* L.	H		
283. *S. media* (L.)Vill. var. *media*	Th-H	16	+
284. *S.media* (L.) Vill. var. *apetala* Gaud.	Th-H		+
285. *Vaccaria hispanica* (Mill.) Rasch.	Th	19, 33	+

SPECIES NAME	Biol. type	Quadrant*	Weed**
XXXI. Celastraceae			
286. *Celastrus orbiculatus* Thunb.	Ph	33	
287. *Euonymus europaeus* L.	Ph	15	
288. *E. japonicus* L. fil.	Ph		
289. *E. radicans* Sieb.	Ph	20	
XXXII. Ceratophyllceae			
290. *Ceratophylum demersum* L.	H	16	
XXXIII. Chenopodiaceae			
291. *Atriplex hortensis* L.	Th	15, 19, 33	+
292. A. oblogifolia Walst. et Kit.	Th	20	+
293. *A. patula* L.	Th	16	+
294. *A. rosea* L.	Th		+
295. *Beta vulgaris* L. ssp. *esculenta* (Salisb.) Gurke in Richt	Th	25	
296. *B. vulgaris* L.ssp.*maritima* (L.) Arcang.	Th-H	16, 17	+
297. *Chenopodium album* L.	Th	16	+
298. *Ch. botrys* L.	Th	15, 16, 21, 33	+
299. *Ch. ficifolium* Sm.	Th	16	
300. *Ch. glaucum* L.	Th	15	+
301. *Ch. opulifolium* Schrad.ex Koch et Ziz.	Th	16, 17	+
302. *Ch. polyspermum* L.	Th	25	
303. *Ch. vulvaria* L.	Th	26	+
304. *Kochia scoparia* (L.) Schrad.	Th		+
305. *Polycnemum arvense* L.	Th		+
306. *Suaeda maritima* (L.) Dum.	Th	33	+
XXXIV. Convolvulaceae			
307. *Calystegia sepium* (L.) R. Br.	H		+
308. *Convolvulus arvensis* L.	H		+
XXXV. Crassulaceae			
309. *Sedum album* L.	H	19	
310. S. hispanicum L.	H	14	
311. *S. pallidum* M.B.	Th-H	33	
312. *S. spurium* M.B.	H	16	
XXXVI. Cucurbitaceae			
313. *Bryonia alba* L.	H		
314. *Cucurbita pepo* L.	Th	16, 19, 20	
315. *Ecbalium elaterium* (L.) A. Richt	H	14	
XXXVII. Cuscutaceae			
316. *Cuscuta campestris* Junck.	Th	16, 33	+
XXXVIII. Cyperaceae			
317. *Carex muricata* L.	H	33	
318. *C. distans* L. var. *distans*	H	33	
319. *C. divulsa* Stockes ex With.	H	15, 16	
320. *C. flacca* Schreb.	H	9, 33	
321. *C. hirta* L.	H	33	
322. *C. hordeistichos* Vill.	H	21	
323. *C. sylvatica* Huds.	H	10	

SPECIES NAME	Biol. type	Quadrant*	Weed**
324. *C. tomentosa* L.	H	21	
325. *C. otrubae* Podp.	H		
326. *Cyperus fuscus* L.	Th	20	+
327. *Eleocharis palustris* (L.) R. Br.	H		
328. *Holoschoenus vulgaris* Link	H	21	
329. *Scirpus sylvaticus* L.	H	16, 17, 21	
XXXIX. Dipsacaceae			
330. *Cephalaria transsilvanica* Schrad.	Th	16, 20, 21	+
331. *Dipsacus laciniatus* L.	Th	16	+
332. *Knautia arvensis* (L.) Coult.	H		+
333. *Scabiosa triniifolia* Friv.	Th	25	
XL. Elaeagnaceae			
334. *Elaeagnus angustifolia* Pursch	Ph	33	
335. *E. multiflora* Thunb.	Ph		
336. *Hippophae rhamnoides* L.	Ph	33, 27	
XLI. Ericaceae			
337. *Erica carnea* L.	Ph	15	
XLII. Euphorbiaceae			
338. *Acalypha virginica* L.	Th	15, 16, 33	+
339. *Euphorbia chamaesyce* L. ssp.*massiliensis*(DC.)Thell	Th		+
340. *E. cyparissias* L.	H	21	+
341. *E. esula* L. ssp.*tomassiana* (Bertol.) Nyman	H	17	
342. *E. helioscopia* L.	Th	21	+
343. *E. maculata* L.	Th		
344. *E. niciciana* Borb.	H		
345. *E. peplus* L.	Th	17, 21	+
346. *E. plathyphillos* L. var.*plathyphillos*	Th	17	
347. *E. serrulata* Thuill.	Th	25	
348. *E. taurinensis* All.	Th	15, 20, 33	
349. *Ricinus communis* L.	Th-H		
XLIII. Fabaceae			
350. Albizia julibrissin Durazz.	Ph	14, 16, 21	
351. *Amorpha fruticosa* L.	Ph	16	
352. *Anthyllis vulneraria* L. ssp. *polyphylla*(DC.) Nyman	H	16	
353. *Astragalus cicer* L.	H-Ph	21	
354. *A. glycyphyllos* L. var.*bosniacus*(Beck.)Aschers.&Graebn.	H		
355. *Caragana frutex* (L.) C. Koch	Ph	16	
356. *Cercis siliquastrum* L.	Ph	33	
357. *Coronilla varia* L. var. *paucifolia* Griseb.	H	33	+
358. *C. varia* L. var. *varia*	H	19	+
359. *Genista ovata* Waldst. et Kit. var. *nervata*(Kit.) Fuss.	Ph	16	
360. *Galega officinalis* L.	H	10, 15, 25, 33	
361. *Gleditschia triacanthos* L.	Ph	21	
362. *Gymnocladus canadensis* Lam.	Ph	20	
363. *Laburnum anagyroides* Lam.	Ph		
364. *Lathyrus aphaca* L. var. *aphaca*	Th	19	+

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365. *L. pratensis* L.	H		+
366. *L. tuberosus* L.	H	19, 21	+
367. *Lotus corniculatus* L.	H		+
368. *Medicago falcata* L. ssp. *urmuvii* Deg. ex Schw.&Klink	H	19, 25	+
369. *M. lupulina* L.	Th-H		+
370. *M. sativa* L.	H		
371. *Melilotus alba* Medic.	Th		+
372. *M. officinalis* (L.) Pall.	Th		+
373. *Onobrychis arenaria* (Kit.) DC.	H		
374. *O. viciifolia* Scop.	H	21	
375. *Ononis arvensis* L. var. *spinescencs* (Ledeb.) Garcke	H		+
376. *Robinia pseudoacacia* L.	Ph		
377. *Sophora japonica* L.	Ph	15, 16	
378. *Spartium junceum* L.	Ph	16	
379. *Trifolium arvense* L.	Th		+
380. *T. incarnatum* L.	Th-H	16	
381. *T. medium* L.	H		
382. *T. michelianum* Savi var. *michelianum*	Th		
383. *T. pratense* L. var. *americanum* Harz	H	16	+
384. *T. patens* Schreb in Sturm	Th	25	
385. *T. repens* L.	H		+
386. *T. resupinatum* L.	Th	16, 33	
387. *T. retusum* L.	Th	21, 33	
388. *T. striatum* L.	Th	16	
389. *T. trichopterum* Panc.	Th		
390. *Vicia grandiflora* Scop.	Th-H		+
391. *V. hirsuta* (L.) S.F.Gray	Th		+
392. *V. melanops* M.B.	Th	21	
393. *V. pannonica* Crantz ssp. *striata* (M. B.) Nyman	H	16	
394. *V. sativa complex* Mettin & Hannelt	TH	16	
395. *V. varia* Host.	Th-H	16, 17, 33	+
396. *V. villosa* Roth var. *macrosperma* Vel.	Th	16	+
397. *Wisteria sinensis* (Sims.) Sweet	Ph	15, 33	
XLIV. Fagaceae			
398. *Castanea sativa* Mill.	Ph	19, 33	
399. *Fagus sylvatica* L.	Ph	33	
400. *Quercus cerris* L.	Ph	33	
401. *Q. longipes* Stev.	Ph	24, 25	
402. *Q. pedunculiflora* C. Koch	Ph	33	
403. *Q. schumardii* Buckl.	Ph	15	
404. *Q. sessilis* Ehrh.	Ph		
405. *Q. rubra* L.	Ph	33	
XLV. Geraniaceae			
406. *Erodium cicutarium* (L.) L'Her	Th-H		+
407. *Geranium dissectum* L.	Th	15, 33	+
408. *G. divaricatum* Ehrh.	Th	15	+

SPECIES NAME	Biol. type	Quadrant*	Weed**
409. *G. macrorhizum* L.	H	15	
410. G. pratense L.	H	15	
411. *G. pusillum* L.	Th-H		+
412. *G. pyrenaicum* Burm.f.	H	15, 19, 33	
413. *G. phaeum* L.	H	33	
414. *G. robertianum* L.	Th-H	33	
415. *G. rotundifolium* L.	Th	33	
XLVI. Haloragaceae			
416. *Myriophyllum spicatum* L.	H	17	
XLVII. Hamamelidaceae			
417. *Liquidambar stiraciflua* L.	Ph	27	
XLVIII. Hippocastanaceae			
418. *Aesculus hippocastanum* L.	Ph		
419. *A. hippocastanum* x *pavia*	Ph	15	
XLIX. Hydrocharitaceae			
420. *Elodea canadensis* Rich. in Michx.	H	25	
L. Hypericaceae			
421. *Hypericum perforatum* L.	H	16	
422. *H. tetrapterum* Fries	H		
LI. Iridaceae			
423. *Crocus pallasii* Bieb.	G	22	
424. *Iris germanica* L	G		
425. *I. sibirica* L.	G	25	
LII. Juglandaceae			
426. *Juglans cinerea* L.	Ph	33	
427. *J. nigra* L.	Ph	15	
428. *J. regia* L.	Ph		
LIII. Juncaceae			
429. *Juncus articulatus* L. var. *articulatus*	H	16	+
430. *J. compressus* Jacq. f.*euxinus* (Vel.) Hayek	H	33	
431. *J. gerardii* Lois.	H		
432. *J. Inflexus* L.	H	21, 25	+
433. *J. lamprocarpus* Ehrh.	H		
434. *J. tenuis* Willd.	H		
LIV. Lactoridaceae			
435. *Ansonia tabernemontana* Wall.	Th		
LV. Lamiaceae			
436. *Ajuga genevensis* L.	H	15	
437. *A. chamaepitys* (L.) Scheber	Th-H		
438. *Ballota nigra* L. ssp. *ruderalis* Sw.	H		+
439. *Calamintha nepeta* (L.) Savi ssp. *nepeta*	H	16	
440. *Galeopsis tetrahi*t L.	Th	16	
441. *Glechoma hederacea* L. ssp. *hederacea*	H		+
442. *G. hirsuta* Waldst. & Kit.	H	15	
443. *Lamium aplexicaue* L.	Th		+
444. *L. maculatum* L. var. *maculatum*	H		

SPECIES NAME	Biol. type	Quadrant*	Weed**
445. *L. purpureum* L. f. *purpureum*	Th	15, 33	+
446. *Leonurus cardiaca* L.	Th-H	19	+
447. *Lycopus europaeus* L.	H	33	+
448. *Melissa officinalis* L. ssp. *officinalis*	H		
449. *Mentha spicata* L. ssp. *tomentosa* (Briq.) Harly	H		
450. *Nepeta cataria* L. var. *cataria*	H	15	+
451. *Prunella vulgaris* L.	H		+
452. *Salvia virgata* Jacq.	H		
453. *S. verticillata* L.	H		+
454. *Stachys annua* (L.) L. var.*adenocalyx* (C.Koch) Hausskn.	Th	20	+
455. *S. germanica* L.	H	25	
456. *S. milanii* Petrov.	Th	15	
457. *Teucrium chamaedrys* L.	H		
LVI. Lemnaceae			
458. *Lemna minor* L.	H		
LVII. Lentibulariaceae			
459. Utricularia vulgaris L.	H	20	
LVIII. Liliaceae			
460. *Allium carinatu*m L.	G		
461. *A. sativum* L.	G	33	
462. *A. scorodoprasum* L.	G		+
463. *Convallaria majalis* L.	G		
464. *Colchicum autumnale* L.	G	25	
465. *Fritillaria imperialis* L.	G		
466. *Gagea arversis* (Pers.) Dum.	G	16	
467. *Muscari comosum* (L.) Mill.	G		
468. *Ornithogalum montanum* Cyr.	G	21, 26	
469. *O. narbonense* L.	G	26	
470. *O. oreoides* Zahr.	G		
471. *O.odoratum* (Mill.) Druce	G		
LIX. Linaceae			
472. *Linum usitatissimum* L.	Th	15	
LX. Loganiaceae			
473. *Buddleia davidii* Franch	Ph	16	
474. *B. variabilis*	Ph		
LXI. Lythraceae			
475. *Lythrum salicaria* L.	H		+
476. *L. virgatum* L.	H		
LXII. Magnoliaceae			
456. *Liriodendron tulipifera* L.	Ph	15, 33	
477. *Magnolia cobus* DC.	Ph	15	
478. *M. grandiflora* L.	Ph	15	
479. *M. liliiflora* Desf.	Ph		
480. *Schisandra chinensis* (Turcz.) Baill.	Ph		
LXIII. Malvaceae			
481. *Abutilon theophrasti* Medic.	Th	16	

SPECIES NAME	Biol. type	Quadrant*	Weed**
482. *Alcea rosea* L.	H	15	
483. *Althaea officinalis* L.	H	21	
484. *Hibiscus trionum* L.	Th	16	+
485. *H. syriacus* L.	Ph		
486. *Lavatera thuringiaca* L.	H		+
487. *Malva neglecta* Wallr.	Th-H	26	+
488. *M. sylvestris* L.	Th-H		
LXIV. Moraceae			
489. *Ficus carica* L.	Ph	15, 21, 33	
490. *Maclura aurantiaca* Nutt.	Ph	15	
491. *Morus alba* L.	Ph		
LXV. Nymphaeaceae			
492. *Nymphaea alba* L.	H	15	
LXVI. Oleaceae			
493. *Fontanesia phyllireoides* Dipp.	Ph	21	
494. *Forsitia suspensa* Vahl.	Ph		
495. *Fraxinus excelsior* L.	Ph		
496. *Jasminum revolutum* Sims.	Ph	20	
497. *Ligustrum vulgare* L.	Ph		
498. *Syringa vulgaris* L.	Ph	15, 33	
LXVII. Onagraceae			
499. *Circaea lutetiana* L.	H	21, 33	
500. *Epilobium dodone*i Vill.	Ph	16	
501. *E. angustifolium* L.	H	16	
502. *E. hirsutum* L.	H		+
503. *E. obscurum* Schreb.	H	21	
504. *E. roseum* Schreb. ssp. *roseum* f. alba	H		
505. *E. tetragonum* L.	H		
506. *Fuchia hybrida* Hort.	H	19, 25	
507. *Godetia grandiflora* Lindl.	Ph	28	
508. *Oenothera biennis* L.	Th-H	19,25	+
LXVIII. Orchidaceae			
509. *Cephalanthera damasonium* (Mill.) Druce	G		
510. *Cephalantera longifolia* (L.) Fritsch	H	10	
511. *Epipactis helleborine* (L.) Crantz	H	10	
512. *E. palustris* (L.) Crantz	G		
513. *Platanthera chlorantha* (Custer) Rchb. in Mossl.	G	33	
514. *Spiranthes spiralis* (L.) Chevall	G		
LXIX. Oxalidaceae			
515. *Oxalis corniculata* L.	Th-H	15	+
516. *O. fontana* Bunge	H	20	
LXX. Papaverceae			
517. *Chelidonium majus* L.	H		+
518. *Corydalis lutea* DC.	G		
519. *Dicentra spectabilis* (L.) Lemaire	Th		+
520. *Fumaria schleiheri* Soj.-Will.	Th	17, 19	+

SPECIES NAME	Biol. type	Quadrant*	Weed**
521. *Papaver dubium* L.	TH	15	+
LXXI. Phytolaccaceae			
522. *Phytolacca americana* L.	Th	16, 26	+
LXXII. Plantaginaceae			
523. *Plantago lanceolata* L.	H		+
524. *P. major* L.	H		+
525. *P. media* var. *urvilleana* Rapin	H		+
LXXIII. Platanaceae			
526. *Platanus hybrida* Brot.	Ph	16	
LXXIV. Poaceae			
527. *Aegilops cylindrica* Host.	Th	15, 19	+
528. *Agrostis stolonifera* L.	H	25	
529. *A. canina* L.	H		
530. *Alopecurus myosuroides* Huds.	Th	15	+
531. *Apera spica-venti* (L.) Beauv.	Th		+
532. *Arrhenatherum elatius* (L.) Beauv. ex L.&C.Presl.	H		
533. *Avena sativa* L.	Th		
534. *Briza media* L. var. *media*	H	16	
535. *Brachypodium sylvaticum* (Huds.) Beauv.	H		
536. *Bromus arvensis* L.	Th		+
537. *B. inernis* Leyss.	H		
538. *B. japonicus* Thunb.	Th	16	
539. *B. tectorum* L.	Th		
540. *Calamagrostis arundinacea* (L.) Roth	H		
541. *C. epigeios* (L.) Roth	H	16	
542. *Catabrosa aquatica* P. B.	H	21	
543. *Crypsis alopecuroides* (Pall.&Mett.) Schrad.	Th	16, 21	
544. *Cynodon dactylon* (L.) Pers.	H		+
545. *Dactylis glomerata* L.	H		
546. *Dasypyrum villosum* (L.) Cand.	H	25	
547. *Digitaria sanguinalis* (L.) Scop.	Th	16, 21	+
548. *Dichanthium ischaemum* (L.) Roberty	H	16, 21	
549. *Echinochloa crus-galli* (L.) Beauv.	Th	16	+
550. *Elymus caninus* (L.) L.	H	33	+
551. *E. hispidus* (Opiz.) Meld. ssp.*barbatus*(Schur) Meld.	H		
552. *E. hispidus* (Opiz.) Meld. ssp. *hispidus*	H		
553. *E. repens* (L.) Gould	H	16	
554. *Eragrostis minor* Host.	Th	16	+
555. *E. pilosa* (L.) Beauv.	Th	15, 16, 21, 24	
556. *Festuca diffusa* Dum.	H	15	
557. *F. heterophylla* Lam.	H		
558. *F. nigrescens* Lam.	H		
559. *F. pratensis* L.	H		
560. *Glyceria maxima* (Hartm.) Holmb.	H		
561. *Holcus lanatus* L.	H	33	
562. *Hordeum bulbosum* L.	H	33	+

SPECIES NAME	Biol. type	Quadrant*	Weed**
563. *H. hystrix* Roth	H	19	
564. *H. murinum* L.	H		
565. *Melica uniflora* Retz.	H	16	
566. *Panicum miliaceum* L.	Th	33	
567. *Phleum phleoides* (L.) Karst.	H	16, 33	
568. *Ph. pratensis* L.	H		
569. *Poa annua* L.	Th		+
570. *P. bulbosa* L. var. *vivipara* Koel.	H		
571. *P. compressa* L.	H		
572. *P. nemoralis* L.	H	33	
573. *P. palustris* L.	H		
574. *P. pratensis* L. var. *falax* (Janka) Fick	H	15	
575. *P. pratensis* L. var. *nodosum* (L.) Schreb.	H	15	
576. *P. trivialis* L.	H	26	
577. *Dasypyrum villosum* (L.) Cand.	H		
578. *Phalaris arundinacea* L. var. *picta* L.	H	33	
579. *Phragmites australis* (Cav.) Trin. ex Steud.	H	33	
580. *Puccinellia distans* (L.) Parl.	H	16, 21	
581. *Sclerochloa dura* (L.) Beauv.	Th	16	+
582. *Secale cereale* L.	Th	15, 21	+
583. *Setaria viridis* (L.) Beauv.	Th		+
584. *Sorghum halepense* (L.) Pers.	H	20	+
585. *Trisetum flavescens* (L.) Beauv.	H	33	
586. *Triticum aestivum* L.	Th	16	
587. *Vulpia myurus* (L.) Gmel.	Th	16	+
LXXV. Polygalaceae			
588. *Polygala anatolica* Boiss. & Heldr. var. *anatolica*	H	21	
LXXVI. Polygonaceae			
589. *Bilderdikya aubertii* (Louis Henry) Moldenke	Ph		
590. *B. convovulus* (L.) Dum.	Th		+
591. *Polygonum aviculare* L.	Th		+
592. *P. orientale* L.	Th		
593. *Persicaria maculata* (Raf.) S.F. Gray	Th	21	+
594. *Reynoutria japonica* Houtt.	H		
595. *Rumex. acetosella* L. var.*acetosella*	H		+
596. *R. acetosella* L. var. *integrifolius* Wallr.	H		+
597. *R. conglomeratus* Murr.	H		+
598. *R. crispus* L.	H	15, 16	+
599. *R. obtusifolius* L.	H	33	+
600. *R. patientia* L.	H	33	+
601. *R. pulcher* L.	H	16, 21	+
602. *R. sanguineus* L.	H		
LXXVII. Portulacaceae			
603. *Portulaca grandiflora* Hook	Th	16	
604. *P. oleracea* L.	Th		+

SPECIES NAME	Biol. type	Quadrant*	Weed**
LXXVIII. Primulaceae			
605. *Anagallis arvensis* L.	Th-H		+
606. *Lysimachia nummularia* L.	Th-H	33	
607. *L. punctata* L. ssp. *punctata*	H		
608. *L. vulgaris* L. ssp. *glanduloso-villosa* (Beck) Peev	H	20	+
609. *Primula acaulis* (L.) L. ssp. *vulgaris*	H	14	
LXXIX. Ranunculaceae			
610. *Adonis aestivalis* L.	Th		+
611. *Aquilegia nigricans* Baumg.	H		
612. *Clematis integrifolia* L.	H	20	
613. *C. vitalba* L.	Ph		
614. *Consolida ajacis* (L.) Schur.	Th		
615. *C. hispanica* (Costa) Greud.& Burded	Th		
616. *C. regalis* S.F.Gray	Th		+
617. *Helleborus odorus* Waldst. et Kit.	H	33	
618. *Nigella arvensis* L.	Th	21	
619. *Ranunculus acris* L.	H	16, 33	+
620. *R. arvensis* L.	Th	26	+
621. *R. bulbosus* L. ssp. *aleae* (Wilk.) Rouy&Fouc.	H	21	
622. *R. ficaria* L.	H	33	
623. *R. polyanthemos* L. f. *polyanthemos*	H	19	+
624. *R. repens* L.	H		+
625. *R. trichophyllus* Chaix. var. *bandotis* Godr.	H	15	
LXXX. Resedaceae			
626. *Reseda lutea* L.	Th-H		+
627. *R. luteola* L.	Th-H		+
LXXXI. Rosaceae			
628. *Agrimonia eupatoria* L.	H		+
629. *Amygdalus nana* L.	Ph	15	
630. *Aremonia agrimonoides* (L.) DC. ssp. *agrimonoides*	H	33	
631. *Cydonia oblonga* Mill.	Ph		
632. *Chaenomeles japonica* (Thunb.) Lindl.	Ph		
633. *Cotoneaster horizontalis* Decne	Ph	15, 16	
634. *C. multiflora* Bge.	Ph		
635. *C. salicifolia* Franch.	Ph		
636. *Crataegus mollis*	Ph	15	
637. *C. monogyna* Jacq.	Ph		
638. *Duchesnea indica* (Andrews) Focke	H	33	
639. *Exochorda aubertii* Rgl.	Ph	15	
640. *E. grandiflora* (Hook) C.K.Schneid.	Ph	21	
641. .*Fragaria vesca* L.	H	33	
642. *Filipendula ulmaria* (L.)Maxim.	H	25	
643. *F. vulgaris* Moench	H	19, 25, 33	
644. *Geum urbanum* L.	H		+
645. *Kerria japonica* (L.) DC.	Ph		
646. *Laurocerasus officinalis* M. J.	Ph	33	

SPECIES NAME	Biol. type	Quadrant*	Weed**
647. *Malus floribunda* Sieb.	Ph	15	
648. *M. niedzwetzkyana* Dieck	Ph	33	
649. *M. sylvestris* Mill.	Ph		
650. *Potentilla argentea* L.	H	10	
651. *P. erecta* (L.) Rausch.	H	25	
652. *P. fruticosa* L.	Ph	21,33	
653. *P. micrantha* Ramond ex DC.	H	10, 15	
654. *P. neglecta* Baumg.	H		
655. *P. reptans* L.	H		
656. *Physocarpus amurensis* Maxim.	Ph	15, 20	
657. *Pyracantha coccinea* Roem.	Ph	16, 21, 33, 19	
658. *Pyrus communis* L.	Ph		
659. *Prunus avium* L.	Ph		
660. *P. mahaleb* L.	Ph	10	
661. *P. virginiana* (L.) Mill.	Ph		
662. *P. padus* L.	Ph	33	
663. *P. persica* Mill	Ph		
664. *Rhodotypus kerrioides* Sieb.&Zum.	Ph		
665. *Rosa jundzilii* Besser	Ph	16, 19	
666. *R. multiflora* Thunb.	Ph	16	
667. *R. turcica* Rouy.	Ph	16	
668. *R. vosagiaca* Desporte	Ph	16	
669. *Rubus discolor* Weine&Nees	Ph		
670. *Sorbus aucuparia* L.	Ph		
671. *S. torminalis* (L.) Crantz	Ph		
672. *Sanguisorba minor* Scop.	H		
673. S. *officinalis* L. var. *auriculata* (Scop./) Focke in Koch	H	16	
674. *Sorbaria sorbifolia* (L.) A.Br. in Aschers.	Ph	16	
675. *Spiraea japonica* L.	Ph	15	
676. *S. salicifolia* L.	Ph		
677. *S. tunbergii* Sibt.	Ph		
678. *S. vanchoutii* (Brot.) Zbl.	Ph		
679. *Stefanandra tanakae* Franch.&Sav.	Ph	33	
LXXXII. Rubiaceae			
680. *Asperula setulosa* Boiss.	H	19	
681. *A. cynanchica* L.	H	15	
682. *Galium album* Mill. ssp. *albul*	H	16	
683. *G. aparine* L.	Th	15	+
684. *G. anisophyllon* Vill.	H		
685. *G. elongatum* C.Presl. in J. et C. Presl.	H	10	
686. *G. verum* L.	H		
LXXXIII. Rutaceae			
687. *Phelodendron amurensis* Rupr.	Ph	15, 21	
688. *Ptelea trifoliata* L.	Ph	33	
LXXXIV. Salicaceae			
689. *Populus alba* L.	Ph	22	

SPECIES NAME	**Biol. type**	**Quadrant***	**Weed****
690. *P. nigra* L.	Ph		
691. *P. tremula* L.	Ph		
692. *Salix caprea* L.	Ph	21	
693. *S. fragilis* L.	Ph	21, 24, 33	
694. *S. purpurea* L.	Ph	25	
695. *S. waldsteiniana* Willd.	Ph	15	
LXXXV. Santalaceae			
696. *Thesium simplex* Vel. ssp. *simplex*	H	20	
LXXXVI. Sapindaceae			
697. *Koelreuteria paniculata* Laxm.	Ph	16, 21	
LXXXVII. Saxifragaceae			
698. *Deutzia crenata* S.&Z.	Ph		
699. *Hydrangea arborescens* L.	Ph		
700. *H. breitschneideri* Dipp.	Ph		
701. *H. hortensis* Smith	Ph		
702. *Phyladelphus coronarius* L.	Ph		
703. *Ph. grandiflorus* Gray	Ph		
704. *Ph. virginalis* Rehl.	Ph		
705. *Ribes multiflorum* Kit. ex Roem.&Schultes	Ph		
LXXXVIII. Scrophulariaceae			
706. *Anthirrhinum majus* L.	H		
707. *Chaenorhinum minus* (L.) Lange in Will. et Lange	Th		+
708. *Cymbalaria muralis* Gaertn.B.Meyer et Scheb.	H	10, 15, 33	
709. *Digitalis lanata* Ehrh.	Th	25	
710. *Kickxia elatine* (L.) Dum. ssp. *crinita* (Mab.) Greut.	Th	25	
711. *Linaria genistifolia* (L.) Mill. ssp. *genistifolia*	H		
712. *L. vulgaris* Mill.	H		
713. *Lathraea squamaria* L.	H	10	
714. *Gratiola officinalis* L.	H		
715. *Odontites verna* (Bell.) Dum	Th		+
716. *Paulownia tomentosa* (Thunb.) Steud.	Ph		
717. *Rhinanthus rumelicus* Vel. ssp. *rumelicus*	Th		+
718. *Verbascum blattaria* L. var. *blattaria*	Th-H	33	+
719. *Verbascum pulverulentum* Vill.	Th-H	16	
720. *V. speciosum* Schrad	Th-H	15	
721. *Veronica acinifolia* L.	Th	16	
722. *V. arvensis* L. f. *polyanthos* (Thuill.) Matth.	Th		+
723. *V. anagallis-aquatica* L.	H	33	
724. *V. chamaedrys* L.	H	21	
725. *V. persica* Poir. in Lam.	Th		+
726. *V. polita* Fries.	Th	15, 16, 21	+
727. *V. serpylifolia* L.	Th	33	
728. *V. sublobata* M. Fischer	Th	15	
729. *V. triloba* (Opiz.) Kerner	Th	21	
LXXXIX. Simarubiaceae			
730. *Ailanthus altissima* (Mill.) Swingle	Ph		

SPECIES NAME	Biol. type	Quadrant*	Weed**
XC. Solanaceae			
731. *Datura stramonium* L.	Th		+
732. *Hyosciamus niger* L.	Th-H		+
733. *Lycium halmifolium* Miler	Ph	10, 15	
734. *Nycandra physaloides* (L.) Gaertn.	Th		
735. *Physalis alkekengi* L.	H	16	+
736. *Solanum dulcamara* L.	Ph	33	+
737. *S. nigrum* L.	Th		
XCI. Tamaricaceae			
738. *Tamarix tetrandra* Pall. ex M.B.	Ph	21	
XCII. Tiliaceae			
739. *Tilia argentea* Desf.	Ph		
740. *T. cordata* Mill.	Ph		
741. *T. rubra* DC. ssp. *caucasica* (Rupr.) Engl.	Ph	33	
XCIII. Typhaceae			
742. *Typha latifolia* L.	H	16	
743. *T. laxmanii* Lepech.	H	14	
XCIV. Ulmaceae			
744. *Celtis australis* L.	Ph	33	
745. *C. occidentalis* L.	Ph	33	
746. *Ulmus laevis* Pall.	Ph	33	
747. *U. minor* Mill.	Ph		
XCV. Urticaceae			
748. *Parietaria officinalis* L.	H		
749. *Urtica dioica* L.	H		+
XCVI. Valerianaceae			
750. Centranthus ruber (L.) DC	H	15	
751. *Valerianella dentata* (L.) Poll.	Th	16	+
752. *V. turgida* (Stev.) Becke	Th		+
XCVII. Verbenaceae			
753. *Caryopteris incana* (Thunb.) Miq.	Ph	16	+
754. *Verbena officinalis* L.	H		+
755. *Vitex agnus-castus* L.	Ph		
XCVIII. Violaceae			
756. *Viola alba* Bess.	H	10, 15, 22	
757. *V. arvensis* Murr.	Th	21	+
758. *V. hirta* L.	H	15, 33	
759. *V. odorata* L	H		
760. *V. reichenbachiana* Jord. ex Boreau	H		
761. *V. suavis* M.B.	H		
762. *V. alba* x *odorata*	H	10, 15, 22	
XCIX. Vitaceae			
763. *Ampelopsis veitchii* Hort.	Ph		
764. *Partenocissus quinquefolia* (L.) Planch.	Ph		
765. *Vitis vinifera* L.	Ph		

SPECIES NAME	**Biol. type**	**Quadrant***	**Weed****
C. Zigophyllaceae			
766. *Tribulus terrestris* L.	Th	16, 17	+

Legend:

[1] **H**	Hemicryptophyte	Perennial plant
[2] **Ph**	Phanerophyte	Tree/Bush
[3] **Th**	Therophytes	Annual plant

* *The study area of the city of Sofia was divided into 25 quadrants, each of them listing the corresponding taxa. Those species not listed in the quadrant are distributed over the whole study area of the city of Sofia.*

** *Weeds in the table are marked with a '+' sign*

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Soil Moisture Regime in Forest Plantations in the Borisova Gradina Park and in the North Park in Sofia

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Summary

This paper presents the results from a study of soil moisture under mature, 80 years old forests of *Quercus. cerris* L., *Q. rubra* L., *Pinus nigra* Arn. and *Picea abies* Karst. in the Borisova gradina park and the North park of the city of Sofia. The study showed that in the one meter soil layer, the available water stock supplies the demands of the tree species. Under severe drought conditions the available water stock in the upper 0-50 cm soil layer is exhausted in July and August. The water contents in the soil is more reduced under *Quercus cerris* oak of old age. The available water stock at these sites is utilized mainly by the under storey forest vegetation.

Key words

Soil moisture regime, green system, Sofia, Bulgaria.

INTRODUCTION

Soil moisture is of crucial importance for determining the quality of the forest site (bonitet) in the low mountain oak zone of Bulgaria. In the region of the Sofia Plain, the importance of this factor increases because of the heavy-textured soils, their lower aeration and the surface root system of the tree species corresponding to these conditions.

Questions about the regime of the soil moisture under the impact of different vegetation compositions, and forest trees in particular, have been studied for many years (e.g. Stoyanov, 1951; Naumov, 1962, 1963). They provide an idea on the regime and dynamics of the soil moisture in different regions and forest sites. According to Kerenski *et al.* (1965), the complete scrutiny of this question should include more extended and differentiated studies.

The purpose of the present study is to determine the moisture supply of the mature forest plantations in the forest-park zone of the Borisova gradina park and the North park with the aim to assess their current state.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 209-212

MATERIAL AND METHODS

In the region of the Borisova gradina park, the regime of the soil moisture was examined in *Quercus cerris* L., *Pinus nigra* Arn., *Pinus sylvestris* L. and *Tilia parvifolia* Ehrh. plantations situated to the North of the tennis courts. South of the Television tower, *Quercus rubra* L., *Quercus robur* L. and *Fraxinus* sp. plantations were studied.

In the North park the research included the plantations of *Picea abies* Karst. and *Q. rubra.*

The soil moisture contents was studied during 1992 and 1993. The samples were gathered monthly at 10cm intervals to 1m depth. The Limit Soil Moisture Capacity was measured after the thawing of snow. The Wilting point is the multiplied value of the Maximum Hygroscopic Capacity by an index of 1.5 (Stranski, 1946).

RESULTS AND DISCUSSION

The soil in the studied sites is relatively good for forest vegetation as regards physical and mechanical properties and major chemical indices (Table 1). This was the reason to include the water supply characteristics of the forest vegetation as a main goal in the scientific research.

The average monthly precipitation for the period 1979–1989 and for the precipitation conditions in 1992 and 1993 are presented in Figure 1.

Precipitation in 1992 and its distribution during the year is close to the average values, while 1993 was a dry year with insignificant winter-spring water supply and continuous drought during the second half of the growth period (July, August, September). The typical summer-autumn drought, caused by low precipitation during August and September and intensive evapo-transpiration lead to the exhaustion of the available water resources in the surface soil horizons (0-50 cm). This drought often has a positive effect on the fruiting and preparation of the plants for the winter period. Earlier and continuous summer droughts often cause premature leaf withering of the lower storey tree and shrub species.

The visible similarity between the water stock in the soil under different plantations in the Borisova gradina park draws our attention. The explanation for this should be related to the equalization of the density and crown transparency of maturity stands, with their amount of foliage and the quantity of soil litter. The high density of the stands and the lack of cultivation have decreased the differences in the water balance.

The better water provision and the smaller deviations of the moisture in the lower soil layer (50-100 cm) show that the vegetation in the Borisova gradina park is supplied mainly by water from the surface soil layer from 0 to 50 cm.

The *terra negra* soil from the North park is better supplied with water. In most of the cases the values of the soil capacity vary from 20 to 30% and the fluctuations by profile depth are small. Only during the summer months, the water supplies decrease in the surface horizon (to 20-30 cm), where the greater part of the spruce root system is distributed.

Figure 2 provides information on the regime of available soil moisture in the profile intervals from 0 to 50 cm and from 50 to 100 cm.

Table 1. Mechanical composition, soil porosity and chemical properties of the soils

Site	Soil type	Soil horizon	Mechanical composition: sand %	clay %	silt %	Soil porosity %	Chemical properties: pH (H_2O)	humus %	Total nitrogen content, %	P_2O_5 mg/100g
Borisova gradina park	cinnamon - coloured soil	A (0-23)	69,0	31,0	15,7	65	4,5	2,5	0,13	3,6
		B (23-51)	69,4	30,6	22,6	46	4,3	1,2	0,06	2,4
		BC (51-100)	67,4	32,6	23,6	-	4,6	0,6	0,03	3,2
North park	smolnitza	A (0-30)	24,3	75,7	49,9	55	5,0	3,1	0,17	4,9
		A (30-70)	38,8	61,3	37,5	41	6,0	1,7	0,09	3,8

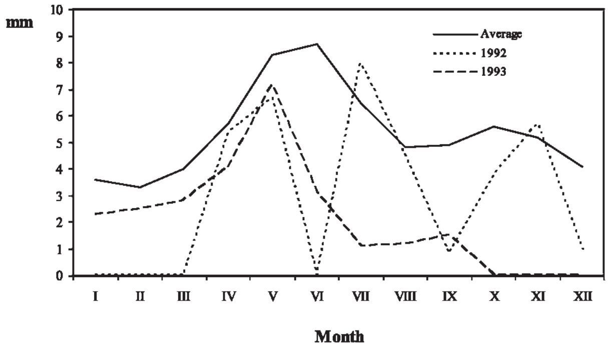

Fig. 1. Average monthly rainfall during the period 1979-1989 and in the years 1992 and 1993.

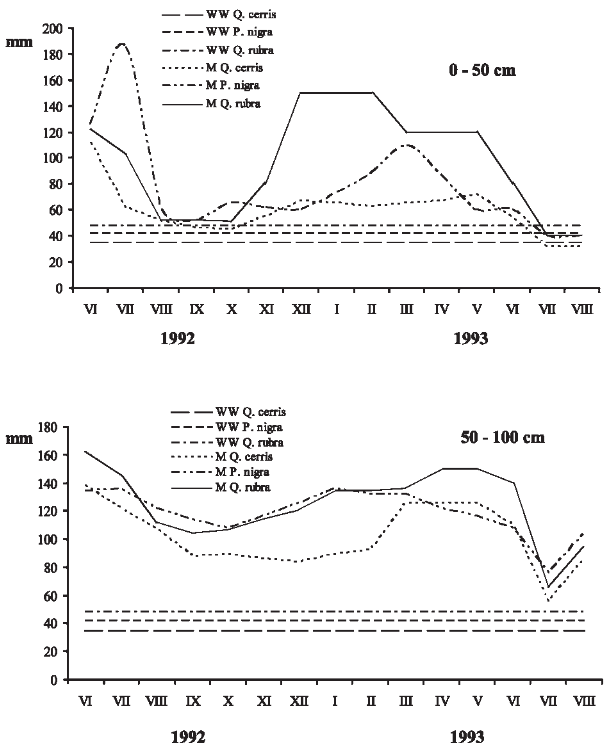

Fig. 2. Withering watter (WW) and moisture (M) in the soil.

The studied forest plantations of *Q. cerris, Q. rubra* and *P. nigra* are well stocked with available moisture. The stock in the lower part of the soil profile is considerable and with small fluctuations. This is the water reserve for supplying the needs of the forest vegetation before autumn, when the available water stock in the upper horizon is already used.

The *Q. rubra* culture is relatively better supplied with available moisture. This is due to both a lack of lower story vegetation and the reduced transpiration losses because of the less developed crowns and foliage. The same holds true for the *P. nigra* plantation.

Q. cerris is not well supplied with available moisture. Here a greater number of the trees suffer from top dieback. The available moisture is utilized mainly by the abundant lower storey vegetation and to a lesser degree by the stem shoots from lower parts of Cerris oak stems.

In the spruce culture, the available water stock is exhausted in July and August in the 0 – 20 cm layer.

Results from this research show that the soils in the Borisova gradina park and the North park contain the necessary amount of available moisture for the forest vegetation. Their relatively good stock with available moisture make it possible to grow permanent forest-park vegetation from the "complex-forest type" with *Q. robur, Fraxinus oxycarpa* and *Tilia argentea.*

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Dendrological Structure of the Green Areas in Sofia

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Abstract

The species diversity of the tree and shrub vegetation of the main green spaces and street plantings of Sofia was determined. The coniferous vegetation is represented by 33 species and the deciduous vegetation by about 230 species. The general condition of the most widely spread and most attractive tree and shrub vegetation was also determined. On the basis of the ecological characteristics of the species and the conditions of the environment in which they grow, a catalogue of the species suitable for planting in Sofia is prepared. In future management, the large-scale use of species vulnerable to declining ecological conditions must be limited, and the use of sustainable species, especially those typical for the region and occurring in the adjacent forests, must be increased. The number of trees and shrubs blossoming in summer is also insufficient, which reflects the ornamental effect of the vegetation. More attention must be paid to the more rarely occurring species, which have proved their tolerance to the conditions of Sofia.

Key words

Landscaping, green spaces, species diversity, tree and shrub species, ecological conditions.

INTRODUCTION

Green areas are important in urbanised territories. They increase the aesthetic expressiveness of the architectural ensembles, help the functional organisation of the urban and suburban zone, influence positively the microclimate and the sanitary and hygienic conditions of the city, and have educational and informative functions. The way to establish green areas must conform to the local natural conditions (relief, climate, soils, water, etc.), the urbanisation factors, to which they belong, as well as to their functional purpose. The last element is closely connected with the functional zoning of the relevant settlement. In general, big cities have differentiated central areas, urban areas and peripheral areas, followed by the adjacent areas. They, in turn, have areas for general public use,

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limited use, special purposes, private properties, etc. The basic building materials in the green system of the cities are the tree and shrub vegetation. Planted in massifs, groups and as soliters, trees and shrubs play an active role in the spatial compositions of all parts of the settlement. The efficiency of their presence depends on numerous factors such as species diversity, conformation with the ecological conditions during the selection of the species, health status, way of creation of the compositions, etc. The use of the basic representatives of the natural phytocoenoses in landscaping is of significant importance. Their use in suburban parks and their composition create typical patterns of the settlement and guarantee qualitative, sustainable and long-lasting species compositions. The introduced species increase the possibilities for a creative formation of free spaces, the achievement of a maximal aesthetic effect and the creation of unique, exotic and attractive elements in the green areas. The purpose of this study is to analyse the species diversity of the tree and shrub vegetation used in the green areas in Sofia, and its expedience according to ecological factors.

MATERIALS AND METHODS

This study focused on green areas in the central part of Sofia. The 29 studied sites are the following: the Boris Garden, the arboretum of the Forest Research Institute at the Bulgarian Academy of Sciences, the City Garden, the parks "Geo Milev" and "St. St. Peter and Pavel", the Doctor's Garden, the gardens "Bukata", "Vlado Trichkov", "Sv. Sedmochislenici", "Sv. Georgi", "National Library", Central Military Club, Vazrazhdane Square, "Maychin dom", National Art Gallery, the University, "Shipka" in Knyazhevo, along Cherni vruh Blvd., Festivalna Hall, St. Alexander Nevski Square, park "Oborishte", the public baths "Lozenec", "Madara", "Ovcha kupel", "Central", the monument of the Soviet Army and numerous streets and boulevards.

For determining the species composition, the route method was applied, which included beating the objects and inventory of the trees along the whole alley network and in the depth of the tree massifs, as well as the use of the available databases in the services of the Landscape Department of Sofia.

The adaptation and demand of the species to the ecological conditions were established through phenological observations on the development of the basic and more attractive species, visual assessment of the total condition of the vegetation according to a 5-degree scale for defoliation of the crowns and their characteristics according to the literature.

RESULTS

The green system of Sofia is situated in the Sofia Plain, which has the character of a field with an average altitude of 550 m above sea level, and is bordered to the North by the southern slopes of the Balkan range and to the south-east by the slopes of the mountains Viskyar, Lyulin, Vitosha, Plana, Lozenska and Ihtimanska Sredna Gora (Galabov, 1966).

The relief of the urban area is plainy and slightly disturbed by the four overflow terraces of the Iskar river which exceeds from 2-3 up to 80 m. The adjacent suburban areas and especially the territories southward are characterised by mountain features of the landscape components -

relief, climate, hydrology, soils, and vegetation. The peculiarities of the relief characterise Sofia Plain as quite closed field with poor air circulation. This is the reason for the unfavourable climatic peculiarities during the cold period of the year - temperature inversions with rather low values, fog, etc. During the warm period of the year, however, there is a favourable influence of the climate on the adjacent mountains and, mainly, the Vitosha Mountain, which refreshes the city with a mountain-valley breeze.

The morphographic peculiarities of the region are reflected on the climatic conditions first of all during the cold period of the year. In spite of the fact that the Balkan range is a protective barrier to some extent against the northeastern breaks, winters are cold. The number of days with a minimum temperature below -10°C during the winter months is 15 to 20 and the absolute minimum temperature has dropped to -31,2°C. The average date of the first frost in Sofia is 29 October and can be as early as late September. The average date of last frost is 8 April and the latest one is 9 May. The period without frost is on average 161 days (Hristov & Tanev, 1978). This value is indicative of a colder climate in comparison with other big cities in the country, where the number of the days without frost is over 200. The maximum temperatures are usually in July and are about 32-34°C. Maximum precipitation is in June. Summer precipitation averages at about 170-210 mm. The predominant winds are westerly as a result of the break from the west of moist air masses from the Atlantic.

During the last 20 years, some changes in the basic climatic indices have occurred, such as a slight increase in the average annual temperatures and a more considerable decrease in precipitation. According to diagrams made after the Walter method (Walter, 1979) and generalised data of the Hydrological and Meteorological Service for the period 1916-1955, there was no dry period in the region of Sofia and the semi-dry period was from the middle of July to the end of August, while for the period 1979-1990, droughts are almost constant during the growing period and in some years they last even until November.

The climate of the adjacent areas is under the direct and strong influence of the surrounding mountains. The relief is the most important factor creating the climate in this area with its significant altitude above sea level and various exposures, which is a reason for the lower temperatures, better solar radiation, higher moisture contents in the air, as well as a decrease in the temperature inversions, which are typical for the bottom of the plain.

The natural zonal soil type in the lowest parts, where the city is situated, is Vertisols. In the outskirts of the city and to the south, Chromic Luvisols, Haplic Luvisols and Distric-Eutric Cambisols alternate consecutively with an increase in altitude. At the foot of the mountains and in the lower coarses of the rivers running into the Iskar, intrazonal types are also present - Alluvial Fluvisols, Eutric Fluvisols and Deluvial Fluvisols.

Natural factors are strongly influenced by human activity. As a result of intensive building processes, developed industry and constantly increasing traffic, the composition and structure of the soils are strongly disturbed and changed, which leads to worsening of their properties and fertility. This is quite clearly observed by the building of new residential areas and roads. Considerable worsening of the soil conditions is observed by street planting in areas where salt and lye are used against ice in streets during winter months. Among the factors complicating the living conditions both for humans and the vegetation, the strong air pollution and the negative effects of the microclimate in the urbanised areas must also be considered.

Vegetation

Park and street plantations in the green system of Sofia are, with a few exceptions, of artificial origin, while the larger part of the vegetation cover in the outskirts of the city is of natural origin (autochthonous). During the last decades, it has been supplemented with artificial afforestations, increased by territory and enriched with numerous introduced species.

According to the forest-vegetation regioning of Bulgaria (Zahariev *et al.*, 1979), the natural vegetation cover in the region belongs to the zone of oaks (*Quercus* sp.) and the Austrian black pine (*Pinus nigra* Arn.) and the zone of beech (*Fagus sylvatica* L.), silver fir (*Abies alba* Mill.) and Scots pine (*Pinus silvestris* L.). In the formations of beech, *Carpinus betulus* L., *Quercus virgiliana* Ten., *Acer campestre* L., *A. platanoides* L., and *A. pseudoplatanus* L. occur. The hornbeam forests are lower in height with accompanying components of *Fagus sylvatica* L., *Quercus virgiliana* Ten., *Acer campestre* L., *Populus tremula* L., *Prunus avium* L., *Tilia tomentosa* Moench., *T. platyphyllos* Scop. and *T. cordata* Mill. The sessil oak forests are mixed with *Carpinus betulus* L., *Fagus sylvatica* L., *Acer tataricum* L., *Pyrus communis* L., *Quercus frainetto* Ten., *Fraxinus ornus* L., and *Acer tataricum* L. As a secondary process, mixed forests of *Betula pendula* Roth. and *Populus tremula* L. are observed. In the lower mountain areas there are *Quercus cerris* L., *Q. frainetto* Ten. and mixed deciduous forests. The autochthonous coniferous vegetation is preserved in small isolated areas. Exceptions are the larger areas of Scots pine stands in the Plana mountain.

All shrub communities have a secondary origin and cover large areas. The most widely spread are *Corylus avellana* L., *Carpinus orientalis* Mill., *Juniperus communis* L. and more rarely *Syringa vulgaris* L. and *Amygdalus nana* L. Among the shrubs, understorey elements such as *Crataegus monogyna* Jacq., *Viburnum lantana* L. and *Euonymus verrucosus* Scop. occur.

The artificial vegetation cover in the outskirts of Sofia dates mostly back from the last few decades. At the northern foot of the mountains, which are in close contact with the urban territory and having important recreational functions, deciduous stands and mixed deciduous-coniferous forests predominate. Of the deciduous species, which predominate and form the individual aspect of the plantations, in particular *Populus* sp., *Robinia pseudoacacia* L., *Betula pendula* Roth., *Tilia* sp. and *Populus tremula* L. have been planted. In the mixed deciduous forests, besides the above mentioned species, *Fraxinus ornus* L., *Acer negundo* L., *Gleditsia triacanthos* L., *Sorbus aucuparia* L., *Acer tataricum* L., *Cerasus avium* (L.) Moench., *Acer platanoides* L., *Salix caprea* L., *Acer campestre* L., *A. pseudoplatanus* L., *Populus* × *euramericana* Guinier, *Salix* sp. and *Quercus rubra* L. can be found, as well as the shrub species *Laburnum anagyroides* Med., *Amorpha fruticosa* L., *Syringa vulgaris* L., *Lonicera* sp., *Berberis vulgaris* L., etc. It must be pointed out that the most widely distributed species in the natural forests are the least used in the plantations.

In the coniferous plantations, monodominant stands are of *Pinus nigra* Arn. and *P. silvestris* L. trees, and sometimes *Picea abies* (L.) Karst. and mixed coniferous stands. The artificial coenoses of *Larix decidua* Mill. and *Picea pungens* Engelm. are quite limited, and *Pseudotsuga menziesii* (Mirb.) Franco, *Pinus strobus* L., *Taxodium distichum* Rich., and *Pinus peuce* Gris. are quite rare. If planted in suitable soil and climatic conditions, these species grow well.

About 33 coniferous tree and shrub species, 128 deciduous tree and 103 deciduous shrub species have been used in the landscaping of the city. The most widely used coniferous species include *Pinus silvestris* L., *P. nigra* Arn., *Picea abies* (L.) Karst., *P. pungens* Engelm., *Thuja orientalis* L., *Abies concolor* Lindl., *Juniperus sabina* L., *Chamaecyparis lawsoniana* Parl. and *Taxus baccata* L. Among deciduous trees, *Betula pendula* Roth., *Aesculus hyppocastanum* L., *Populus pyramidalis* Rasier., *Quercus robur* L., *Q. rubra* L., *Acer platanoides* L., *Robinia pseudoacacia* L., *Tilia cordata* Mill., *Fraxinus oxycarpa* Willd., *Fr. americana* L., *Acer saccharinum* L., *Fraxinus excelsior* L., *Acer pseudoplatanus* L., *A. negundo* L., *Catalpa bignonioides* Walt., *Sophora japonica* L., *Gleditsia triacanthos* L. and *Ailanthus altissima* (Mill.) Swingle are mostly used.

In the studied sites in the central area, 80% of the conifers include the tree species *Picea abies* (L.) Karst. (26%), *Juniperus* sp. (23%), *Picea pungens* Engelm. (19%), *Pinus nigra* Arn. (4,5%), *Thuja* sp. (4%) and *Taxus baccata* (3,5%).

At the same sites, the presence of the main deciduous species is richer - 74% of the total number are made up of the following species: *Betula pendula* Roth. (13%), *Fraxinus* sp. (12%), *Acer* sp. (10,5%), *Aesculus hippocastanum* L. (8%), *Tilia* sp. (6,5%), *Populus pyramidalis* (6%), *Quercus* sp. (5,5%), *Hibiscus syriacus* L. (5%), *Robinia pseudoacacia* L. (4%), *Sophora japonica* L. (1,5%) and *Gleditsia triacanthos* L. (1%).

The numerous shrubs are represented mainly by *Mahonia aquifolium* Nutt., *Philadelphus* sp., *Symphoricarpus* sp., *Forsythia* sp., *Syringa vulgaris* L., *Spiraea* sp., *Ligustrum vulgare* L., *Lonicera* sp., *Deutzia* sp., and *Chaenomeles japonica* Lindl.

The low occurrence of tree and shrub species flowering in summer is noteworthy. There are only a few species blossoming in July - *Catalpa* sp., *Viburnum opulus* L., *Sorbaria sorbifolia* A.Br., *Polygonum aubertii* L. Henry, *Hibiscus syriacus* L., and *Buddleia davidii* Franch.

In the street planting *Aesculus hyppocastanum* L. (15,5%), *Fraxinus oxycarpa* Willd. (14%), *Fraxinus* sp. (13,9%), *Robinia pseudoacacia* L. (9,2%), *Populus* × *euramericana* Guinier (7,9%), *Betula pendula* Roth. (7,6%), *Populus alba* L. var. *pyramidalis* (5,6%), *Acer platanoides* L. (5.3%), *Tilia cordata* Mill. (5,2%), *Tilia* sp. (3,7%), *Acer pseudoplatanus* L. (3,6%), and *Quercus rubra* L. (1,4%) are widespread.

The diversity of the tree and shrub species in the green areas of Sofia, their ecological characteristics and the ways of their usage are given in Appendix 1.

Species diversity gives an opportunity to evaluate the individuality to the green spaces. More attention must be paid to rare species that have proved their adaptability to the conditions of Sofia and that have ornamental properties. These are *Sequoiadendron giganteum* (Lindl.) Buchh., *Cedrus* sp., *Sorbus* sp., *Paulownia tomentosa* Steud., *Cercis siliquastrum* L., and *Magnolia kobus* DC, the species, forms and varieties with red and variegated leaves, *Kolkwitzia amabilis* Graebn, *Kerria japonica* DC and *Tamarix* sp. Their presence will increase the ornamental value of the sites.

In the vertical structure of the plant communities, high trees (43%) and medium high shrubs (22%) predominate. Very small trees and high shrubs total 18%, with 3% each for the small trees and the climbing shrubs. Least presented are the small shrubs - 2%.

According to the colour of the flowering species, most common are the yellow, white and yellow-green colours, followed by pink and significantly more rarely are the red, violet, purple and blue colours.

The analyses concerning the tolerance of the species to climatic factors show that the cold-resistant species predominate (76%), followed by the moderate cold resistant (21%) and the thermophyllic species are only of 3%. This correlation is logic due to the continental climate of the region. Concerning air and soil humidity, the data show the following: medium drought-resistant - 64%, drought-resistant - 18% and hygrophytes - 18%. At the moment this distribution guarantees good growing condition for the vegetation but in the future management of the green spaces, more attention must be paid to drought-resistant species, because of the unfavourable forecast about the changes in climatic parameters (long periods of droughts and increasing temperatures), as well as the existing financial difficulties in maintening the green spaces. This is one of the reasons for the declining conditions of some species, especially those used in street plantings, small gardens and between residential spaces.

According to the tolerance to soil conditions, 44% of the species are moderately tolerant but the proportion between the intolerant and tolerant species is 33% compared to 23%. Considering that the predominant soils in the central area of the city are anthropogenic, with a disturbed structure and poor in nutrients, the recommendation is to pay more attention to tolerant species in future management.

From Appendix 1 it can be seen that most of the investigated species are tolerant to the pollution of the urban environment and can be used in the future for reconstructions of the existing green spaces and creation of new plantings.

CONCLUSION

In the green spaces of the city of Sofia the diversity of tree and shrub species is high and provides opportunities for the creation of a typical look, individuality and unique shape of the single sites and the whole green system. The choice of species is to a large extent in accordance with climatic and soil characteristics. In future management, the use of less tolerant species must be limited and the participation of sustainable species must be increased, especially those that are typical of the region and are to be seen in the adjacent forests. In this way, the typical look of the objects will be enhanced and an easy, gradual and natural connection will be established between settlements and the environment. This, together with the improvement of communication with adjacent territories, will help and enrich the various opportunities to access the attractiveness of the green system.

The general assessment of the condition of the tree and shrub vegetation is good. Certain damages are caused by extreme climatic situations like the very low and very high temperatures and by droughts. Freezing is rare because thermophyllic species are rare. During summer months, one can often observe burns on the leaves and weathering, which can be prevented through regular watering.

Air pollution has a negative impact on the species growing in close proximity to road systems. That is why species that have proved their sustainability and are shown in the Appendix, must be used for these places.

Finally, management is particularly important for the effective maintenance of the structure and condition of green areas. In the modern conditions, when the form of property is being changed, there is a real danger of the destruction of valuable green spaces. It is also possible that new owners, because of personal reasons, will not be able to create and maintain green spaces. This demands management decisions, which will provide optimal solutions of creating, managing and utilising of green spaces of different forms of ownership.

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APPENDIX 1

Legend to catalogue

Column 2 - soil conditions:
intol. - intolerant
med.tol - mediate tolerant
tol - tolerant

Column 3 - thermal conditions:
cdres - cold-resistant
med.cdres - mediate cold-resistant
thphyl - thermophyllic

Coloumn 4 - light:
helphyl - heliophyllic
med.helphyl - mediate heliophyllic
shdtol - shade tolerant

Coloumn 5 - soil moisture:
xerphyl - xerophyllic
med.xelphyl - mediate xerophyllic
hydphyl - hydrophyllic

Coloumn 6 - air pollution:
+++ - resistant
++ - mediate resistant
+ - sensitive
- - very sensitive

Coloumn 7 - diseases and insects:
+++ - resistant
++ - mediate resistant
+ - sensitive
- - very sensitive

Applicable as:
Coloumn 8 + as main species
Coloumn 9 + as additional species
Coloumn 10 + as alley species

C A T A L O G U E

of the tree species in the green areas of Sofia and evaluation of their possibilities for adaptation to ecological conditions.

Tree species	Soil conditions	Thermal conditions	Light	Soil humidity	Air pollution	Disease insects	Applicable as: main species	addit. species	Str. line trees
1	2	3	4	5	6	7	8	9	10
I.Conifers									
Abies alba Miller	intol	med.cdres	med.helphyl	hydphyl	-	++		+	
Abies concolor (Gord et Glend) Lindl	intol	cdres	med.helphyl	med.xerphyl	+	++	+	+	
Abies pinsapo Boiss.	tol	med.cdres	helphyl	xerphyl				+	
Cedrus atlantica Manetti	tol	med.cdres	helphyl	xerphyl	++	++	+	+	
Chamaecyparis Lawsoniana (A.Murr) Parl	med.tol	cdres	med.helphyl	med.xerphyl	++	+		+	+
Chamaecyparis pisifera Siel et Zucc	med.tol	cdres	med.helphyl	med.xerphyl	++	+		+	+
Criptomeria japonica D.Don	intol	thphyl	med.helphyl	med.xerphyl	-			+	
Ginko biloba L	med.tol	cdres	med.helphyl	med.xerphyl	++	++		+	+
Juniperus chinensis L.	med.tol	cdres	helphyl	med.xerphyl	++	+		+	
Juniperus communis L	tol	cdres	helphyl	xerphyl	++	++		+	+
J. communis f.*depresa*	tol	cdres	helphyl	xerphyl	++	++		+	
Juniperus sabina L	tol	cdres	helphyl	xerphyl	++		+	+	+
Juniperus virginiana L.	med.tol	cdres	med.helphyl	xerphyl	++			+	
Larix decidua Muller	tol	cdres	helphyl	med.xerphyl	+	+	+	+	
Libocedrus decurrens Torr	med.tol	med.cdres	med.helphyl	hydphyl	+			+	
Metasequoia gliptostroboides Hu et Gheng	med.tol	cdres	helphyl	hydphyl	+			+	
Picea abies (L) Karsten	tol	cdres	shdtol	med.xerphyl	-	++		+	
Picea pungens Engelmann	tol	cdres	helphyl	xerphyl	++	++	+	+	
P. pungens f.*argentea*	tol	cdres	helphyl	xerphyl	++	++	+	+	
P. pungens f.*glauca*	tol	cdres	helphyl	xerphyl	++	++	+	+	
Pinus nigra Arnold	tol	cdres	med.helphyl	xerphyl	+	++	+	+	
Pinus ponderosa Laws	tol	cdres	helphyl	med.xerphyl	++		+	+	
Pinus strobus L.	med.tol	cdres	med.helphyl	hydphyl		-		+	
Pinus sylvestris L.	tol	cdres	helphyl	xerphyl	-	+	+	+	
Pinus wallichiana Jacks.	med.tol	cdres	helphyl	med.xerphyl				+	

1	2	3	4	5	6	7	8	9	10
Pseudotsuga menziesii (Mirb) Franco	med.tol	med.cdres	med.helphyl	hydphyl	+	-		+	
Ps.menziesii ssp *glaucescens*	med.tol	med.cdres	med.helphyl	hydphyl	+	-	+	+	
Sequoiadendron giganteum (Lindl) Buch.	intol	med.cdres	med.helphyl	med.xerphyl	+	++	+	+	
Taxodium distichum (L) Rich	intol	cdres	helphyl	hydphyl	+	++		+	
Taxus baccata L	med.tol	cdres	shdtol	hydphyl	++	++		+	+
Thuja occidentalis L.	med.tol	cdres	med.helphyl	med.xerphyl	++	++	+	+	
Thuja orientalis (L) Endl	med.tol	cdres	med.helphyl	xerphyl	++	++	+	+	
Thuja plicata Donn	med.tol	cdres	med.helphyl	hydphyl	+			+	
II. Deciduous									
Acer campestre L.	med.tol	cdres	shdtol	med.xerphyl	+	++	+	+	+
f.*globosus*	med.tol	cdres	shdtol	med.xerphyl	+			+	+
Acer ginnala Maxim.	tol	cdres	med.helphyl	xerphyl	-	-		+	
Acer negundo L.	med.tol	cdres	helphyl	med.xerphyl	++			+	+
Acer palmatum Thunb.	med.tol	med.cdres	med.helphyl	med.xerphyl	+			+	
Acer platanoides L.	intol	cdres	shdtol	hydphyl	+		+	+	+
A. pl. f.*globosa*	intol	cdres	shdtol	hydphyl	+			+	+
A. pl. f.*rubra*	intol	cdres	shdtol	hydphyl	+		+	+	+
A. pl. f.*Schvedleri*	intol	cdres	shdtol	hydphyl	+		+	+	+
Acer pseudoplatanus L.	intol	cdres	med.helphyl	hydphyl	+	++	+	+	+
A. pseudoplatanus f.*purpurea*	intol	cdres	med.helphyl	hydphyl	+	++	+	+	+
Acer saccharinum L.	med.tol	cdres	shdtol	med.xerphyl	++	++		+	+
Acer tataricum L.	tol	cdres	shdtol	xerphyl	+	++		+	
Aesculus carnea Hayne	intol	cdres	shdtol	hydphyl	+			+	+
Aesculus hippocastanum L.	intol	cdres	med.helphyl	hydphyl	-	-		+	
Ailanthus altissima Swngle	tol	cdres	helphyl	xerphyl	+++	+++		+	+
Alnus glutinosa Gaertn	intol	cdres	helphyl	hydphyl	+	++		+	
Alnus incana Moench	intol	cdres	med.helphyl	hydphyl	+	++		+	
Amelanchier canadensis (L) Medik.	med.tol	med.cdres	helphyl	xerphyl	+			+	
Amorpha fruticosa L.	tol	med.cdres	med.helphyl	xerphyl	+	++		+	
Amygdalus nana L	med.tol	cdres	helphyl	xerphyl	+			+	
Berberis thunbergii DC	tol	cdres	helphyl	med.xerphyl	+			+	

1	2	3	4	5	6	7	8	9	10
B. th. f.*atropurpurea*	tol	cdres	helphyl	med.xerphyl	+			+	
B. vulgaris L.	tol	cdres	helphyl	xerphyl	+			+	
B. v. f.*atropurpurea*	tol	cdres	helphyl	xerphyl	+			+	
Betula pendula Roth.	tol	cdres	helphyl	med.xerphyl	+	+	+	+	+
Broussonetia papyrifera (L.) Vent.	tol	med.cdres	helphyl	xerphyl				+	
Buddleia Davidii Franch.	intol	med.cdres	helphyl	med.xerphyl	+			+	
Buxus sempervirens L.	tol	med.cdres	shdtol	med.xerphyl	+	-		+	
B. s. f. *arborescens*	tol	med.cdres	shdtol	med.xerphyl	+			+	
Caragana arborescens Lam.	tol	cdres	med.helphyl	xerphyl				+	
Carpinus betulus L.	med.tol	cdres	med.helphyl	hydphyl	+	+		+	
Catalpa bignonioides Walt	intol	cdres	helphyl	xerphyl	+	+		+	+
Castanea sativa Mill.	intol	med.cdres	med.helphyl	hydphyl				+	
Celtis australis L.	tol	med.cdres	med.helphyl	xerphyl	++			+	+
Cercis siliquastrum L.	tol	med.cdres	helphyl	xerphyl	++			+	
Chaenomeles japonica (Thunb.) Lindl.	med.tol	med.cdres	helphyl	med.xerphyl	+			+	
Clematis vitalba L.	intol	med.cdres	med.helphyl	hydphyl				+	
Cornus alba L.	med.tol	cdres	shdtol	med.xerphyl	+			+	
Cornus mass L.	tol	cdres	med.helphyl	xerphyl	+			+	
Cornus sanguinea L.	tol	cdres	med.helphyl	med.xerphyl	+			+	
*Cornus stolonifera (*Michx.) Rydb.	med.tol	cdres	shdtol	med.xerphyl	+			+	
C. stolonifera f.*flaviramea*	med.tol	cdres	shdtol	med.xerphyl	+			+	
Corylus avellana L.	med.tol	cdres	med.helphyl	med.xerphyl	+	++		+	
C. avellana f.*atropurpurea*	med.tol	cdres	med.helphyl	med.xerphyl	+	++		+	
Corylus colurna L.	med.tol	cdres	shdtol	hydphyl	+	++	+	+	+
Cotinus coggygria Scop.	tol	cdres	helphyl	xerphyl	+++	++		+	
Cotoneaster horizontalis Dcne.	tol	med.cdres	med.helphyl	xerphyl	+			+	
Cotoneaster integerrimus Med.	tol	cdres	med.helphyl	med.xerphyl	+			+	
*Crataegus mollis (*Torr.et Gray) Scheele	tol	cdres	med.helphyl	med.xerphyl	++	++		+	+
Crataegus monogyna Jacq	tol	cdres	med.helphyl	med.xerphyl	++			+	+
Cr. m. f. *punice*	tol	cdres	med.helphyl	med.xerphyl	++			+	+
Cr. m. f. *rosea-plena*	tol	cdres	med.helphyl	med.xerphyl	++			+	+
Deutzia crenata	med.tol	cdres	helphyl	med.xerphyl	+			+	

1	2	3	4	5	6	7	8	9	10
Deutzia gracilis Sieb.et Zucc.	med.tol	cdres	helphyl	med.xerphyl	+			+	
D. gracilis f.*rosea*	med.tol	cdres	helphyl	med.xerphyl	+			+	
Deutzia hybrida	med.tol	cdres	helphyl	med.xerphyl	+			+	
Eleagnus angustifolia L.	tol	cdres	helphyl	xerphyl	+++	+++		+	+
Eleagnus argentea Pursh.	tol	cdres	helphyl	xerphyl	+++	+++		+	+
Eleagnus multiflora Thunb.	tol	cdres	helphyl	xerphyl	+++	+++		+	+
Euonymus europea L.	med.tol	cdres	helphyl	xerphyl	+	++		+	
Euonymus japonica L.	med.tol	med.cdres	helphyl	med.xerphyl	+			+	
Euonymus latifolia Mill.	med.tol	cdres	helphyl	xerphyl				+	
Euonymus verrucosa Scop.	tol	cdres	helphyl	xerphyl	+	++		+	
Fagus silvatica L.	med.tol	med.cdres	med.helphyl	med.xerphyl	+	++	+	+	
F. silvatica f.*atropurpurea*	med.tol	med.cdres	med.helphyl	med.xerphyl	+	++		+	
F. silvatica f.*pendula*	med.tol	med.cdres	med.helphyl	med.xerphyl	+	++		+	
Forsythia suspensa (Thunb.) Vahl.	med.tol	med.cdres	helphyl	xerphyl	+			+	
Fraxinus americana L.	intol	cdres	helphyl	med.xerphyl	++	+		+	+
Fraxinus exelsior L.	intol	cdres	helphyl	med.xerphyl	+	-(+)	+	+	+
Fr. exelsior var.*monophylla*	intol	cdres	helphyl	med.xerphyl	+	-(+)	+	+	+
Fr. exelsior var.*pendula*	intol	cdres	helphyl	med.xerphyl	+	-(+)		+	+
Fraxinus ornus L.	med.tol	cdres	med.helphyl	xerphyl	+	+		+	
Fraxinus oxycarpa Willd.	intol	cdres	helphyl	med.xerphyl	+	++	+	+	+
Gleditschia triacanthos L.	tol	cdres	helphyl	xerphyl	+++	+++	+	+	+
Gl. triacanthos f.*pendula*	tol	cdres	helphyl	xerphyl	+++	+++		+	
Hedera helix L.	intol	cdres	shdtol	hydphyl	++				
Hibiscus syriacus L.	med.tol	med.cdres	helphyl	med.xerphyl	+			+	+
Hydrangea arborescens L.	med.tol	med.cdres	med.helphyl	med.xerphyl				+	
*H. macrophylla (*Thunb.) DC var.*Hortensia*	med.tol	med.cdres	med.helphyl	med.xerphyl				+	
Hypericum calicinum L.	intol	thphyl	shdtol	xerphyl				+	
Hypericum patulum Thunb.	intol	thphyl	shdtol	med.xerphyl				+	
Juglans nigra L.	intol	cdres	helphyl	hydphyl	+			+	
Juglans regia L.	med.tol	med.cdres	med.helphyl	med.xerphyl	+	++		+	
Kerria japonica (L.) DC.	intol	cdres	med.helphyl	hydphyl	+			+	
Koelreuteria paniculata Laxm	intol	med.cdres	med.helphyl	med.xerphyl	+			+	+

1	2	3	4	5	6	7	8	9	10
oluwitzia amabilis Graebn.	intol	cdres	helphyl	med.xerphyl	+			+	
Laburnum anagyroides Medic.	intol	med.cdres	helphyl	med.xerphyl	+			+	
Laurocerasus officinalis Roem.	intol	med.cdres	shdtol	hydphyl				+	
Ligustrum ovalifolium Hassk.	med.tol	thphyl	med.helphyl	hydphyl	+			+	
Ligustrum vulgare L.	med.tol	cdres	helphyl	med.xerphyl	+			+	
Liquidambar styraciflua L.	intol	cdres	helphyl	hydphyl	+			+	
Lonicera caprifolium L.	tol	cdres	helphyl	hydphyl	+			+	
Lonicera maackii Rupr.	tol	cdres	med.helphyl	xerphyl	+			+	
Lonicera nitida Wils	tol	thphyl	helphyl	hydphyl	+			+	
Lonicera tatarica L.	tol	cdres	med.helphyl	xerphyl	++			+	
Lonicera xylosteum L.	med.tol	cdres	shdtol	xerphyl	++			+	
Lycium europaeum L.	tol	cdres	helphyl	xerphyl	++			+	
Magnolia cobus Thunb	intol	med.cdres	med.helphyl	hydphyl	+			+	
*Magnolia stellata (*Sieb.et Zuc.) Maxim.	med.tol	med.cdres	helphyl	hydphyl	+			+	
*Mahonia aquifolium (*Rupr.) Nutt.	med.tol	cdres	med.helphyl	med.xerphyl	+			+	
Malus baccata (L) Borkh	tol	cdres	med.helphyl	med.xerphyl	++			+	
Malus Niedzwetzkiana Dieck	tol	cdres	helphyl	xerphyl	+			+	
Malus silvestris (L) Mill	intol	cdres	med.helphyl	med.xerphyl	+			+	
Mespilus germanica L.	intol	cdres	shdtol	hydphyl				+	
Morus alba L.	tol	cdres	helphyl	xerphyl	+++	+++		+	
M. alba f. *pendula*	tol	cdres	helphyl	xerphyl	+++	+++		+	
Morus nigra L.	tol	med.cdres	helphyl	xerphyl	+	+	+	+	+
Pauiownia tomentosa(Thunb.)Steud.	tol	med.cdres	helphyl	med.xerphyl	+			+	
Parthenocissus quinquefolia (L.) Planch.	med.tol	med.cdres	med.helphyl	med.xerphyl	+			+	
*Parthenocissus tricuspidata(*S et Z) Planch.	med.tol	med.cdres	med.helphyl	med.xerphyl	+			+	
Padus racemosa (Lam.) Gilib.	med.tol	cdres	helphyl	hydphyl				+	
Phellodendron amurense Rupr	med.tol	cdres	shdtol	hydphyl	++			+	
Philladelphus coronarius L.	intol	cdres	helphyl	med.xerphyl	+			+	
Philladelphus lemoinei Lemoine	intol	cdres	helphyl	med.xerphyl	+			+	
Philladelphus microphyllus Gray.	intol	med.cdres	med.helphyl	hydphyl	+			+	
Physocarpus opulifolia (L.)Maxim.	tol	cdres	med.helphyl	xerphyl	++			+	
Platanus acerifolia (Ait) Willd	med.tol	cdres	helphyl	med.xerphyl	++	+	+	+	+

1	2	3	4	5	6	7	8	9	10
Polygonum aubertii L.	intol	cdres	helphyl	med.xerphyl				+	
Populus alba L.	med.tol	cdres	helphyl	hydphyl	++	+	+	+	
Populus balsamifera L.	tol	cdres	helphyl	xerphyl		-		+	
Populus candicans Ait.	intol	cdres	helphyl	hydphyl		-		+	
Populus deltoides Marsh.	intol	cdres	helphyl	xerphyl-hydphyl	+			+	
Populus X euramericana	med.tol	med.cdres	helphyl	hydphyl	+++	++		+	+
Populus nigra L.	med.tol	cdres	helphyl	xerphyl-hydphyl	+		+	+	+
Populus piramidalis Rozier	tol	cdres	helphyl	xerphyl-hydphyl	+	++		+	+
Populus tremula L.	tol	cdres	helphyl	med.xerphyl	+	++		+	
Potentilla fruticosa L.	intol	cdres	helphyl	med.xerphyl				+	
Prunus cerasifera var.*divaricata*	med.tol	cdres	helphyl	med.xerphyl	+++			+	
Pr. cerasifera var.*atropurpurea*	med.tol	cdres	helphyl	med.xerphyl	+++			+	
Prunus japonica Thunb	intol	cdres	med.helphyl	med.xerphyl	+			+	
Prunus persica f.*alboplena*	tol	med.cdres	helphyl	med.xerphyl				+	
Pr. persica f. clara	tol	med.cdres	helphyl	med.xerphyl				+	
Ptelea trifoliata L.	tol	cdres	shdtol	med.xerphyl				+	
Pterocarya fraxinofolia (Lam) Spach	med.tol	cdres	med.helphyl	hydphyl	++		+	+	
Pyrus communis L.	intol	cdres	med.helphyl	med.xerphyl	+			+	
Quercus castaneifolia C.A.Mey	med.tol	cdres	med.helphyl	med.xerphyl	+		+	+	
Quercus cerris L.	med.tol	cdres	med.helphyl	xerphyl	+	+	+	+	
Quercus frainetto Ten	tol	thphyl	helphyl	xerphyl	++	+	+	+	
Quercus petraea (Mattuschka) Liebl	med.tol	cdres	helphyl	xerphyl	++	+	+	+	
Quercus pubescens Willd.	tol	med.cdres	helphyl	xerphyl	++			+	
Quercus robur L.	intol	cdres	helphyl	med.xerphyl	++	+	+	+	
Quercus rubra L.	med.tol	cdres	med.helphyl	xerphyl-hydphyl	+++	++	+	+	+
Rhamnus cathartica L.	tol	cdres	shdtol	xerphyl-hydphyl				+	
Rhus typhina L.	tol	cdres	helphyl	xerphyl	-			+	
Ribes aureum Pursh.	med.tol	cdres	med.helphyl	xerphyl	+			+	
Ribes nigrum L.	intol	cdres	med.helphyl	hydphyl	+			+	
Ribes sanguineum Pursh.	intol	cdres	med.helphyl	hydphyl	+			+	
Robinia hispida L.	tol	med.cdres	helphyl	xerphyl	++			+	+
Robinia pseudoacacia L.	tol	cdres	helphyl	xerphyl	++	+	+	+	+

1	2	3	4	5	6	7	8	9	10
R. ps. f.*globosa*	tol	cdres	helphyl	xerphyl	++	+		+	+
R. ps. f.*pyramidalis*	tol	cdres	helphyl	xerphyl	++	+		+	+
Rosa canina L.	tol	cdres	helphyl	xerphyl				+	
Rosa hibrida	intol	med.cdres	helphyl	med.xerphyl	+				
Rosa multiflora Thunb.	intol	cdres	helphyl	med.xerphyl				+	
Rosa Paul-scarlet	intol	med.cdres	helphyl	med.xerphyl	+				
Salix alba L.	intol	med.cdres	helphyl	hydphyl	++	++		+	
Salix babilonica L.	med.tol	med.cdres	helphyl	hydphyl	++	+++		+	
Salix caprea L.	med.tol	cdres	shdtol	med.xerphyl	++	+++		+	
Salix purpurea L.	med.tol	cdres	med.helphyl	hydphyl	++	++		+	
Sambucus nigra L.	intol	cdres	shdtol	med.xerphyl	++			+	
S. nigra f.*variegata*	intol	cdres	shdtol	med.xerphyl	++			+	
Sophora japonica L.	med.tol	med.cdres	med.helphyl	med.xerphyl	+++	++	+	+	+
Sorbaria sorbifolia (L.) A.Br.	intol	cdres	med.helphyl	hydphyl	+			+	
Sorbus aucuparia L.	intol	cdres	med.helphyl	xerphyl	+			+	+
S. auc. f. *fastigiata pendula*	intol	cdres	med.helphyl	xerphyl	+			+	+
Sorbus torminalis (L.) Crants.	intol	cdres	helphyl	med.xerphyl	+			+	+
Spiraea arguta Zab.	intol	cdres	helphyl	med.xerphyl	+			+	
Spiraea cantoniensis Lour.	intol	med.cdres	helphyl	med.xerphyl	+			+	
Spiraea crenata L.	med.tol	cdres	helphyl	xerphyl	+			+	
Spiraea douglasii Hook.	med.tol	cdres	helphyl	med.xerphyl	++			+	
Spiraea japonica L.	intol	cdres	helphyl	med.xerphyl	+			+	
Spiraea prunifolia Sieb.et Zuc.	med.tol	med.cdres	helphyl	med.xerphyl	+			+	
Spiraea salicifolia L.	med.tol	cdres	helphyl	med.xerphyl	+			+	
Spiraea vanhouttei (Briot.) Zab.	med.tol	cdres	helphyl	med.xerphyl	++			+	
Staphylea pinnata L.	intol	med.cdres	med.helphyl	hydphyl				+	
Symphoricarpus albus (L.) Blake.	tol	cdres	med.helphyl	med.xerphyl	+			+	
Symphoricarpus orbiculatus Moenh.	tol	cdres	med.helphyl	med.xerphyl	+			+	
Syringa amurensis Rupr	intol	cdres	helphyl	med.xerphyl	+			+	+
Syringa josikaea Jacq.	tol	cdres	helphyl	med.xerphyl	+			+	
Syringa vulgaris L.	tol	cdres	med.helphyl	xerphyl	+	++		+	+
Tamarix pentandra Pall.	tol	cdres	helphyl	xerphyl	++			+	

1	2	3	4	5	6	7	8	9	10
Tamarix tetrandra Pall.EX M.B.	med.tol	med.cdres	helphyl	xerphyl	++			+	
Tilia cordata Mill	med.tol	cdres	med.helphyl	hydphyl	+	++	+	+	+
Tilia platiphillos Scop	med.tol	cdres	med.helphyl	hydphyl	-	++	+	+	+
Tilia tomentosa Moench	intol	cdres	med.helphyl	med.xerphyl	++	++	+	+	+
Ulmus glabra Huds.	intol	cdres	shdtol	hydphyl	+			+	
Ulmus glabra f. *pendula*	intol	cdres	shdtol	hydphyl	+			+	
Ulmus laevis Pall.	intol	cdres	shdtol	hydphyl	+			+	
Ulmus minor Mill.	med.tol	cdres	shdtol	hydphyl	+			+	
Viburnum lantana L.	med.tol	cdres	med.helphyl	med.xerphyl	++	++		+	
Viburnum opulus L.	med.tol	cdres	med.helphyl	med.xerphyl	++	++		+	
V. opulus - sterilae	med.tol	cdres	med.helphyl	med.xerphyl	++	++		+	
Vinca major L.	med.tol	med.cdres	shdtol	hydphyl				+	
Vitex agnus-castus L.	tol	med.cdres	helphyl	xerphyl	++			+	
Weigela florida (Bge.) A.DC.	intol	cdres	med.helphyl	hydphyl	+			+	
Weigela hybrida	intol	cdres	med.helphyl	hydphyl	+			+	
Wisteria sinensis (Sims.) Sweet.	med.tol	med.cdres	helphyl	xerphyl	++			+	

Environmental Problems for Trees in the Green System of Sofia

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Summary

Negative changes in the conditions of the urban environment have been monitored by determining the amounts and dynamics of the main pollutants of the air, precipitation and soils. Air pollution, such as sulphur dioxide, lead aerosols and dust were measured in the central urban part and the northern quarters of Sofia. Pollutant concentrations were higher during winter periods. The sulphate ions in precipitation were found to increase during 1990-1997, their values being higher during winter, and the concentration of nitrates were found to be higher in July-September. The amounts of Pb and Cd increased, and those of Fe, Mn and Sr decreased.

The quantities of the analysed heavy metals in dust depositions prove to be toxic for the vegetation, and appears to be one of the main reasons for the worsened health condition of the trees in the central city park and most of the tree species situated close to heavy traffic roads.

The investigated tree species have accumulated heavy metals and lead. The interaction between air pollution and tree vegetation studied by the accumulation of chemical elements in the species is expressed in the different accumulating capacity of the particular species and the amounts of the elements in the ambient air. There is a positive correlation between the amount of particular elements in the dust and their values in leaves. Environmental pollution affects photosynthesis, and therefore the health condition of the tree vegetation. The impact depend both on the pollution level and on the resistance of the particular species.

The health condition of trees in the parks and suburban areas is acceptable. There are severe disturbances in development and duration of some phenophases (untypical colouring, premature leaf shedding, secondary leaf development) of the tree species growing in the highly polluted environment of the central city part. Besides pollution, climatic factors influence the condition of the tree vegetation together with its position nearby buildings, sidewalks, roads, etc. Age is also of considerable importance.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 229-247

Key words

Ecological conditions, greenbelt setting, green area, tree species, shrub species, acid rain, air pollution, chlorophyll, phenological observation, urban environment, Sofia, Bulgaria.

INTRODUCTION

Urbanization causes complex relations between the anthropogenic factors and the natural environment. Thus, ecosystems with very altered soils, plant and animal communities are formed. The structure and functioning of these ecosystems is closely related to human activities. In order to maintain an ecological balance in them, it is necessary to make a thorough analysis of the changes in the ecological parameters and to develop scientific background for the formation of the city environment.

As green areas are one of the basic components of the urbanized territories, their construction and management should be based on precise data of the tolerance of the species to the changed ecological conditions. This require complex studies for assessing the mechanisms of the interaction between the city conditions and plants. During the last decades many studies have been performed both abroad and in Bulgaria. It has been shown that the impact of harmful substances in the air, precipitation, water and soils on plants depends on: the kinds of pollutants, their concentration, duration of impact, the relative tolerance of the species and particular individuals, the physiological stage of the plants, etc. The influence of the atmospheric toxins commence with disturbances in the bio-chemical processes and changes in the cell organelles, which can be defined as an "invisible" and "hidden" strike. Later in the scientific literature the term "stress condition" was introduced (Ilkun, 1971; Guderian, 1979; Kondratyuk & Tarabrin 1980; Dessler, 1981; Smith,1981; Treschow, 1984; Kurteva & Gateva, 1998; Naidenova, 1999).

Later on, the most common visible changes in the plants occur, resulting from atmospheric pollution, such as various spots, discoloration or leaf color (most often chloroses) due to the destruction of pigments, necroses, defoliation, leaf lamina reduction, turgor decrease and suppression of leaf growth and the plant as a whole, dying of individual branches, whole plants, plant groups and plantations, etc.

Toxic gases accelerate the aging and dying out processes of the assimilative organs, which in turn lead to general weakening and earlier dying of the whole plant. Leaf shedding during episodic, intense gas loads does not necessarily mean the death of all branches and plants as a whole. Secondary frondescence, typical for many species, is an example of this. Some authors consider that plant survival under extreme environmental conditions depends on the morphological maturity of the assimilative organs and the micro-climatic peculiarities at the polluted region. Thus, for example, Kulagin (1976) determined that gas impacts during spring and the end of summer were not as devastating for deciduous species as those in mid summer, because the secondary frondescence during spring rapidly compensates the loss of the immature leaves, and at the end of the summer period the leaf shedding is close, in time, to the natural shedding during the autumn, so that the harm is considerably small.

Morphological changes under atmospheric air pollution are manifested by the reduction of the leaf lamina and thickness, deformations and decrease in number, etc. City environment pollution influences the phenological development of the plants. The deviations in the terms and duration of the phenophases provide important information for the tolerance of the particular species to the city environment conditions.

In the present paper we examine changes in ecological factors, their impact on the vegetation in the urbanized regions, and above all, on the main urban tree and shrub species. Furthermore, we study the classification of these species according to their tolerance to the negative changes in the city environment. This is of considerable importance for the quality and functioning of the green ecosystems.

MATERIAL AND METHOD

In the present study, we focus on Sofia because it is the largest town in Bulgaria, and includes anthropogenic sources of almost all the negative factors present in the urban areas. The study subjects include individuals, groups and plantations of trees situated at different degrees of air pollution in Sofia. The soils are anthropogenic with comparatively similar parameters. Negative changes in the ecological characteristics of the modern town were sought mainly with respect to air quality, pH of precipitation water and their chemical loads, the components of the dust pollution, as well as their dynamics during the year and between years. These contaminations are a result of the industrial activity and great intensity of traffic.

Comparative assessment of air pollution was made from data from the Ministry of Environment and Water (MEW). The studies on the precipitation water quality, snow water quality and the dry depositions in the region of Sofia were made over the territory of the Forest Research Institute (FRI) of the Bulgarian Academy of Sciences, situated in the southern part of Sofia Plain at an altitude of 620 m. The data are sampled in the period 1990-1999, and include measurements of pH, sulphate and nitrate ions in precipitation and snow water, and 11 macro- and microelements in dust depositions. The samples were gathered in plastic vessels, placed in the open at height of 1.50 m. pH measurement was made directly after sampling and the chemical components were analysed within 5 days. Acidity was measured with pH meter TM-4, the nitrates were analysed using the diphenylamine method, sulphates – following a unified methodology for background monitoring of the natural environment pollution, and the chemical elements by the AAS method.

RESULTS AND DISCUSSION

Air and precipitation water pollution

According to data from the MEW, air pollution is greatest in the central part of the city. Dust pollution is greatest at the “Stamboliiski” Blvd (in its section around the “Vazrazhdane” square), where the average 24 hour concentrations reach 0.47-0.25 mg/m^3, with maximum allowable concentration (MAC) for non-toxic dust being 0.15mg/m^3 (after Bulgarian State Standard /BSS/). Heavily polluted are also the streets "Bregalnitsa", "Orlandovtsi" housing estate and the region of the Central Railway Station. During particular months there was considerable pollution registered in the municipalities "Studentska" and "Novi Iskar". "Boyana" housing estate had the lowest dust quantities in the air.

The dynamics of the dust pollution expressed maximums during winter months (I, II, XI, XII) and lowest values in IV and IX. About 61% of the average monthly quantities of dust pollution are above the MAC.

The amount of the dust deposition and its components, that determine the degree of toxicity, are of considerable importance for vegetation health. The studies at the region of the FRI show that the quantity of the depositions varied from 0.64 to 10.83 g/m^2, which is within the normal limits. It is alarming that the analysed parameters of the dust indicated that it is toxic to the vegetation. The monthly values of the measured elements were as follows: - 378 mg/m^2, Na - 62.7 mg/m^2, Ca - 294 mg/m^2, Mg - 86 mg/m^2, Mn - 4.6 mg/m^2, Fe - 195 mg/m^2, Cu - 3 mg/m^2, Zn - 19.3 mg/m^2, Pb - 3 mg/m^2, Cd -2.8 mg/m^2 and Sr - 1.03 mg/m^2. There is greater pollution during the vegetation period, which does not favour growth.

The four macroelements, studied as components of the dry deposition, may have negative effects when being in direct contact with the aboveground organs of the plants and at great quantities. In this case they increase the total dust amount that respectively covers greater parts of the plant assimilation area, thus hindering respiration and photosynthesis processes.

The microelements Mn, Fe, Cu, Zn, Pb, Cd, Sr are in small quantities in the chemical composition of the soils and plant tissues, but when their concentrations increase above the normal contents, they become toxic and may have a lethal impact on the health of the plant organs.

In the dust pollution of the air, measured at the territory of the FRI, manganese and iron in the greater majority of the samples were normal. Every month from 0.66 to 4.63 mg manganese and from 0.73 to 194.66 mg iron are deposited over an area of 1m^2. For both elements there is no clear regularity in their quantitative distribution by seasons. Their presence in the dust pollution probably cannot significantly affect soil quality, but the depositions on the leaf surface should be carefully kept under observation while taking into consideration the possibility for a direct toxic impact.

The chemical characteristic of the deposited dust at the region of the FRI shows that Cu, Zn, Pb, Cd, Sr are in quantities above normal. This implies a negative anthropogenic impact on the quality of the atmospheric air.

The results show that when elucidating the reasons for the worsening health condition of the tree and shrub vegetation in Sofia, special attention should be paid to heavy metal air pollution.

SO_2 is a dangerous component to the vegetation. It reaches its highest values during the winter period (January – March and October – December), when the MACs are exceeded manyfold. The measured concentrations are extremely high in January and February in the central part of the city (at "Stamboliiski" Blvd. – 6 fold above MAC, at the territory of "Orlandovtsi" housing estate – 8 fold above MAC and at "Mladost" housing estate - 6.5 fold above MAC).

Based on these data we identified conflict zones from the city center to the northwestern direction ("Orlandovtsi" housing estate and "Nadezhda" housing estate) and east-southeastern part ("Mladost" housing estate and "Druzhba" housing estate). It is comparatively favourable for the vegetation that the high SO_2 values are registered during the winter months when, due to the slow physiological activity of conifers, the impact is weakly expressed on them and on deciduous trees.

According to the Bulgarian State Standard (BSS), the Maximum Allowable Concentration of NO_2 is 0.04 mg/m^3 in the air but with respect to plant species the MAC for NO_2 is 0.0005 – 0.0008 mg/m^3 (Supuka, 1992). These criteria for atmospheric air pollution are unfavourable for the tree vegetation in the green areas of Sofia because a greater part of the registered monthly average values (for 24 hours) are up to several fold above the MAC according to the BSS, while observing the limit concentrations for vegetation, the excess is much greater.

The dynamics of NO_2 expressed no regularity by months. "Stamboliiski" Blvd and the Central Railway Station had higher values and "Druzhba" housing estate and "Mladost" housing estate had lower values. In contrast to the territory dynamics of SO_2, the region of "Orlandovtsi" housing estate was least polluted with NO_2 and at "Boyana" quarter its concentrations were above the MAC almost during all months.

Another air pollutant in the big agglomerations is the HS. Its amount in the imissions of Sofia varied from almost insignificant (0.0001 mg/m^2) to 4.5 fold above the MAC (0.0364 mg/m^2). The pollution was greatest in the region of the Central Railway Station, where a great number of samples showed values above MAC. High values were also registered at "Druzhba" housing estate, "Mladost" housing estate, "Boyana" quarter and "Lyulin" housing estate. The HS pollution over the territory of Sofia was with a mosaic distribution. Its greater impact on the vegetation should be expected at the North Park, West Park and the garden near "Mother's home", the green areas in the housing estates "Druzhba" and "Mladost" and the yard places in the "Boyana" quarter.

The inspection of the tree-shrub vegetation at these places did not show visible signs of damage, which did not exclude the presence of changes in the physiological and biochemical processes in the plants. Under continuous impact, external signs could also appear together with the reduction of their life span.

The lead aerosols, as a component of the toxic admixtures in the dust deposition, were present in greatest quantities in the air pollution along roads. The amounts measured at "Stamboliiski" Blvd were above the MAC during the whole year. Higher values were registered during particular months at the regions of the Central Railway Station, "Bregalnitsa" street, "Lyulin" housing estate, "Orlandovtsi" housing estate and "Druzhba" housing estate. About 23% of the average monthly values in the studies areas were at the MAC limit – 0.0003 mg/m^2, 27% are above the MAC and were within the allowable range. This shows that the air of Sofia is moderately polluted with lead aerosols but in this case their deposition in the soil and the aboveground organs of the plants should be taken into consideration where gradual accumulation increases lead to toxic levels.

The toxic admixtures in the atmospheric air increased the chemical loads in the wet depositions and deteriorated their qualities, and this influenced the health condition of the vegetation. A typical example is the formation of acid rain. The results from the precipitation quality in Sofia showed that the amounts of sulphate ions in rain and snow water vary within a broad range. For precipitation these ions varied from 0.67 to 72.46 mg/l, the average month values were between 2.71 and 54.92 mg/l and the average year values were between 10.65 and 13.19 mg/l. After data from Izraely *et al.* (1989), sulphate ions in quantities greater than 6 mg/l are typical for polluted, mainly industrial regions. Average concentration level of 1-6 mg/l is typical for the regional background of the territories and is to a great extent determined by long distance transfer. The lowest concentration levels, below 1 mg/l, are observed far away from industrial centres and characterize the global background of the sulphates in the precipitation. Our results revealed that there is considerable contamination of rainwater with sulphate ions in the Sofia region. There is an increasing dynamic tendency throughout the years. Their distribution over the scale of Izraely showed that 65% of the samples had high concentration of sulphate ions, 34% had average concentration and only 1% had less than 1mg/l.

Nitrate quantities varied within the range of 0.04 to 11.33 mg/l. and, like with sulphates, there was an increase observed during the last years. After data from Argirova *et al.* (1986), nitrate concentrations in precipitation water less than 4 mg/l characterize the region as not being polluted. It was shown by our research that for the period 1994-1997, nitrates in the precipitation above this level comprised 43%, 30% were with concentrations of 2-4 mg/l and 27% contained less than 2 mg/l.

The results for the acidity of precipitation water showed that for the period 1994-1997 the average annual values of pH increased. This is clearly seen both for the average annual values of pH, which from 1994 to 1997 were 5.2 – 5.15 – 5.0 – 4.67, and by the percent distribution of the particular precipitation according to their acidity (Table 1). Precipitation with pH less than 5.0 made up 46%-70% of the samples. In 1999, an increase was observed in the pH values and 48% of the analysed samples were with pH above 6.0. These data, however, included the second half of the year and thus no general conclusion could be drawn for the whole year. Nevertheless, it has to be noted that there was definitely a change in the rain quality. This was also seen from the data on the acidity of the precipitation at the region of "Zheleznitsa" village (Vitosha mountain) for the same period (Table 2). Only one of 24 precipitation samples was

Table 1. Percent distribution of acidity in the precipitation.

pH	1994	1995	1996	1997	1999
> 4.5	31	32	31	47	10
4.5-5.0	15	22	24	23	16
5.01-5.5	15	10	18	17	13
5.51-6.0	18	18	18	7	13
6.01-6.5	8	8	6	3	22
> 6.5	10	10	3	3	26

Table 2. Average monthly values of pH and SO_4 in precipitation water, "Zheleznitsa" village, 1999.

Months	V	VI	VII	VIII	IX	X	XI
pH	7.14	7.37	7.14	7.23	7.21	6.60	6.80
SO_4	17.02	8.86	11.50	26.82	22.27	16.97	11.21

with pH below 5.5 and the rest were with pH above 6.5 and even above 7.0. As there were no data available for the precipitation quality during 1998 and the first half of 1999, it is not possible to provide a precise explanation for this change. Additional observations are necessary to assess whether or not such change is permanent.

Our former studies provided additional information for the chemical load of the precipitation water. These were also performed over the territory of the FRI and showed that the precipitation is polluted with chemical elements. Analyses of the precipitation for the period 1990-1993 showed that half of the average monthly amount of lead and a quarter of cadmium were above the MAC for first category water, according to BSS, and copper and zinc concentrations showed a trend of increase.

Our results showed that the tree and shrub vegetation in the green system of Sofia city is subjected to permanent negative effects both from air pollution and precipitation.

Impact of air pollution on the vegetation

The forests and plantations in the green system of the city of Sofia are a typical example of ecosystems that influence, and are influences by, the urban environment and the industrial activity. The pollution sources may be combined into three major groups, which determine the character, degree and territorial range of negative impact: industrial sources, automobile transport, and long distance transfer. All areas of the green system of Sofia are subjected to a weaker or stronger degree of anthropogenic impacts, that requires detailed research to determine the damages on particular species, their different tolerance capacity in anthropogenically influenced environments, their ability to serve as bio-indicators of environmental pollution, and as clearing filters.

The major tree species of the green system are important to the city environment also from aesthetical point of view. Studies on the abiotic damages of the main tree species used for landscaping in Sofia were performed in several directions: influence of air pollution on the accumulation of inorganic elements in the leaves and possibilities to induce harm; determining the impact of the pollution on the synthesis of pigments (chlorophyll “a” and chlorophyll “b” and carotenoids) as a possibility for early diagnostics of negative impacts; phenological observations for determining the anthropogenic influence on the development, duration and anomalies of certain phenological phases; study of the condition of tree species growing near conflict points of transportation and communication links of the city and elucidating their tolerance to deteriorated ecological conditions.

Accumulation of inorganic elements in the leaves of the tree species used for landscaping in the green system of Sofia

The studies were conducted on several tree species in Sofia frequently used for landscaping along transportation routes and green areas, for example: birch (*Betula pendula* Roth.) horse-chestnut (*Aesculus hippocastanum* L.), small-leaf lime-tree (*Tilia cordata* Mill.), silver-leaf lime-tree (*T. tomentosa* Moehch.), American oak (*Quercus rubra* L.), field maple (*Fraxinus oxycarpa* Willd.), Norway maple (*Acer platanoides* L.) and maple (*A. pseudoplatanus* L.). Plant material was gathered along transects with a north-south and east-west direction and included the industrial zone of the city, the transport segments with heavy traffic, and the green areas in the centre and the peripheral city territories. Within the range of the outer town ring of the green zone, plant material were analysed from Elin Pelin, Bankya, and the northern slopes of the Vitosha and Lyulin mountains. Applying the AAS methods, the quantities of K, Na, Ca, Mg, Mn, Fe, Cu, Pb, Cd and Zn in leaves were measured. The samples were gathered at the end of the vegetation season – August.

The results revealed the following:

Potassium – According to data from Grishina & Samoilova (1971), the amount of potassium in the vegetation varies within the range of 500-3000 mg/100 g. In the leaves of the examined species, potassium contents varied within quite a broad range, from 195 to 217 mg/100 g dry weight (Table 3). The highest values were in the leaves of the tree species growing in the "Nadezhda" housing estate, the Central Railway Station region, "Stochna gara" Railway Station and "Bulgaria" Blvd. The lowest values were in leaves from "Simeonovo" housing estate – FRI, where in the horse chestnut and birch, quantities were below the normal limit.

The quantitative distribution of potassium in the leaves of the different tree species, and per site, did not show a clear relationship with the leaf structure and air pollution. The highest amounts were measured in maple, and the lowest in the horse chestnut and birch, which to a certain degree correlated with their health condition.

For *Sodium*, low values between 8.53 and 38.8 mg/100 g were recorded while the normal range is 10-100 mg/100 g (Table 4). The lowest concentrations were analysed in maple leaves and the highest in American red oak. The territorial distribution showed that the highest values were measured in the samples from the central and southeastern part of Sofia (FRI, the airport). It is possible that the studied species suffer from sodium deficiency because the analysed values in all the measured were close to the lower limit of 10 mg/100 g.

Calcium – As a metabolism element, it participates with amounts varying from a hundredth of a part of a percent to 2% of the absolute dry weight of the plants. The presence of calcium in dust pollution causes an increase in contents above the normal limits in leaves of Norway maple, maple and small-leaf lime-tree from the regions of "Bulgaria" Blvd, "Zaimov" housing estate, "Stochna" Railway Station, the Airport and the FRI, while in the other sites, for all the species, the values were between 1223 mg/100 g and 2132 mg/100 g dry weight (Table 5). It is possible that the greater amount of calcium could disturb the normal processes in the plants.

Magnesium – the analyses of its contents in the studied species showed that all the values were within the normal limits (100 - 500mg/100g dry weight) (Table 6). Thus, the plants do not, probably, suffer from magnesium deficiency.

Manganese - According to data from Grishina & Samoilova (1971) the approximate amount of Fe, Na, and Mn is from 0.001 to 0.1% of the absolute dry weight in plants that do not grow on saline soils. Baker and Chesnin (1975) state that the normal manganese contents in the leaves of the tree vegetation is from 15 to 150 mg/kg. According of other sources, when manganese is below 20 mg/kg, the plants suffer from deficiency and when the concentration is above 500 mg/kg it has a toxic effect.

The analyses of manganese contents in the leaves of the examined tree species showed that its amount varied from 31 to 965mg/kg. A toxic effect is expected for birch from the "Nadezhda" housing estate and the airport. The lowest values were registered in maple leaves (Table 7).

Table 3. Accumulation of K in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	Tree spesies							
	B. pendula Koth	A. hippo-castanum L.	T. cordata Mill	T. tomentosa Moench	Q. rubra L.	Fr. oxicarpa Willd	A. plata-noides L.	A. pseudo-platanus L.
Lyulin	608		1223	856			1086	897
Nadezhda	542		983	1601			999	1125
Mother's home	1452		1399			1913		
Stochna gara						2187		
TZUM					1125			
Stamboliiski blvd					972			
Orlov most	1003	975	900	975	623			
Borisova gradina	1952		827	845	877			
Aerport	649		926	1027			1045	782
FRI-BAS	446	195	888	1099	652		896	
Bankia	781		1112	832	625			
Bulgaria blvd							1375	

Table 4. Accumulation of Na in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	Tree spesies						
	B. pendula Koth	T. cordata Mill	T. tomentosa Moench	Q. rubra L.	Fr. oxicarpa Willd	A. platanoides L.	A. pseudo-platanus L.
Lyulin	10.5	15.9	10.9			12.4	17
Nadezhda	11	12.5	20.2			11.2	13.3
Mother's home	12.4	13					
Stochna gara					8.53		
TZUM				29.4	9.45		
Stamboliiski blvd				25.4			
Vl.Zaimov blvd						22.1	
Aerport	13.1	11.8	15.1			19.7	32.9
FRI-BAS				38.8		14.2	
Bulgaria blvd						23.1	

Table 5. Accumulation of Ca in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	Tree species						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	1479		1725	2132		1673	1185
Nadezhda	1337		1734	1223		1472	1877
Mother's home	2088		2018		1772		
Stochna gara					3409		
Vl.Zaimov blvd						3702	
Aerport	1531		2929	1491		1752	1472
FRI-BAS						2891	
Bulgaria blvd						3768	

Table 6. Accumulation of Mg in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	Tree species						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	415		350	431		390	352
Nadezhda	345		335	406		307	323
Mother's home	422		283		379		
Stochna gara					446		
Vl.Zaimov blvd						316	
Aerport	384		385	313		245	287
FRI-BAS						360	
Bulgaria blvd						252	

Table 7. Accumulation of Mn in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	Tree species						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	8.51		10.4	7.5		10.2	7.7
Nadezhda	96.5		21	17.7		19.7	16.6
Mother's home	6.3		6.6		3.1		
Stochna gara					3.5		
Vl.Zaimov blvd						10	
Orlov most	10.3	10.2	19.1	7.5			
Borisova gradina	22	5.8	5.6	3.9			
Aerport	63.6		27.9	43.7		20.8	26
FRI-BAS	12.6	3.9	13.4	20		31.8	
Bankia	3.3	8.2	4.6	2.9			
Bulgaria blvd						9	

Iron – Its amount correlated with its presence in the aerosol air pollution. All measured values in the leaves of the species from the "Nadezhda" housing estate and the airport were higher than the normal amount of 20 to 300 mg/kg (Baker and Chesnin, 1975). This may be explained by the impact of industrial pollution, including that from the "Kremikovtsi" plant. The lowest values were in plant samples from the "Bankia" quarter and the park of the FRI (Table 8).

Copper – higher copper values (not above the MAC) were measured again in the vegetation from the "Nadezhda" housing estate and the trees along the routes with heavy traffic in the city - crossroads "Stochna" Railway Station and "Lyvov most" (Table 9). The amounts were considerably lower in the leaves from the trees in the park of the FRI and the values from the rest of the sites were in between these two.

Table 8. Accumulation of Fe in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	**Tree species**						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	61.6		53.4	48.54		47.5	54.2
Nadezhda	92.7		83.5	142.6		73.3	95
Mother's home	42.7		54.1		47.2		
Stochna gara					37.6		
Orlov most	33.8	34.5	62.5	32.3			
Borisova gradina	25.9	36.6	40	44.9			
Aerport	81.2		64.1	75.3		78.6	69.5
FRI-BAS	27	32.1	20.7	22.9		26.9	
Bankia	20.2	25.7	36.7	22			
Bulgaria blvd						63.9	

Table 9. Accumulation of Cu in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	**Tree species**						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	1.19		1.2	1.5		1.26	1.34
Nadezhda	1.84		2.38	2.8		1.34	1.45
Mother's home	1.15		1.44		1.15		
Lyvov most.			2.19				
Stochna gara					3.46		
Vl.Zaimov blvd						0.8	
Orlov most	0.74	1.1	1.05	1.1			
Borisova gradina	0.39	0.7	0.87	0.91			
Aerport	1.28		1.08	1.23		0.96	1.21
FRI-BAS	0.55	0.48	0.55	0.48		0.63	
Bankia	0.3	1	1.1	0.75			
Bulgaria blvd						0.91	

Lead – Lead is considered one of the main and most dangerous toxins for living organisms. Izraely *et al.* (1989) showed that the amount of lead in leaves of deciduous and coniferous vegetation in Europe varies between 1.5 and 2.1 mg/kg.

All registered values in the leaf analyses of tree species from different parts of the Sofia city green system were higher than the cited data for Europe (Table 10). The lowest measured amounts in leaf samples from the "Bankya" quarter were 4.7-6.3 mg/kg, i.e. 3 fold higher than the average value for Europe. The tree species along the transportation routes "Bulgaria" and Stamboliiski boulevards, the crossroad "Orlov most", the airport and "Nadezhda" housing estate accumulated the greatest quantities of lead. In Norway maple leaves from "Bulgaria" boulevard the contents reached 34.1 mg/kg, in American red oak leaves from samples along the "Stamboliiski" boulevard, the amount was 33.5 mg/kg and in birch from crossroad "Orlov most" – 30.5 mg/kg. The concentrations in the leaves of the small-leaf lime-tree were also considerable. It is obvious that, despite the comparatively low concentrations of the measured lead aerosols in the air, the vegetation is not protected from their negative influence due to the capacity of lead to accumulate in the plant organs and in soil.

Cadmium - Cadmium is an element that, together with lead, is referred to as one of the spread toxins. In the tree vegetation in Europe its contents is 0.05 mg/kg (Izraely *et al.*, 1989) and according to data from Baker and Chesnin (1975), its normal amount is 0.05-0.2 mg/kg.

Cadmium concentrations in the leaves of the examined tree species sampled from different parts of Sofia varied within the range of 0.13-1.86 mg/kg, i.e. from the upper limit of the norm to 9 fold greater values (Table 11). Unlike the rest of the analysed elements, cadmium is accumulated mostly in the leaves of tree species from the locations to the east of crossroad "Orlov most" (crossroad "Orlov most", Airport, FRI). Birch had the highest values, followed by Norway maple, small-leaf lime-tree and silver-leaf lime-tree.

Zinc – Despite the considerable presence in the dust pollution, its accumulation in the leaves was within the norm (1.5-15.0 mg/100 g) (Table 12). Only in birch and silver-leaf lime-tree leaves from the region of the airport, zinc amount is two fold higher. It is possible that this is due to the

Table 10. Accumulation of Pb in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	**Tree species**						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	1.95		0.91	1.34		1.16	1.54
Nadezhda	2.38		2.99	2.4		1.33	2.21
Mother's home	2.24		2.4		0.89		
Stochna gara					1.23		
Vl.Zaimov blvd						2.51	
Orlov most	3.05	0.93	1.87	1.36			
Borisova gradina	0.9	1.62	1.58	1.36			
Aerport	2.86		2.33	2.59		2.11	1.67
FRI-BAS	1.77	1.03	0.89	0.74		1.85	
Bankia	0.48	0.47	0.94	0.62			
Bulgaria blvd						3.41	

Table 11. Accumulation of Cd in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	**T r e e s p e c i e s**						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	0.07		0.092	0.09		0.06	0.08
Nadezhda	0.07		0.092	0.08		0.05	0.06
Mother's home	0.07		0.096		0.04		
Stochna gara					0.03		
Vl.Zaimov blvd						0.07	
Orlov most	0.17	0.09	0.129	0.1			
Borisova gradina	0.037	0.1	0.07	0.08		0.08	0.08
Aerport	0.185		0.01	0.11		0.13	
FRI-BAS	0.102	0.111	0.14	0.14			
Bankia	0.026	0.013	0.05	0.06			
Bulgaria blvd						0.08	

Table 12. Accumulation of Zn in the leaves of tree species from the green area of Sofia (mg/100g).

Locality	**T r e e s p e c i e s**						
	B. pendula Koth	**A. hippo-castanum L**	**T. cordata Mill**	**T. tomentosa Moench**	**Fr. oxicarpa Willd**	**A. plata-noides L.**	**A. pseudo-platanus L.**
Lyulin	18.7		6.7	3.3		3.9	4.3
Nadezhda	13.4		2.5	3.4		2.9	4.5
Mother's home	6.4		3		7.7		
Stochna gara					1.8		
Vl.Zaimov blvd						2.9	
Orlov most	8.1	7.1	7.3	10.7			
Borisova gradina	15	9.3	11.5	7.3			
Aerport	30.5		3.2	35.4		5.3	4.6
FRI-BAS						3.1	
Bankia	14.5	9	9	10.7			
Bulgaria blvd						3.3	

non-ferrous metals plant situated in the vicinity. Generally, it seems that birch tends to accumulate this element most, followed by the silver-leaf lime-tree and the American red oak.

The normal amounts of the studied elements in the leaves of the tree species, according to literature references are of the following order:

Ca >= K > Mg > Na > Fe > Mn > Zn > Cu > Pb > Cd.

In our studies, despite greater quantities, the macroelements followed the same order. However, the concentration of potassium was higher than calcium in the leaves of species from the crossroad "Orlov most", park "Borisova gradina", FRI and "Bankya" quarter.

With respect to the microelements, in most cases iron came after magnesium. To a certain extent this is due to the "Kremikovtsi" metallurgy complex, situated nearby. Sodium, zinc and manganese exhibited considerable mobility and at different sites changed position, most often in combination with Mn > Na > Zn and Mn > Zn > Na. In the last positions, lead and copper exchanged positions which showed both lead pollution and accumulation in the leaves of the tree species. Thus, according to our studies the order was as follows:

Ca >=K > Mg > Fe > Mn > Na > Zn > Pb > Cu > Cd

Ca >= K > Mg > Fe > Na > Mn > Zn > Pb > Cu > Cd

K >=Ca > Mg > Fe > Mn > Zn > Na > Pb > Cu > Cd

The grading of the accumulating capacity of the examined species is impeded by the complex dynamics of the elements. Only for potassium and magnesium the accumulation followed the order: ash>silver-leaf lime-tree> birch>small-leaf lime-tree> Norway maple>red oak> horse chestnut.

From the other comparisons it became clear that birch accumulated the greatest amount of manganese, lead, cadmium and zinc; silver-leaf lime-tree – accumulates most iron; red oak – sodium and Norway maple – calcium. These results showed the necessity of additional measurement in order to be able to clarify the regularities in accumulation capacity of the different species and the factors that determine it.

The data from the leaf analyses of the tree species in the city part of the Sofia green system were compared with those from leaf analyses of deciduous species from the zone outside the city – the south slopes of the Balkan mountain (the region of the town "Elin Pelin"), Vitosha mountain ("Vladaya" quarter), Lyulin mountain ("Bonsovi polyani" meadows), and Lyulin mountain ("Malo Buchino" village) (Table 13). The quantitative presence of the elements is followed a more defined ordering:

Ca > K > Mg > Mn > Fe > Zn > Pb > Cu > Cd.

Compared to the previous, there was more manganese than iron and lead, and more of these elements than copper. The maximum measured quantities of calcium and potassium were about two fold lower than in the leaves of the some species from the city, magnesium is with smaller difference (about ¼ less than in the city), while manganese is with considerable concentrations compared to the city. The maximum values of iron, copper, zinc, lead and cadmium were 2-3 to 5 fold lower than in the city. Compared to MAC, the data showed that all measured values of K, Ca, Mg, Cu were within the norm. Iron was above the MAC only in the leaves of the Hungarian oak from the "Vladaya" quarter and zinc in the beech leaves from the region of the town Elin Pelin. Manganese, lead and cadmium were considerably above the allowable concentrations in all the samples. It is obvious that the tree vegetation outside the city developed under better ecological conditions. It is not possible, however, to assume that there is no environmental pollution here. Two questions arise here and can be solved through longer research and monitoring of the parameters of the forest ecosystems: What are the background quantities of the studied elements in the plant tissues? and What is the background (for Bulgaria) presence of these elements in the atmosphere as well as what are the possibilities and the tendencies for pollution through long-distance transfer?

Physiological reactions of the trees to air pollution

Photosynthesis activity has been shown to decrease under the influence of photo toxins (Ilkun, 1971; Kondratyuk, Tarabrin, 1980; Smith, 1981). Our research on determining the impact of the industrial and town pollution on the quantities of the main components of the pigment complex (chlorophyll A, chlorophyll B and carotenoids) were focused on four tree species: birch (*B. pendula*), American ash (*Fr. americana* L.), American red oak (*Q. rubra*) and *Eleagnus angustifolia*. Sampling sites with different degree of pollution were chosen at the region of "Kremikovtsi" metallurgic plant and as a reference, plant materials from the park of FRI were used. Chlorophyll was extracted with 80 % acetone from fresh material. Its quantity was determined colorimetrically by UV-VIS spectrophotometer. The results showed changes in chlorophyll induced both by climatic factors, such as sampling time, and by the level of environmental pollution.

Eleagnus angustifolia, Red oak and American ash showed similar reactions to a certain degree. The amounts of chlorophyll A and B were the highest during June in the leaves both in the control and in the "Kremikovtsi" park. The amounts gradually decrease from June to September. The ratio of chlorophyll A to B was highest during June and July, which shows that during the period of active growth, chlorophyll A is formed faster. The ratio was greatest for red oak (1:3.4 – 1:4) and birch (1:3.6) that can be related to a certain degree with their heliophylous nature. According to Kondratyuk, and Tarabrin (1980), together with leaf ageing, the amount of chlorophyll decreases, and the change in ratio between chlorophyll A to B is due to faster decomposition of chlorophyll A. Our results showed a complex situation in this respect. The amount of chlorophyll A changed faster than chlorophyll B, together with leaf ageing. However, when a comparison was drawn between the amounts sampled at one time but from sites with different degrees of pollution, there was a tendency that, during the active photosynthesis periods, chlorophyll B was more susceptible to pollution.

Birch proved to be rather sensitive to pollution. This is probably because of its lower resistance that was also represented in visible signs of damages. In June and September the highest values of chlorophyll A and B and of carotenoids were analysed in the leaves from the most polluted site "Koksochyma", "Kremikovtsi".

The dynamics of carotenoids is multidirectional and does not allow us to draw reliable conclusions. The results reviewed relate to leaves without visible damage when the negative processes are reversible. The analysis of necrotic leaves, which for birch appear already in July, and for ash and red oak in August – September, proved the intensive decomposition of chlorophyll A and B and carotenoids. In closing, environmental pollution affects the photosynthesis activity, and hence the health of trees. The results depend both on the levels of pollution and on the resistance of the particular species. The arguments of some authors that the ratio between chlorophyll A and B could be an indicator for early diagnosis of air pollution, were not supported in our study.

Phenological observations

Phenological observations were performed on the main tree species in the parks of FRI, "Borisova gradina" and "Doktorska gradina". The impact of automobile traffic is the greatest over the territory of the city. It mainly damages tree vegetation used for landscaping of the streets and boulevards. The tolerance of tree species to traffic pollution in urban environments were determined by studying the condition of the main tree species, used for the landscaping of some roads in Sofia with the highest traffic use – crossroad "Orlov most", the boulevards "Tsar Osvoboditel", "Tsarigradsko Chaussee", "Slivnitsa", "Bulgaria", "Stamboliiski" and 29 streets and adjacent yards, small parks and squares in the "Serdika" municipality. The research included, determining the visible damages and morphological changes on the above ground parts of the trees and changes in the radial increment of the trees growing along and aside the roads with heavy traffic. The study was performed for 2 years, during the spring when phenological phases change very fast; the observations were made every three days, during the summer and autumn – every 5-6 days, and during the winter period every 15 days. It was shown that, in park environments, the condition of tree vegetation was good. Especially the ash, oak, Norway maple, *Sophora japonica*, and lime trees showed good development. In the parks of the FRI and "Borisova gradina", frost damage was registered on the leaves of sequoia (*Sequoiadendron giganteum* (Lindl) Buchhotls), cedars (*Cedrus atlantica*, Manetti), cryptmeria (*Cryptomeria japonica* D.Don), *Laurfcerasus officinalis* Roem and *Viburnum rhytidohillum* Hemsl, but during summer, these plants regained their normal status. In *Platanus acerifolia*, top dieback and leaf spots caused by the fungus *Gnomonia veneta* were registered. On the leaves of horse chestnut there were serious damages from the mining mole and the fungus *Guignardia aesculi* in both years. There were serious damages in the development and duration of some of the phenophases observed for tree species growing in highly polluted environment. The necrosis and burn damages are a recent phenomenon together with atypical colouring, premature leaf shedding, secondary leaf development and blossoming. Such phenomena were especially typical for the horse chestnut, lime trees and birch that are not tolerant to traffic polluting environments. Norway maple and common locust were in a better condition, chlorosis and necrotic spots on the leaves appeared but the crowns remained in full foliage until autumn. Up to now, red oak and ash that are in a relatively good condition, are comparatively tolerant to highly polluted urban environments without any visible damages. Age is of considerable importance for the condition of tree vegetation. It is worth noting that the trees planted 30-40 years ago were in better condition compared to younger alley and internal quarter plantations. One of the reasons is possibly more favourable environmental conditions in the past that helped and strengthened their growth and development and with age increased their resistance capacity. This shows that when landscaping the streets of the new quarters, besides using species with a relative tolerance to urban environment, it is necessary to take special care of the young seedlings until they mature and adapt. Some of the species studied, such as the silver-leaf lime tree, and to a certain degree the small-leafed lime tree and birch are shown by some authors (Dessler, 1981) to be tolerant to urban pollution. Our research showed that when used for landscaping of streets and crossroads with heavy traffic, these species showed serious damages on the aboveground organs, which is most probably a result of the complex impact of many ecological factors, including the long-lasting droughts during certain years. The negative impact of traffic is supplemented to a great extent by the fact that road cover is composed of asphalt, basalt and other layers. This worsens the growth conditions and normal functioning of the root system, hence of the whole plant. This is, to a certain extent, the explanation for the fact that some species growing along streets heavilly loaded by traffic and nearby main crossroads (but with streets covered by paves and less consolidated and narrow sidewalks, thereby characterized by better soil conditions and a greater capacity for the root system to reach the adjacent areas) have considerably better habitus. A typical example of this is the horse chestnut trees nearby the crossroad "Orlov most" and neighbouring small streets. A greater part of the foliage dry in midsummer (July – August) while the latter remain almost until the period of natural leaf shedding (second half of September – October).

Measurements of the radial increment of horse chestnut trees growing along "Tsar Osvoboditel" boulevard. and in park "Borisova gradina" showed that after planting (~ 1918) until 1959 the increment of the trees along the boulevard is greater than the trees in the garden. After 1959 the increment of the trees in park "Borisova gradina" remains constant while that of the trees along the boulevard decreased continuously and around 1983 is threefold lower than that of the park trees. Perhaps one of the main reasons for this is the abrupt and permanent increase of the automobile traffic along the boulevard and the consequent worsening of environmental conditions. Considerable dust pollution was observed on the leaf surface of the trees growing nearby the crossroad. The heavy metals content of the dust and especially lead, zinc, cobalt, cadmium, and nickel has increased. This is one more proof of the unfavourable impact of traffic pollution on tree vegetation. Depending on traffic load, the studied species exhibited different degrees of damage and may be grouped as follows:

A) trees along streets and crossroads with heavy traffic

In very bad condition – *Acer negundo*, *Aesculus hippocastanum*, *Tilia* sp. and *Platanus acerifolia*

In bad condition (with considerable damage) – *Betula pendula*, *Robinia pseudoacacia*, *Acer pseudoplatanus*

In good condition (with little damage) – *Gleditsia triacanthos*, *Populus* sp. *Fraxinus* sp., *Acer saccharinum, Acer platanoides* (sphere form)

In very good condition – *Ailanthus altissima, Quercus rubra*

B) trees growing along small streets and aside

In bad condition – *Acer negundo, Platanus acerifolia, Betula pendula*

In good condition – *Fraxinus* sp., *Acer pseudoplatanus, Robinia pseudoacacia, Catalpa bignonioides, Populus* sp., *Tilia* sp., *Aesculus hippocastanum*

In very good condition –*Ailanthus altissima, Sophora japonica, Gleditsia triacanthos, Acer platanoides, Celtis australis*

In the conditions of anthropogenically influenced environment at the territory of the FRI, the bulk of the existing tree species was studied. Among these, in very good condition are:

Coniferous: *Abies concolor* (Gord et Glend) Lindl., *Picea pungens* Engelm., *Sequoiadendron giganteum* (Lindl) Buchh., *Cedrus atlantica* (Endl) Manetti, *Chamaecyparis Lawsoniana* Parl., *Juniperus sabina* L., *Thuia occidentalis* L.

Deciduous: *Quercus* sp., *Acer campestre* L., *A.saccharinum* L., *Fraxinus* sp. and many shrubs.

Satisfactory is the condition of: *Pinus ponderosa* Dougl., *P. sylvestris* L., *P. nigra* Arn., *Phelodendron amurense* Rupr., *Alnus* sp., *Catalpa bignonioides* Walt., *Acer platanoides* L., *Tilia tomentosa* Moench. and many shrubs.

In bad condition are: *Aesculus hippocastanum* L., *Betula pendula* Roth, *Tilia cordata* Mill, *Platanus acerifolis* Willd, which are characterized by leaf discolouration and dying already in August. Besides the anthropogenic impacts, the reasons for this fact could be summer drought, development of the Ascomycetes fungus *Uignardia aesculi* on horse chestnut leaves and the abovementioned diseases on *Platanus acerifolia*.

CONCLUSIONS

The tree and shrub vegetation of the green system of Sofia is subjected to permanent negative impacts – both from air pollution and precipitation (e.g. acid rain). The main pollutants are SO_2, NO_2, H_2S and dust in the ambient air, pH of the precipitation and their chemical loads. Pollution is greatest in the central city park, where average annual concentrations of the emission components reached 2-3 fold amounts above the maximum allowable concentrations. The amounts of the toxins decreased more slowly to the North and West and faster to the South and southwest.

The quantities of the analysed heavy metals in dust depositions were at toxic levels for the vegetation and this is one of the main reasons for the worsened health condition of the tree vegetation in the central city park, and mostly of the tree species situated close to heavy traffic roads.

Tree species have a cumulative capacity for heavy metals, mainly lead. This requires a more precise selection of species with greater tolerance for bad ecological conditions for landscaping of the central city part and the roads. The interaction between air pollution and tree vegetation, studied by the accumulation of chemical elements in the species examined, is expressed in the different accumulative capacities of the particular species and the amounts of the elements in the ambient air. There was a correlative relationship between the amount of the particular elements in dust pollution and their values in the leaves of the tree species. The concentrations of lead, cadmium and iron were the greatest. The ranking of the accumulated elements by their quantitative availability showed three situations where the sequence of the normal quantities (in undisturbed environment) was disturbed by the mobility of sodium, zinc and manganese, by the greater quantities of iron and the permanent change of the placements of lead and copper. Because of the high level of lead pollution, its amount was always greater than that of copper. The tree vegetation in the outer part of the city green system developed under considerably more favourable ecological conditions. The accumulated amounts of most of the analysed elements were within the norm. The allowable concentrations of manganese, lead and cadmium were exceeded in some occasions. The questions "what are the natural (background) quantities of the studied elements in the vegetation tissues?" and "what is the background (for Bulgaria) concentration of these elements in the ambient air?" stay open together with the capabilities for long distance pollution.

The environmental pollution plays an active role in the photosynthesis, and therefore the health condition of the tree vegetation. The impacts depend both on the pollution level and the resistance of the particular species. The argument of some researchers that the ratio of chlorophyll A to chlorophyll B could be an index for early diagnostic of the air pollution impact was not confirmed.

The condition of the tree vegetation in the parks and suburban city areas was good. There were severe disturbances in the development and duration of some phenophases of the tree species growing in the highly polluted environment of the central city part. Common problems for these species include chlorosis, leaf necrosis, leaf, branch and tree dieback, early leaf shedding, secondary blossoming, etc. Besides pollution, climatic factors have a definite impact on the conditions of the tree vegetation together with its position nearby buildings, sidewalks, roads, etc. Tree age is also of considerable importance.

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Medicinal Plant Species and Edible Macromycetes in the City of Sofia - Dangerous for Man?

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SUMMARY

The aim of the study was to determine the concentrations of 19 macro- and microelements (N, P, K, Ca, Mg, S, Mn, Fe, Al, Na, Zn, Cu, Co, Ni, Pb, Cd, As, V, Cr) in the aboveground biomass of four medicinal plant species (*Tussilago farfara* L., *Capsella bursa-pastoris* (L.) Medic., *Taraxacum officinale* Web. and *Plantago lanceolata* L.) and in the fruiting bodies of *Agaricus arvensis* Schaeff., *Agaricus campestris* L., *Marasmius oreades* (Bolt.: Fr.) Fr., *Lepista sordida* (Schum.: Fr.) Sing. and *Bovista plumbea* Pers. : Pers., collected in the eastern and southern parts of the city of Sofia. The assessment of the accumulation of the elements (heavy metals and toxic elements) in the medicinal plant species and edible higher fungi with the recommended norms for dry vegetables and mushrooms in Bulgaria was done. Some species (especially *Plantago lanceolata* and *Capsella bursa-pastoris*) should be not used as plants for home preparations, and the mushrooms (especially *Agaricus arvensis*) should not be consumed.

KEY WORDS

Medicinal plant species, edible macromycetes, healthful Bulgarian norms, urban habitats.

INTRODUCTION

Since historical times, humans have used plants to treat different kinds of illnesses. Nowadays medicinal plants have a continuously great importance in the healthcare of mankind. In the review of Zimmer (2002), the criteria for the quality assessment of the medicinal plants, including the content of the active substances and possible micro-organism infestation, pesticide and heavy metal contamination, were discussed. Schilcher (1994) and Kabelitz (1998) published data on the maximum amount of some heavy metals in various medicinal plants. A review of the wild

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 249-256

medicinal plant resources in Bulgaria and some recommendations for their development was published by Hardalova *et al.* (1998). Unfortunately, no recommended levels of contaminants (including heavy metals) in the medicinal plants are accepted in our country. With respect to inorganic elements as contaminants in various medicinal plant species, some data were published in Djingova & Kuleff (1986), Kabata-Pendias & Dudka (1991), Simon *et al.* (1996), Aksoy *et al.* (1999), Czarnowska & Milewska (2000), Kugonič & Rode (2000) and others.

According to Drumeva-Dimcheva & Gyosheva-Bogoeva (1998), higher fungi such as *Agaricus arvensis*, *A campestris* and *Marasmius oreades* are from category 1 (edible fungi, bearing fruiting bodies annually and frequently), and are collected on a large scale, while *Bovista plumbea* and *Lepista sordida* belong to category 4 (edible fungi, bearing fruiting bodies annually and frequently), but are not collected on a large scale (unfamiliar or not so delicious). The health norms for permissible content of chemical and biological pollutants in the food (incl. mushrooms) were published in REGULATION 5 (1984). The accumulation capacity of various mushrooms species for heavy metals were discussed by Byrne *et al.* (1976), Seeger (1978), Minagawa *et al.* (1980), Brunnert & Zadražil (1985), Zurera *et al.* (1986), Schüepp *et al.* (1987), Markert & Steinbeck (1988), Kojo & Lodenius (1989), Kovács (1992), Mejstžik & Lepšova (1993), Wondratschek & Röder (1993), Fakirova *et al.* (1996), Yurukova & Fakirova (1996), Yurukova *et al.* (1997), Thomet *et al.* (1999), and Kalač & Svoboda (2000).

MATERIAL AND METHODS

The subject of the study were the widely distributed (in the parts of the city of Sofia eastern and southern part) medicinal plant species *Tussilago farfara* L. (Coltsfoot, House weed), *Capsella bursa-pastoris* (L.) Medic. (Shepherd's purse), *Taraxacum officinale* Web. (Common dandelion) and *Plantago lanceolata* L. (Ribwort plantain), as well as the edible higher fungi *Agaricus arvensis* Schaeff. (House mushroom), *Agaricus campestris* L. (True mushroom), *Marasmius oreades* (Bolt.: Fr.) Fr. (Scotch bonnet), *Lepista sordida* (Schum.: Fr.) Sing. and *Bovista plumbea* Pers.: Pers. (Grey puff-ball). The main sampling period was during the periods April-June in 1998-1999.

About 1.5 g of the powdered and dried (at 80°C for 48 hours) material of the aboveground biomass of the vascular plant species or the whole fruiting bodies of the macromycetes was treated with 15 ml nitric acid overnight. The wet-ashed procedure continued with heating on a water bath, followed by adding 2 ml of hydrogen peroxide. This treatment was repeated until complete digestion. The filtrate was diluted with double-distilled water to 50 ml. The 18 elements (P, K, Ca, Mg, S, Mn, Fe, Al, Na, Zn, Cu, Co, Ni, Pb, Cd, As, V, Cr) were analyzed using inductively coupled plasma (ICP) with atomic emission spectrometry (AES) with a SPECTROFLAME instrument. Total nitrogen was determined by the Kjeldahl method (H_2SO_4+H_2O_2). Parallel soil samples were air-dried and crushed to pass through a 2-mm sieve. Weighed samples of about 2 g were treated with a mixture of nitric and perchloric acid (3:1) on a hot sand bath at 90°C to near dryness, after cooling followed by treatment with 10% HCl on a water bath for one hour. The solution was filtered and then diluted to 50 ml with double-distilled water. The ICP-AES method, described above, was used for macro- and microelements.

All samples were analyzed in triplicate. The deviation between the parallel methods was usually less than 5%. Blanks and standard Merck solutions were used. The accuracy was checked through analyzing soil standard reference material CRM 142 R (light sandy soil) and plant reference material CRM 281 (Rye grass). The results of ICP-AES analysis were in good agreement with certified values (RSD < 5%). The concentrations are presented in mg/kg dry weight.

RESULTS AND DISCUSSION

The content of 18 macro- and microelements in the aboveground phytomass of the four medicinal plant species (*Tussilago farfara*, *Capsella bursa-pastoris*, *Taraxacum officinale, Plantago lanceolata*) and five macromycetes (*Agaricus campestris*, *Agaricus arvensis, Marasmius oreades*, *Lepista sordida, Bovista plumbea*) is presented in Table 1. Some values of the elements Co, Ni, As and Cr were below detection limits, 0.2, 0.2, 0.6 and 1.5 mg/kg respectively.

The macroelements N, P and K were in descending order of: *Tussilago farfara>Capsella bursa-pastoris>Taraxacum officinale>Plantago lanceolata,* calcium and cadmiun were decreasing in the following order: *Capsella bursa-pastoris> Plantago lanceolata> Taraxacum officinale> Tussilago farfara,* whereas manganese and cobalts, and aluminium and nickel had the greatest accumulation in *Plantago lanceolata.* The ranges of elements found were Na (14 times), Pb (9 times), Mn and Fe (7 times), K (6 times), Al and Co (5 times). Some of the studied medicinal plant species (*Taraxacum officinale* and *Plantago lanceolata*) were quite different with respect of the position of magnesium. The heavy metals manganese and lead have increased values in *Tussilago farfara<Capsella bursa-pastoris<Taraxacum officinale<Plantago lanceolata.*

According to data from Czarnowska & Milewska (2000) for *Taraxacum officinale* grown in Warsaw (Poland), the results in this study are close to the higher limits of copper, whereas the elements Mn and Zn are in the lower ranges, but lead and cadmium are twice as low. As regards to *Capsella bursa-pastoris*, the found values for Zn are 3-fold higher, and one order of magnitude less for Cd (Aksoy *et al.,* 1999).

With respect to the descending order of the macro- and microelements in the edible mushrooms (Table 1), iron and aluminium followed the following order: *Agaricus campestris> Agaricus arvensis>Marasmius oreades>Bovista plumbea>Lepista sordida.* Lead, cadmium, sodium and manganese (6-fold), calcium and aluminium (4-fold), iron and copper (3-fold) had maximum variation in the higher fungi. The elements Na, Cu, and Al had quite different position in the descending orders of the five macromycetes species.

Minimum, maximum and average concentrations of 16 elements in the four medicinal plant species, as well as 14 elements in the five edible mushrooms are shown in Figure 1. The higher values of nitrogen, phosphorous, zinc and copper, and strongly lower calcium concentrations were observed in edible mushrooms.

The concentrations of Al, Zn, Cu, Pb and Cd in the four medicinal plants, and the permissible Bulgarian norms for dry vegetables (there is no recommended content for heavy metals and toxic elements in medicinal plants in our country) are presented in Figure 2. Aluminium and lead in the aboveground phytomass of *Plantago lanceolata* and zinc and cadmium in *Capsella bursa-pastoris* had higher values compared to the norms.

Table 1. Concentrations of macro- and microelements in four medicinal plant species and five higher macromycetes (mg/kg d.w., ± SD).

Element /Species mg/kg d.w.	***Tussilago farfara***	***Capsella bursa-pastoris***	***Taraxacum officinale***	***Plantago lanceolata***	***Agaricus campestris***	***Agaricus arvensis***	***Marasmius oreades***	***Lepista sordida***	***Bovista plumbea***
N	39300 ± 1965	32600 ± 1630	29000 ± 1450	20600 ± 1030	88200 ± 4410	78900 ± 3945	60900 ± 3045	88300 ± 4415	90500 ± 4525
P	5177 ± 63	4868 ± 59	3059 ± 37	2052 ± 25	14928 ± 182	11697 ± 143	14294 ± 174	21573 ± 263	18088 ± 221
K	30870 ± 167	25483 ± 138	23031 ± 124	5512 ± 30	46159 ± 249	39201 ± 212	28527 ± 154	47077 ± 254	28084 ± 152
Ca	5955 ± 271	16480 ± 750	9370 ± 426	14944 ± 680	474 ± 22	889 ± 40	438 ± 20	563 ± 26	231 ± 11
S	4112 ± 42	4754 ± 48	2710 ± 27	1776 ± 18	6084 ± 61	5382 ± 54	9152 ± 92	4341 ± 44	5730 ± 58
Na	252 ± 1	350 ± 2	2028 ± 10	142 ± 1	45 ± 0.2	56 ± 0.3	96 ± 0.5	277 ± 1	137 ± 0.7
Mg	2358 ± 21	1845 ± 17	3403 ± 31	1606 ± 15	1632 ± 15	1211 ± 11	1166 ± 11	1611 ± 15	1619 ± 15
Mn	13 ± 0.04	31 ± 0.1	35 ± 0.1	97 ± 0.3	19 ± 0.1	20 ± 0.1	75 ± 0.2	32 ± 0.1	13 ± 0.04
Fe	301 ± 3	245 ± 2	622 ± 6	1679 ± 17	273 ± 3	215 ± 2	174 ± 2	105 ± 1	158 ± 2
Al	368 ± 5	295 ± 4	338 ± 4	1539 ± 20	174 ± 2	157 ± 2	141 ± 2	41 ± 0.5	62 ± 0.8
Zn	33 ± 0.3	86 ± 1	39 ± 0.4	35 ± 0.3	105 ± 1	105 ± 1	118 ± 1	157 ± 1	123 ± 1
Cu	18 ± 0.5	8.9 ± 0.2	14 ± 0.4	9.7 ± 0.2	216 ± 6	165 ± 4	68 ± 2	65 ± 2	69 ± 2
Pb	1.8 ± 0.4	4.8 ± 1.0	4.2 ± 0.8	16 ± 3	1.2 ± 0.2	7.0 ± 1	3.6 ± 0.7	3.1 ± 0.6	6.2 ± 1
V	1.7 ± 0.01	1.8 ± 0.01	2.4 ± 0.01	6.9 ± 0.04	n.a	n.a	n.a	n.a	n.a
Cd	0.26 ± 0.06	0.99 ± 0.24	0.39 ± 0.09	0.49 ± 0.12	0.89 ± 0.21	1.3 ± 0.3	0.21 ± 0.05	1.3 ± 0.3	1.0 ± 0.2
Co	0.30 ± 0.03	0.38 ± 0.04	0.44 ± 0.05	1.4 ± 0.1	<0.2	<0.2	<0.2	<0.2	<0.2
Ni	2.4 ± 0.4	1.5 ± 0.2	1.8 ± 0.3	4.6 ± 0.7	1.6 ± 0.3	1.9 ± 0.3	<0.2	0.89 ± 0.14	<0.2
As	0.91 ± 0.22	<0.6	<0.6	<0.6	1.4 ± 0.3	3.1 ± 0.8	<0.6	0.90 ± 0.22	<0.6
Cr	<1.5	<1.5	<1.5	1.9 ± 0.4	n.a	n.a.	<1.5	n.a.	<1.5

n.a. - not analyzed

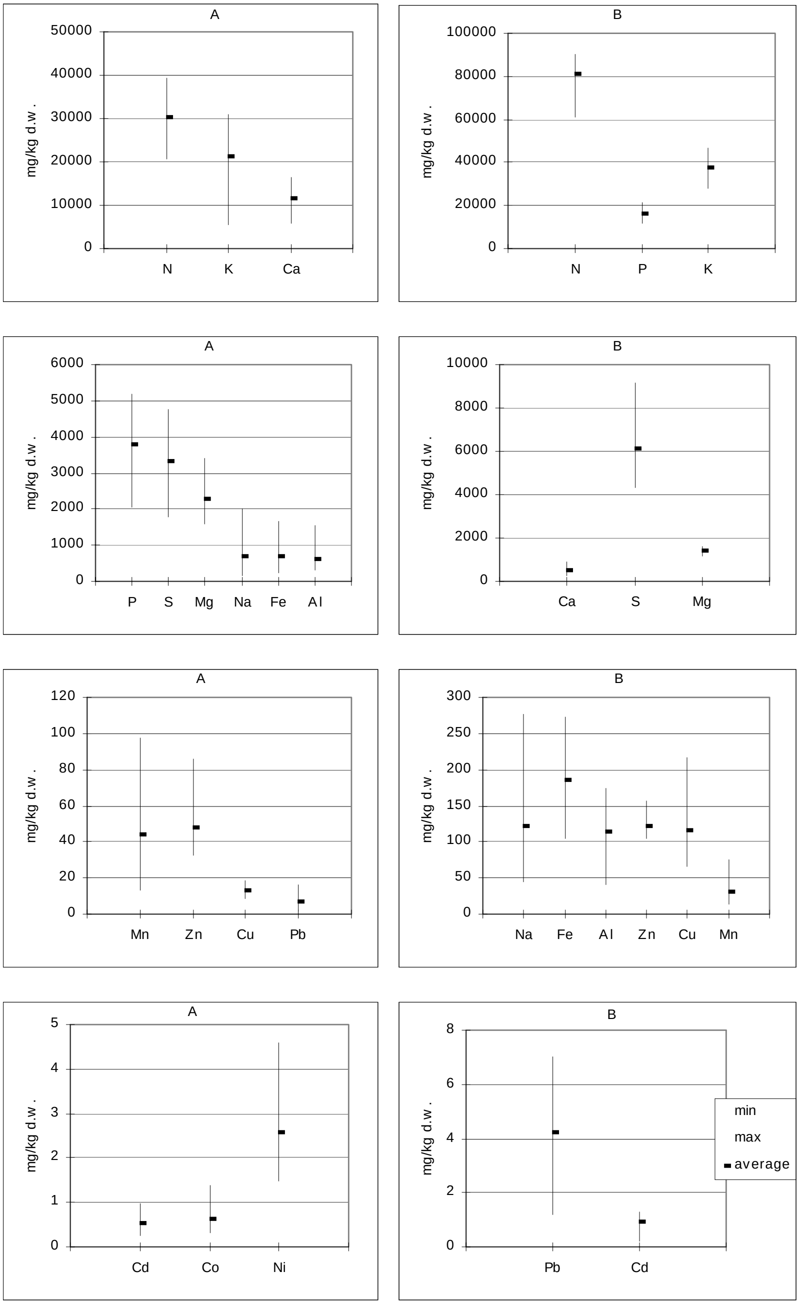

Figure 1. Minimum, average and maximum values of the 16 elements in four medicinal plants (A) and 14 elements in five higher fungi species (B) from the city of Sofia, mg/kg dry weight.

The health norms for permissible content of As, Zn, Cu, Pb and Cd in edible mushrooms in Bulgaria and analyzed average values in the five species sampled in the city of Sofia are shown in Figure 3. *Agaricus arvensis* fruiting bodies accumulated Pb, Cu and Cd, *Lepista sordida* – Zn and Cd, *Bovista plumbea* – Zn and Pb above the norms. The permissible content of copper was also exceeded in *Agaricus campestris*.

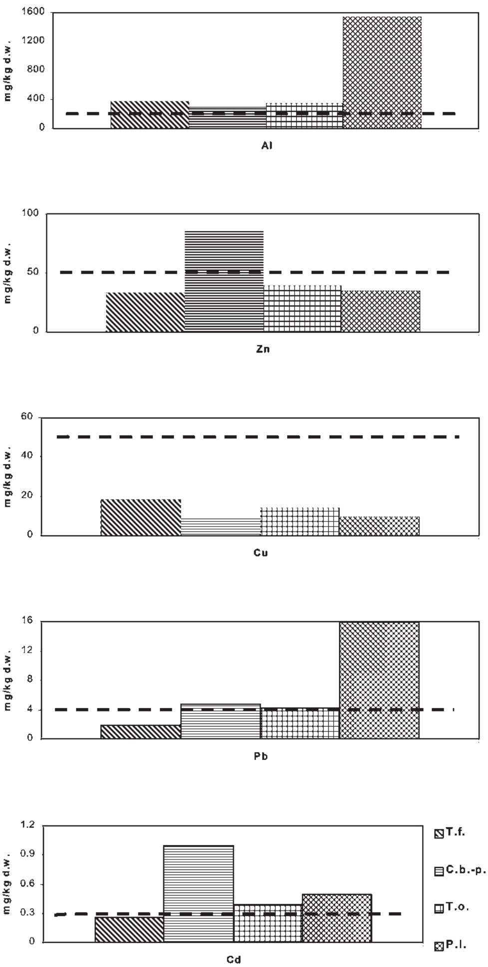

Figure 2. Average concentrations of Al, Zn, Cu, Pb, and Cd in *Tussilago farfara* (T.f.), *Capsella bursa-pastoris* (C.b.-p.), *Taraxacum officinale* (T.o.), and *Plantago lanceolata* (P.l.) and the Bulgarian health norms for permissible content of these elements (- - - -) in dry vegetables, mg/kg dry weight.

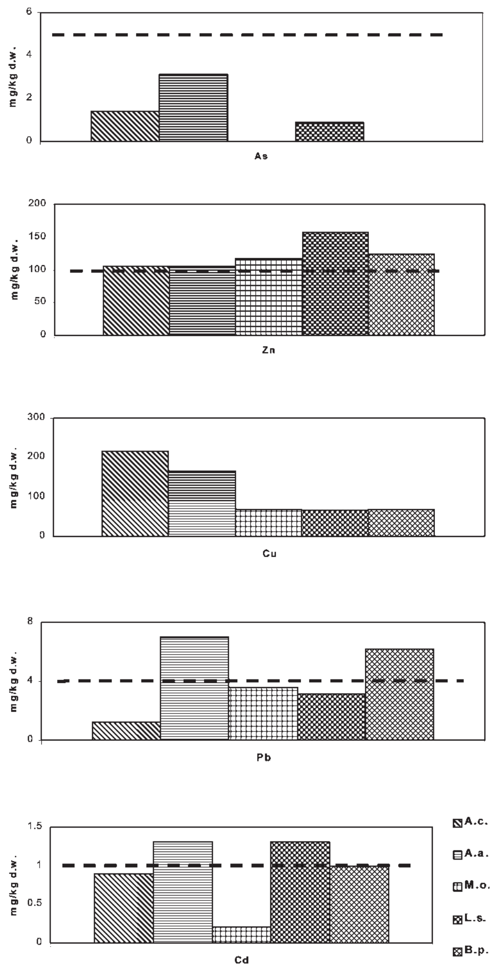

Figure 3. Average concentrations of As, Zn, Cu, Pb, and Cd in *Agaricus campestris* (A.c.), *Agaricus arvensis* (A.a.), *Marasmius oreades* (M.o.), *Lepista sordida* (L.s.), *Bovista plumbea* (B.p.) and the Bulgarian health norms for permissible content of these elements (- - - -) in dry mushrooms, mg/kg dry weight.

Data of the correlation matrix for 16 elements in the four medicinal plants studied, showed 21 positive and 14 negative correlations with different level of reliability ($p<0.05$, $p<0.01$, $p<0.001$). The main biogenic elements N, K and P correlated positively with one another, whereas these elements correlated negatively with some of the heavy metals. Positive correlations were shown for 2 groups of elements: Mg, Fe, Al, Pb and Co, Co, Ni. The elements Na, Mg and Cu correlated only with one other element.

A lower number of correlations were found in the accumulated elements in mushrooms: 8 positive and 9 negative significant relationships. The groups of P, Na, Zn and Fe, Al, Cu correlated positively. Calcium and potassium had no significant correlations with other macro- and microelements, while magnesium correlated positivly with nitrogen.

No statistically significant correlations were shown between inorganic element content in the studied medicinal plants and/or higher fungi and the concentrations in the surface soil layers.

ACKNOWLEDGEMENTS

I would like to thank my colleagues Rositsa Andreeva for her lab work with sample preparation before ICP-AES analysis, and Maria Paneva for help with the presentation of the results in the figures. Special thanks are due to Dr. D.J. Kotze and Dr. Lyubomir Penev for final editing of the manuscript.

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Pathological and Entomological Problems of Trees in the Sofia City Green System

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Summary

The species composition and the impact of disease agents and insect pests on the health condition of trees used for planting along streets, in parks and the suburban area of Sofia city were studied. The research included the most widely used tree species: *Aesculus hyppocastanum* L., *Platanus acerifolia* (Ait.) Willd., *P. orientalis* L., *P. occidentalis* L., *Fraxinus exelsior* L., *Fr. oxycarpa* Willd., *Quercus cerris* L., *Q. robur* L., *Q. rubra* L., *Populus pyramidalis* Roz., *P. deltoides* Marsh., *P. tremula* L., *Fagus silvatica* L., *Robinia pseudoacacia* L., *Betula alba* Schmalh., *Pinus nigra* Arn., *P. sylvestris* L., *Picea abies* Karst., *P. pungens* Engelm., *Larix europaea* Mill. and *Pseudotsuga menziesii* (Mirb.) Franco.

In the central area, in the park zone and in the plantations in the outskirts of the city, the influence and damages by pathogens and insects were quite different – some are slightly expressed, others have chronic development.

Insect pests were a real accelerator of pathological processes for tree species growing under unfavorable ecological conditions in the urban environment, and this is especially true for those species not in their natural range.

The tree vegetation in and around big cities needs more care and protection against mechanical and other impacts so that it could maintain its decorative, shelter and other functions.

Key words

Diseases of ornamental trees, insect pests, green system, Sofia, Bulgaria.

INTRODUCTION

The green system of Sofia is a major element of the city's structure that creates better ecological conditions for the existence and diversity of life for the citizens. The health of the vegetation

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 257-268

is an indicator of the condition of the natural environment in the capital and for the levels of pollution.

The vegetation inside and around the big city is influenced by many factors of abiotic and biotic origin. Most often the abiotic factors, such as drought, frost, salinization, soil compactness, human activity and others, create conditions for the physiological weakening and worsening of the trees and shrubs, even causing its dieback. As a result, suitable conditions are created for the development of pathogenic fungi that assist the acceleration of the negative processes, such as tree top dieback, untimely pathological changes in the foliage colour, defoliation, and the death of the whole tree. Conditions are created for greater damages by insect pests that may cause defoliation, leaf and branch dieback, and damage to the bark and wood.

In the region of Sofia, partial studies of the health of tree vegetation and the factors determining it have been carried out by Georgiev & Delkov (1997), Georgiev & Velcheva (1999), Georgiev & Beshkov (2000), Ovcharov & Andonova (1993), and Pelov *et al.* (1993).

The aim of this study is to determine the health state of the tree vegetation used in street and park landscaping in the Sofia outskirt zone, to identify the major pathological causes and illness agents, insect pests, and the disturbencies in their development.

MATERIAL AND METHODS

The study objects were the most commonly used tree species in the landscaping practice of Sofia. Individual trees surveyed include those in the landscaping of streets, boulevards and interstitial areas of the Sofia central part, parks and forest-park regions from the Borisova gradina park, South and West park and the arboretum of the Forest Research institute, and the suburban areas including the plantations along the northern slopes of the Vitosha, Ljulin and Plana mountains. All these sites containing forest vegetation are very interesting because they are subjected to intense abiotic effects such as air pollution, recreational load, etc., as well as to considerable biotic damages mainly by pathogens and insects.

The research method applied for studying the damages are routine phytopathological and entomological ones: macroscopic observation of individual trees and damages on them; sample plots for quantitative and qualitative assessment of the degree of damage and description of some morphological and biological peculiarities and ecological impacts; comparative morphological analysis of the results from gathered sample material, fruit bodies on leaves, branches, bark, and the damage caused by insects at different development phase.

Laboratory macroscopic methods were also applied using wet cameras, and the breeding of insects to determine the type of pathogens and insects causing the respective damages.

RESULTS AND DISCUSSION

The condition, development and damage on the tree species in the three studied zones (the central city zone, the park zone and the suburban area) varied considerably. Some of the trees in the central city zone were in a very bad condition. These were, for example *Aesculus hyppocastanum*

L. and *Platanus acerifolia* (Ait.) Willd. Others were in a satisfactory condtion, such as *Fraxinus* sp., *Betula alba* Schmalh., *Populus* sp. and *Tillia* sp., some were in comparatively good condition, *i.e. Acer platanoides* L. and *Quercus rubra* L.

The abovementioned species are of different growth and development in the park zones and the suburban area, but the manifestation of some pathogens and insect pests showed typical symptoms of negative impacts on the vegetation.

The most important damage from pathogens and insect pests, and their importance, are presented in Table 1. The particular problems caused to different tree species are discussed below.

Table 1. Tree species and importance of the fungi.

Tree species, fungi	Type of Damage	Damaged organs	Importance in region		
			Central city zone	Park zone	Suburban area
Aesculus hippocastanum					
Guignardia aesculi	Spots	leaves	+++	+++	+
Fagus silvatica					
Nectria ditissima	Canker	branches	-	-	++
Nectria galligena	Necrosis	bark,branches	-	-	++
Fomes fomentarius	Rot	stem	-	-	++
***Fraxinus* sp.**					
Cytophoma pulchella	Canker	branches, stem	+	++	+
Endoxylina stellulata	Canker	bark	+	++	+
Ganoderma applanatum	Rot	stem	-	+	+
Hysterographium fraxini	Dead	branches	+	+	+
Nectria cinnabarina	Dead	branches	+	+	+
Pleorotus ostreatus	Rot	stem	-	+	+
Larix europea					
Armillaria mellea komplex	Rot	root	-	+	+
Trichoscyphela willkommii	Canker	bark, stem	-	++	+++
Picea abies					
Armillaria mellea komplex	Rot	root	-	-	++
Chrysomixa abietis	Dead	needles	-	+	++
Heterobasidion annosum	Root	stem	-	++	+
Fomitopsis pinicola	Root	stem,stump	-	+	+
Stereum abietinum	Root	stem	-	+	+
Pinus nigra					
Cenangium ferruginosum	Dead	bark	-	+	+
Gremmeniella abietina	Dieback	shoots	-	+	++
Lophodermium seditiosum	needle cast	needles	-	+	+
Pinus peuce					
Heterobasidion annosum	Root	rot	-	-	++
Pinus silvestris					
Armillaria mellea komplex	Root	rot	-	+	++
Heterobasidion annosum	Root	rot	-	+	++

Table 1. Continued.

Tree species, fungi	Type of Damage	Damaged organs	Importance in region		
			Central city zone	Park zone	Suburban area
Lophodermium pinastri	needle cast	needles	-	++	++
Sclerophoma pithyophila	dead	shoots, needle	-	+	+
Platanus acerifolia					
Gnomonia veneta	Antracnhosis	shoots,leaves	+++	+++	-
Populus sp.					
Dotichiza populnea	Necrosis	shoots, stem	++	++	++
Fomes fomentarius	Root	stem	++	++	+
Ganoderma applanatum	Root	stem	+	+	+
Marsonina populi	Spots	leaves	+	+	+
Melampsora alli-populina	Rusts	leaves	+	+	+
M. larici-populina	Rusts	leaves	+	+	+
Melampsora pinitorqua	Rusts	leaves	+	+	+
Phellinus igniarius	Root	stem	++	+	+
Polyporus sulfureus	Root	stem	+	+	+
Peudotsuga menziesii					
Phomopsis pseudotsugae	Dead	stem, branches	-	++	++
Rhabdocline pseudotsugae	needle cast	needles	-	++	+
Quercus cerris					
Armillaria mellea komplex	Root	rot	-	+	+
Diplodia mutila	Necrosis	bark	-	++	+
Hypoxylon mediterraneum	Necrosis	bark	-	++	+
Microsphaera alphitoides	Mildew	leaves, shoots	-	+	+
Quercus robur					
Armillaria mellea komplex	Root	rot	-	+	+
Bjercandera adusta	Root	stem,stump	-	+	+
Ceratocystis sp.	Dead	branches	-	++	+
Daedalea quercina	Root	stem, stump	-	+	+
Ganoderma lucidum	Root	stump	-	+	+
Leatiporus sulfureus	Root	stem	-	+	+
Quercus rubra					
Pezicula cinnamomea	Canker	stem	+	++	+
Schizophilum commune	Root	branches	-	+	+

***Aesculus hyppocastanum* L.** (horse chestnut). This species is widely used for planting along streets, boulevards, in residential areas in Sofia and as park alley tree. The trees are severely damaged by the pollution from automobile traffic. Gradually, during the last 10 years a great number of the horse chestnut trees along the boulevards with heavy traffic have perished. First, the leaves are damaged, and they develop necroses and shed leaves at the end of May to the beginning of June. To a lesser extent the street trees and to a greater extent the park trees are damaged by the fungus *Guignardia aesculi* Stewart. During early spring, after the formation of leaves, brown spots of different size appear on them. These spots grow fast, merge and on their surface small black dots that are the fruiting bodies of the fungus appear. The infected leaves die and shed at the end of July or the beginning of August. New spores disperse from them during the next spring. Especially favorable to the fungus are warm and humid days during spring. There is a chestnut variety that is not so severely harmed by this illness (Petkov, unpublished data) and may be used.

During the 1990's serious damages were caused to the horse chestnut by *Cameraria ohridella* Deschka et Dimic 1986 (Lepidoptera: Gracillariidae). This species was first detected in Bulgaria around Sofia in 1989 (Pelov *et al.*, 1993) and gradually became the most important insect pest on the leaves of horse chestnut. Studies revealed that the trees in the parks were more severely affected than those used for landscaping along the streets. On average, 204 mines were counted per leaf in July on park trees which caused total damage to the leaf lamina (Tsankov *et al.,* 2000). The insect hibernates as a pupa in the leaf mines. This explains the higher number of the insect in parks where the leaves are not gathered and burnt during the autumn. Three generations develop per year.

***Platanus* spp.** (*P. acerifolia* (Ait.) Willd.*, P. orientalis* L.*, P. occidentalis* L.) (plane tree). The plane tree varieties are used infrequently in the Sofia region, and mainly as alley trees along streets and squares and as single trees and groups in the park zones.

The fungus *Gnomonia platani* Kleb. *(=Gnomonia veneta* (Sacc. and Speg.) Kleb.) with anamorph *Discula platani* Sacc causes illness on the leaves and branches of the plane tree. Under favourable conditions, i.e. warm humid spring, the fungus develops acutely and causes total withering, black colouring and shedding of the leaves. Later, the illness causes brown spots distributed along the main veins of the new leaves. On the spots, underneath the leaves, aservuls are formed, filled with conidiospores. The fungus causes bark damage and cancer formations on the branches. Above the place of cancer formation the branch dies. On the dead bark, fruit bodies are formed (peritecia) from which new spores emerge and disperse during the next spring. Peritecia are also formed on the shed leaves. The illness is wide-spread and causes a decrease in tree growth and dieback of the thin branches, thereby reducing their decorating properties. This brings forth the necessity to perform sanitary activities – pruning and cutting intensively damaged trees, and gathering and burning of the shed leaves that bear fruiting bodies and spores.

Of the insect pests, only *Lithocolletis platani* Stgr. (Lepidoptera, Gracillariidae) was registered on the plane tree. The caterpillars eat the parenchyma of the leaves making mines. Damage is rather small.

Species of the genus ***Fraxinus* L.** (*Fr. exelsior* L., *Fr. oxycarpa* Willd.) are used as ornamental trees along streets in the central city part and especially for establishing mixed plantations in the forest-park areas of the Borisova gradina park, South, West and North parks. Young ash trees grow well and tolerate the air pollution under urban conditions, but after 20-25 years of age top dieback appears, and necroses and cancer are formed on the branches and the stems. The study revealed that the damages are mainly caused by the fungi *Cytophoma pulchella* (Sacc.) Gutn. and *Endoxylina stellulata* Rom. In the beginning these fungi cause spots on the stems and branches, depressions in the bark and later – longitudinal cracks and withering. These cancer formations last for many years.

Studying the ash plantation in the Borisova gradina park revealed that 51.3 % of the trees had top dieback, 23.8 % had cancer on the stem and thick branches, and 6.2% were dead. The damage was caused by the fungi *C. pulchella* and *E. stellulata.* The intense drought during 1982-2000 and environmental pollution are the prerequisites for the development of these illnesses. The wood destroying fungi *Ganoderma applanatum* (Pers. ex Wallr.) Pat, *Pleurotus ostreatus* Fr., as well as *Hyster-*

ographium fraxini de Not and *Nectria cinnabarina* (Tode.) Fr., were also found. However, *Armillaria mellea* (Fr.) Quel. was rarely found on the roots.

During the study period no considerable damages caused by insects were registered in the Sofia parks although infestations from Tenthredinidae were observed on the trees used for planting along the streets in the central city part.

An economically important insect pest in the dense forests of East Bulgaria is *Stereonychus fraxini* Deg. The ecological conditions in the city are rather different and do not provide conditions for this species to become a problem for the Sofia green system. Pencheva (1997) reported 18 phytophages in the Sofia city parks, of which the main leaf-eating insect is *Euproctis chrysorrhoea* L. The highest species diversity was observed in the well structured plantations in the parks, while on the road and alley trees the diversity is low, although numbers of individuals may be high.

Species of the genus **Quercus L.** *(Q. cerris* L., *Q. robur* L., *Q. rubra* L.) are of great significance in the forest-park and suburban city zone. The health of *Quercus*, especially that of the Cerris oak (*Q. cerris*) is becoming worse. Many water shoots form on the tree stems which is an indicator of the weakening of the tree. Wet black-brown watery spots were observed on the bark, and in the future they cause laceration of the bark and bleeding from the trunk. When a girdle is formed around the stem, the tree dies. The fungi *Diplodia mutila* (Fris) Mont. and *Hypoxilon mediterraneum* (de Not) Ces et de Not. are causing this illness. The study of the Cerris oaks in the Borisova gradina park revealed that 32.5% of the trees had water shoots, 29.6% had damages from the two fungi, and 11.3% of the trees were dead. The condition of the Cerris oaks in the Ljulin and Vitosha mountains is similar (the area Cherniya kos), and there 15-30% of the trees were damaged.

Poor health was observed for the Common oak (*Q.robur*) in the Borisova gradina park and on the Sessile oak (*Q. sessiliflora* Salisb.) in the coppice plantations of Vitosha and Ljulin mountains. 6.2% of the Common oak trees were dead, 18.8-25% showed defoliation and had dry branches. Up to 1/3 of the Sessile oak trees had dead tops. The intense drought together with the abundant development of the tracheomicose fungi from the genus *Ceratocystis (Ophistoma) - C. roboris* G. ex T. and *C. valahicum* Georg., Teod. et Bad., were the main reasons for that situation. For elder trees, one more agent - *Armillaria mellea* - was observed.

The health of red oak (*Q. rubra* L.) in both the Borisova gradina park and West park is comparatively good. Mechanical damages were registered on the stems and this is the reason for infestation with facultative parasite fungi, such as *Schizophillum commune* Fr., and *Stereum* sp., that cause wood rotting. Besides, there are cancer damages found on single trees, induced by the fungus *Pezicula cinnamomea* (DC.) Sacc.

The fungus *Microsphaera alphitoides* Griff. et Maubl. (leaf mildew) is abundant on all oak species, and it causes damage mainly on the leaves of the young growth and lower tree branches. The leaves are covered with a white floury coating from spores and mycelia, brown spots are formed and premature shedding occurs.

The saprophyte fungi *Bjercandera adusta* Karst., *Daedalea quercina* (L.) Fr., *Ganoderma lucidum* Karst., *Leatiporus sulfureus* (Bull.) Fr., and *Stereum* sp., were found on the dead branches and stems. These are of little importance for the pathological condition of the trees, but contribute to the decay and decomposition of the litter- and tree-fall.

During the current study, serious damages from leaf-eating insects were registered in the Sofia city parks. *Q. robur* was more severely affected than *Q. rubra.* The defoliation of *Q. robur* was between 25 and 50% and for some individual trees above 60%, while in neighbouring groups of *Q. rubra* it was 10-15% on average.

Leaf-eating moths of the family Geometridae have a major role as they formed 76.5% of the number of registered species. Second most abundant are representatives of the family Tortricidae – 18.8%, followed by Noctuidae – 3.1 % and Lasiocampidae – 1.6 %.

The most abundant insect species was *Operophthera brumata* L. which made up almost half (43.7%) of the leaf-eating insect pests. Second by number were *Erannis defoliaria* Cl. and *Tortrix viridana* L. with 18.7 % and 14.1 %, respectively. *Erannis aurantiaria* Hb. (9.4 %), *E. leucophaeria* Schiff. and *Cacoecia xylosteana* L. (each of 4.7 %), form the last group of registered leaf-eating insects with damages of considerable importance.

Haltica saliceti Wse. was also observed in the parks, but its number and the damage it causes are limited.

Chrysobothris affinis Fabr., found on *Q. rubra*, is a typical representative of the group of stem parasites that colonize extremely weak trees and are not very aggressive, so that there is no real danger of damage to healthy trees.

Damage caused by *Kermes roboris* Fourc., *Neuroterus numismalis* Fourc., *N. quercus-baccarum* L. and *Diplolepis quercus-folii* L. are small on *Quercus* sp.

The research showed that the acorns of the introduced species *Q. rubra,* are to a lesser extent damaged by insect pests compared to the local oak species. The analysis of 1082 acorns of *Q. cerris* and 1173 acorns of *Q. rubra,* gathered from the forest-park Borisova gradina, revealed that for *Q. cerris* 47.5% of the acorns were damaged from larvae of fruit worms and weevils, while for *Q. rubra* the percentage was only 6.4% caused by fruit worms, whereas damage from weevils was not found.

Ovcharov & Andonova (1993) reported 16 species of insect pests on the leaves of *Quercus* sp. in the parks of Sofia. They also found that the tree species most susceptible to damages is *Q.robur* and particularly its early leafing form.

Tree species of the genus ***Populus* L.** (*P. pyramidalis* Roz., *P. deltoides* Marsh., *P. tremula* L.) are extensively used in the planting practice along streets, in parks and outskirt afforestations due to their fast growth and good landscaping characteristics.

The health of the poplars is quite variable and depends on the site conditions. The illnesses of the leaves, branches and stems are of particular importance.

Mass infestation with rust fungi were observed on the leaves of *Populus* spp., caused by *Melampsora alli-populina* Kleb*., M. larici-populina* Kleb. and *Marsonina brunea* Ell. et Ev. that form small brown spots and initiate premature shedding.

Besides these, on the bark and the stems the fungus *Dothichiza populnea* Sacc. et Briard. (=*Chondroplea populea* (Sacc.) Kleb.) develops. As a result of its growth, necrotic spots are formed, the bark dies and in many cases the whole trees die. The infestation and development of this illness is related to the physiological weakening of the trees and mechanical damage.

Damage from the wood destroying fungi *Fomes fomentarius* (L.) Gill*., Ganoderma applanatum* (Pers ex Wal.) Pat., and *Polyporus sulfureus* Bull ex Fr., increase on the older trees and this reduces the firmness of the branches and stem, and make the trees susceptible to breaking from wind or snow.

The above-mentioned pathogens develop abundantly on poplars growing both along the alleys, as single trees or in groups in the parks. The poplars are comparatively resistant to traffic-polluted air but *P. pyramidalis* is very susceptible to frost damage.

P. tremula, which is distributed in the suburban regions of the Vitosha and Ljulin mountains, suffers considerably from *Melampsora pinitorqua* Rostr. and especially from *Phellinus igniarius* (Fr.) Quel., that cause core rotting of the stem wood.

The observations showed that it is not possible to differentiate between the degree of damage by insects on poplars growing along the streets and in the city parks. Damage on the leaves, buds, young shoots, stems and branches was registered. From the described 84 insect species trophically related to poplars, only some species could influence their health due to the high intensity of damage (Georgiev & Delkov, 1997; Georgiev & Velcheva, 1999; Georgiev & Beshkov, 2000). No serious defoliations were registered in the studied region. *Gypsonoma aceriana* Dup. and *Paranthrene tabaniformis* Rott. could be listed as the most serious insect pests. The primary importance of the first species is determined by its relatively high number, compared to the remaining insect species, and the character of damage this insect causes on the buds and the immature shoots. Damage from *P. tabaniformis* is irreversible and the colonized tree is under increased risk to die under the influence of abiotic factors, such as wind.

Beech (***Fagus silvatica* L.**) forms vast compact plantations in the Vitosha, Plana, Ljulin and on the southern slopes of the Balkan mountain range. These areas are mainly managed as coppice forests. The health of beech is good, but partial damage caused by snow-breaks in younger plantations was observed.

Small pathological damages were registered from *Nectria ditissima* Tul. and *Nectria galligena* Bres. which develop in the bark and cambium and thus form long standing cancers causing dieback of individual branches or stems. After stem injury, the wood destroying fungus *Fomes fomentarius* Gill. develops intensively and produces marble rot.

Rhynchaenus fagi L. is the main insect pest of the beech formations from the suburban zones of Sofia, inducing severe damage on the trees. The damage is caused mainly by the larvae (making mines) and the adults puncturing the leaf lamina during feeding.

Quantitative parameters of damage in the northern outskirt zones vary within a broad range: the holes – a result of feeding – 1.0 to 20.2 per leaf, and mines – from 0.15 to 0.92 per leaf. Total defoliation is between 1.29 and 20.02%.

Birch (***Betula alba* Schmalh.**) is a widely used species in the landscaping practice in the studied region. In general, this species is comparatively resistant and is used for planting along streets, alleys, roads and in groups of ornamental trees in parks and forest-park zones. Birch is very sensitive to direct opening to light when growing in groups of ornamental trees and plantations because of the drying of soil and habitat, and branches breaking because of snow.

The rust *Melampsoridium betulinum* Kleb. caused discoloration and premature shedding in June and July. With this illness, orange groups of uredo- and teleito- spores and rust spots are formed under the leaf. The picnidia and aecidia develop in larch needles. The fungus spends during winter in the form of teleito-spores on the shed birch leaves and from there, during spring, the basidia develop with basidio-spores that infest the needles of the larch.

Growing the two species close to each other is a prerequisite for the development of the illness and for greater damages on both larch and birch.

Damage from the wood destroying fungi: *Inonotus oblicus* (Fr.) Pil. – causing rotting of the stem wood, known as "chaga"; *Schisophillum commune* Fr. - more often on the branches and stems with mechanical injuries and *Stereum purpureum* Pers. – causing brown mixed rotting of the wood on the branches and the stems, were registered on birch in the Borisova gradina park and in the small size groups of trees in the Vitosha and Ljulin mountains.

Insect pests are not an important factor directly influencing the health of birch. However, *Byctiscus betulae* L., *Croesus septentrionalis* L. and the adults of *Phyllobius argentatus* L. during feeding cause limited damage. In the suburban area, birch is colonized by *Fenusa pusila* Lep. and during particular years damage could be considerable.

The common locust (*Robinia pseudoacacia* L.) is insignificantly affected by insect pests. Damages on the leaves were caused by *Parectora robiniella* (Clemens) (Gracillariidae: Lepidoptera). In the region of Sofia, this insect species was registered for the first time in 1991 (Trenchev *et al.*, 1993). It develops three generations per year and mines leaves of the whole crown. Colonization of individual trees was observed.

Coniferous tree species are important elements in the landscaping of Sofia, mainly as individual trees and groups of ornamental trees around blocks of flats, and as pure or mixed plantations in the park and suburban zones. The most widely used species that were studied with respect to pathological and entomological damages are from the genus *Pinus* Link.– *P. nigra* Arn., *P. sylvestris* L. and *P. peuce* Griseb.; from the genus *Picea* Diert. – *Picea abies* Karst. and *P. pungens* Eng., as well as *Larix* sp. Mill. and *Pseudotsuga menziesii* (Mirb.) Franco.

Pathological damage on *P. nigra* and *P. sylvestris* mainly affects the needles and are expressed as discoloration and premature defoliation (shedding). The reasons for that illness are the fungi: *Lophodermium seditiosum* Minter, Staley & Millar, *Loph. pinastri* Chev. and *Sclerophoma pithyophila* (Cda) Höhn. Some branches die in the lower part of the crowns due to infestation of the fungus *Cenangium ferruginosum* Fr.

More significant are the illnesses from the root pathogen *Heterobasidion annosum* (Fr.) Bref. in the Scots pine and Macedonian pine (*P. picea* G.) cultures at the northern slopes of the Vitosha mountain (around the huts Aleko, Boeritsa, Selimitsa), where as a result of root decay, the trees die and a foci of infection of dead trees with an area of 500-700 m^2 are formed. The illness is chronic because, besides spores, the fungus spreads by contact from root to root. On the affected Scots pine trees, the following fungi develop secondary: *Schizophylum commune* Fr., *Stereum* sp., *Fomitopsis pinicola* Fr., and *Pholiota adiposa* Fr. that accelerate the decay of the wood. On the damaged Macedonian pine trees the fungi *Sch. commune*, *Armillaria mellea* and *Polyporus schweinitzii* Fr. spread widely. This calls for forest protection measures to be applied, including a change in tree species under certain site conditions.

Perhaps pine, particularly *P. sylvestris*, should be regarded for landscaping, as a necessary element in the park construction, but under urban conditions, especially with respect to older trees, it is a vanishing species. This is mostly true for the Borisova gradina park, where 90% of the trees are withering or dead. The stem insect pests *Rhagium inquisitor* L. and *Monochamus galloprovincialis* Oliv. were registered and they are typical representatives of the group of species that attack weak and dying trees. Larvae of *Pissodes* sp. were also found. *Pissodes* species are characterized by increased aggressiveness and may also colonize healthy trees. *M. galloprovincialis* appears most often at the outbreak sites of the root pathogen.

Damage, caused by insect pests, was limited with the exception of reduced by extent damage by *Pineus pini* Macq., *Leucaspis loewi* Colvee and *L. pini* L.

P. abies and *P. pungens* are widely distributed. They grow on moist soils and develop shallow root system, which makes them susceptible to droughts, bogging and mechanical injuries. Spruce is susceptible to the polluted air which causes the shedding of needles and reduction of their life span.

The rust *Chrysomyxa abietis* (Wallr.) Ung. periodically grows on spruce and causes damages, resulting in red colouring of the needles (age 1 year or more) and mass shedding. As a result of this, crown transparency increases and the growth of the trees is reduced together with depreciation of their landscape qualities.

The root fungus *H. annosum* is a serious pathological problem for spruce. Rossnev's research (1986) revealed that the disease, resulting in the rotting of roots and the core of stems, is registered everywhere in Bulgaria and this damage affected 22.5% of the trees in the south Rila mountains and up to 55.9% in the west Rhodopi mountains.

The 11 plantations studied at the Vitosha mountains (location "Ofeliite", nearby Aleko Hut, etc.) show that tree damage reached 27.5%. Damage is greater on trees growing at rich and fresh sites and more limited at dry sites. Root fungus diseases were registered on spruce in Borisova gradina park (Hunting Park) and West Park. It is typical that the outer appearance of infected trees is little affected, but the growth and resistance of trees to wind and snow are considerably reduced due to rotting of the main (skeleton) roots. The infestation and dissemination of *H. annosum* and other accompanying wood destructing fungi, such as *Fomitopsis pinicola*, *Armillaria mellea*, and *Stereum abietinum* (Pers.) Fr. are directly related to the hydro-thermal indices of the environment that change with altitude and exposition. The development of the disease on individual trees is related to its particular characteristics, ecological factors and duration of pathogen development on the host. Mechanical injuries at the lower parts of stems and roots are also of special significance. At tree age of 60-80 years the rot covers 22-70% of the circular area at the base, and reaches a height of 8-10 meters.

Rot is important and can be regulated through a system of prophylactic and biological measures in younger plantations. For older trees, the mechanical injuries during silvicultural and other activities should be reduced.

Picea pungens is used solitary or in small groups in the parks. It shows good resistance to biotic and abiotic damages. Its health is good and consequently is recommended for expanded planting. The damage on *Picea* sp. are mainly divided in two groups: on needles and on stems. With respect to insect pests, there is a clear trend that the greater species composition is found on trees in the parks forming small groups, compared to individual trees growing along alleys and roads. Damages of a relatively great extent were caused by *Chermes abietis abietis* L. and *Ch. strobilobius* Kalt.

Pencheva (1993) reported eight insect pests in Sofia and seven of these are piercing-sucking from the order Homoptera and one – from the order Lepidoptera: Tortricidae. Significant damages are caused by the two most commonly observed species: *Physokermes hemicryphus* (Dalman) and *Nuculaspis abietis* Schrank (Homoptera).

In suburban areas, the stem pests are considerably harmful. Using pheromone collectors in the Vitosha mountains the ratio in abundance between the three most important pests was determined. *Ips typographus* L. was most abundant, followed by *Trypodendron lineatum* Ol. and *Pityogenes chalcographus* L. The ratio between the number of individuals of *I. typographus* and *T. lineatum* was 13:1 and between *I. typographus* and *P. chalcographus* L. 24.5:1. We also found that at some regions of the Vitosha mountains (Brocks Hut) the number of stem insect pests was almost equal to the number of insect pests at windfalls in the biosphere reserve Parangalitsa, Southwest Rila Mountains.

Larch (***Larix europaea* Mill.**) has a limited distribution in Sofia and its health is unsatisfactory. Of the trees observed in the Borisova gradina park (area of Pioner station), the arboretum of the FRI, and the plantation in the Vitosha mountains, it became clear that some trees are dead, damaged by the *Armillaria mellea* complex in the roots and the low stem. According to Tcheremissinov *et al.* (1970), larch is susceptible to damage by *H. annosum* and *Polyporus schweinitzii* Fr., but this damage was not registered in Bulgaria. On dead branches in the Vitosha plantation, there were cancer formations where the fungus *Trichoscyphella willkommii* (Hartig) Nannf. (=*Dasyscypha willkommii* (Hartig) Rehm.) was detected. This fungus is a parasite causing perennial cancer formations and dieback of branches and stems.

Of the insect pests, the most severe damage is caused by *Coleophora laricella* Hb., which is widely distributed in the parks. The insect colonizes the trees for several years and this results in their physiological decline. Although limited in scale, damage from *Chermes abietis viridis* Rarz. also caused decline.

The cultivation of larch could be more successful if its biological and ecological requirements are taken into consideration. At lower altitude, larch should be planted on fresh soils and sites.

Douglas fir (*Pseudotsuga menziesii* Mirb. Franco) is an introduced tree species in Bulgaria. In Sofia it is used as an individual tree or in groups in parks or in small plantations in the Plana, Ljulin and Vitosha mountains.

The health of the more widely used form v*iridis* is relatively good. It is very susceptible to the polluted air and low air humidity. It is rarely infested by the fungus *Rhabdocline pseudotsugae* Syd. which causes shedding of the needles. The pathogen was described by Rossnev (1978) for the region of Koprivshtitsa, Borisova gradina park (Hunting Park) and Vrana Park but it is noted that the damages are greater on the "grey" and "blue" Douglas fir.

Damage caused by the fungus *Phomopsis pseudotsugae* Wils. is of greater importance. The pathogen causes dieback of the crown, from the location of disease development, in the bark of the stem or the branches. At the infestation spot the bark necroses, depresses, changes colour to red-brown and dies. The flow of nutrients and minerals to the crown is terminated. The needles turn red, wither and stay on the tree for a long time. Below the spot of disease development, the branches and crown remain vital and green. The fungus is a relatively weak parasite but under favourable conditions and the presence of mechanical injuries on the stems and branches, or piercing and other insect damages, the disease could develop fast and cause irreversible damage. The spread and damage by *Phomopsis pseudotsugae* Wils. are great in Vrana park, the arboretum of FRI, and in Ljulin mountain, where 20-70% of the trees at the age between 10 and 70-80 years are dead.

Regardless of infestation and damage by *Phomopsis pseudotsugae* Wils., Douglas fir is a tree species with decorative qualities and should be used more for landscaping in the region, but on richer and fresh sites mainly in groups of ornamental trees in the park zones.

On Douglas fir in the parks, colonization by *Gillettella colleyi* Gill. was detected. While observing the damaged trees, the pest was not found during the following years. The insect attack did not considerably affect tree condition. *G. colleyi* was detected for the first time in Bulgaria in 1989 in the region of Nevestino village, nearby Kjustendil, southwest Bulgaria, at the border with Serbia. Now we have data for its distribution almost across the whole country.

The results of this study show that appropriate measures are necessary to improve the physiological condition of the forest vegetation. Care for the survival and protection of many declining individuals of both deciduous and especially coniferous trees, require faster reactions and cutting of dead trees. Insect pests are accelerators of pathological processes for tree species growing under unfavourable ecological conditions, caused by the adverse urban environment.

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Lead in the Atmosphere-soil-plant System in the Forest Park of Boris' Garden - Sofia

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Abstract

Lead content is particularly high in the street dust and in the surface soil layer in big cities. Lead passing over from the atmosphere into the soil gets taken up in the food chains. This study was performed during the period 1984-1999 and involved the measurement of the heavy metals content in soil, litter and in the ground and tree floor of the vegetation. The most important consequence of the impact the polluted air exerts on plants is the change in the ratio of chemical elements in the plant tissues. This, most likely, cause physiological and phenological modifications in the plant, which in turn reduce the tree's resistance to adverse factors and cause stress. Lead pollution of soils in two experimental sites was quite significant (227% and 105%), as compared to the average for the country. We recorded a steady increase in Pb along with an increase in the soil solution acidity for the 15-year period of the study. The ratio between different microelements was disrupted, bearing evidence for a human-induced geochemical anomaly, which together with the increased acidity may cause an enhanced migration ability of lead followed by substantial changes in the soil-plant complex and reducing of overall resistance of the vegetation to stress and adverse influence. Vertical lead distribution within the plantations is as follows: **litter > grass > soil > bark of coniferous trees > bark of broad-leaved trees > coniferous tree needles > leaves > xylem**. This distribution shows that aerosol pollution takes place predominantly close to the ground. This clearly expressed horizontal distribution shows an increase of lead content in all plant components closer to the highways (boulevards) and shows that pollution is mostly due to the busy automobile traffic.

Key words

Pb, lead, soil, vegetation, litter, air pollution, automobile transport.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 269-278

INTRODUCTION

Lead and lead compounds are emitted with exhaust gases from automobiles and consequently diffuse into the soil surface and find their way into water and eventually into vegetation, from where they start a new cycle of migrations. Increased concentrations of this highly toxic metal have been recorded in the natural environment close to motorways as well as within urbanized areas in different parts of the globe. Lead content is particularly high in the street dust and in the surface soil layer (topsoil) in big cities. There, it is measured in hundreds of milligrams per kilogram, a value 2 to 15 orders above the background lead content in soil. It should be noted that the main danger this heavy metal posesses is not direct lead poisoning but its increased concentration up the food chains, which in turn disrupts the functioning of individual biosphere components. This means that even though the insignificant concentrations of lead emitted by exhaust gases cannot affect the components of nature directly, their continuous impact can lead to functional consequences.

Lead passing from the atmosphere into the soil and later into the food chains, as well as its ability to accumulate there, have provoked justified interest on the part of researchers throughout the world. Judging data supplied by Siccama & Smith (1978), the annual flow of lead in a forest ecosystem is about 266 *g/ha/year*. The amount of lead deposited on the soil surface depends largely on the source intensity. In urban areas where vehicle traffic is rather busy, the flow of Pb can reach 3000 *g/ha/year* (Chow & Earl, 1970), while in areas located away from cities and industrial zones, the rate of lead deposition hardly reaches 200 *g/ha/year* (Chow & Johnstone, 1975).

Lead concentrations in clean soil, adopted as a baseline concentration for soils worldwide, is 10 *ppm* (Vinogradov, 1957).

Lead is an element not required by plants and animals for their existence. However, because of the increased technogenic migration in recent years, its content in soils and the atmosphere has increased significantly and plants assimilate it. Lead aerosols, accumulated on the leaf surface, may cause a series of negative changes, among them blocking the leaf stomata and disrupting gas exchange as well as the basic functions of the plant (Adriano, 1986).

Depending on the plant species, authors have pointed out varying values of plant tolerance to Pb. For instance, Berry (1924, cited after Adriano, 1986) pointed out that 25 ppm is the maximum concentration of lead that crops may withstand without manifested changes in their functions, while at concentration of 50 ppm the plant dies. For tree species, the limit of tolerance is considered to be 10 ppm (Bowen, 1979).

The aim of this study is to present the lead contents progression in the atmosphere-soil-plant system in an urban area over 15 years.

MATERIAL AND METHODS

The largest forest park within the boundaries of the city of Sofia is Boris' Garden. It was created in 1882 over a surface area of 244.12 ha, 85% of which have been planted with trees. Being encircled on all sides with highways and boulevards with busy traffic, the park is chronically exposed to pollution with heavy metals, most of all lead. Amongst the most frequently occurring tree species are the Red Oak (*Quercus rubra*), the Common or Pedunculate Oak (*Quercus pedunculata*), the Small-leafed Lime (*Tilia parvifolia*), Ash (*Fraxinus excelsior*), *Acer nigundo*, Sycamore or Great Mapple (*Acer pseudoplatanus*), Common Hawthorn (*Crategus monogyna*), Austrian and Scots Pine (*Pinus nigra and P. sylvestris*), and European Spruce (*Picea abies*). In order to carry out the necessary investigations, two experimental sites were set up. They were considered representative of the forest park zone of Boris' Garden according to the results from the landscape-forestry analysis.

Experimental site No. 1 is close to the "Tsarigradsko Shosse" Blvd., section 9, subsection "zh" of the park (Forest Management Plan or FMP, of 1980): a coniferous plantation. The dominant species is the Austrian Pine with individual trees of Scots Pine, Small-leaved Lime, Ash, and Black Locust. The undergrowth is composed of broad-leaved species, of 40% coverage. According to the type of the landscape, it is a closed-type plantation, vertically canopied, with a spacing index of 0.7 to 1.0. The soil is Luvic Chernozems-Vertisols (FAO Soil Classification, 1987), which is the main soil type of Boris' Garden. Morphologically, the soil is distinguished by its prominent humus horizon, its crumb-like grain structure and heavy mechanical composition.

Experimental Site No. 2 is a pure broad-leaved plantation of Red Oak (*Quercus rubra*) with single trees of Small-leaved Lime (*Tilia parvifolia*). It is not far from the TV Tower in section 21, subsection "d". The undergrowth is composed entirely of Red Oak saplings and is of rather small coverage of only 10%. It is a closed-space type, horizontally canopied, of spacing index 1.0. The soil at this site is Chromic Luvisols (FAO Soil Classification, 1987). Well-expressed genetic horizons, crumb-like grain structure and heavy mechanical composition typify it.

This study was performed during the period of 1984-1999 and involved measurements of the heavy metals content in soil, litter and both of the ground vegetation and trees.

Soil profiles were selected in each experimental site. Soil reaction was determined with a potentiometer and total nitrogen was determined using the method of Keldal. Phosphorus was measured with a calorimeter; and the heavy metals, using a atomic absorption spectrophotometry.

The litter was divided into fractions and an averaged sample was prepared by mixing parts of all, observing the correct percentage of each fraction at the same time.

The distribution and accumulation of lead in vegetation were studied in the ground and tree floors of the sites. The most abundant grass species was the Meadow Fescue Grass (*Festuca elatior*). From the tree floor of site 7, different species were selected for the study: Austrian Pine (*Pinus nigra*), Black Locust (*Robinia peudacacia*), Scots Pine (*Pinus silvestris*), Red Oak (*Quercus rubra*), Sycamore, or Great Mapple (*Acer pseudoplatanus*) and Ash (*Fraxinus excelsior*). Samples were taken from three different parts, or fractions of the trees: xylem, bark and leaves, and were averaged for each particular fraction for each particular tree.

In order to determine the influence of traffic on the accumulation of lead in the different components, a series of samples at 5, 10, 20, 100 and 200 m from the respective boulevard were collected. Roadside geochemical anomalies vary greatly but in the presence of a forest canopy the highest values of geochemical variations are up to a distance of 20 m; the influence is felt to a certain extent to a distance of 100 m, and at a distance of 200 m the concentrations of heavy metals are close to the background values.

All samples were collected from five replications and, after being reduced to dry ash, were subjected to atomic absorption analysis. The regression analyses, used to reveal the connection between various components of the environment and the correlation analysis, which aims at finding the influence of the automobile transport, were performed with the help of standard computer software.

RESULTS AND DISCUSSION

Soils

Soil analyses found the following basic chemical soil characteristics and the quantities of lead (Table 1):

Table 1. Soil characteristics and quentities of lead at both experimental sites.

Experimental Site	Horizon	Humus %	1984		1994		1999	
			PH	Pb ppm	PH	Pb ppm	PH	Pb ppm
No 1	A1	2,52	6,6	67,3	5,5	87,90	5,3	89,99
	A2	1,78	6,8	19,2				
	AB	9,30	7,1	19,3				
	B	0,92	7,2	19,3				
	BC	0,31	7,5	28,8				
No 2	A	3,65	6,3	48,1	5,1	68,7	5,1	67,3
	AB	2,74	6,7	19,2				
	B	1,37	7,0	28,8				
	C	1,08	7,2	24,0				

The analyses of samples from **Experimental Site No. 1** indicated that the surface soil layer (the topsoil) had been polluted substantially compared to the average content of lead in Bulgarian soils (39.0 ppm). Vertisols are montmorilonitic soils and because of their heavy mechanical composition, 63% to 95% of the lead is tied up with the soil clayey fraction. Its vertical distribution along the soil profile (cross-section) confirms its humus-accumulative character and close relation with the soil organic substance. There is a probability of polluting the soil with lead of anthropogenic origin in case its content in the soil' "A" horizon (topsoil) exceeds considerably its content in the soil' "B" horizon by more than 40% (Raykov *et al.*, 1983). The increase of accumulated lead in horizon "A1" compared to that in horizon "B" was 349% and this demonstrates the anthropogenic origin of lead found in Site No. 1. These results confirm the claim about the anthropogenic quantities of lead being held down in the topsoil and its slow movement downward (Adriano, 1986). At pH = 6.6 lead is a slow-moving migrant. Importantly, the amount of accumulated lead tends to increase with the passing of years while the pH values tend to go down. It should be stressed that the contents remain around the admissible limit values but are considerably higher than the average for the country and act as an agent causing chronic stress to the park vegetation.

The soil in the Red Oak (*Quercus rubra*) plantation (**Experimental Site No. 2**) is Chromic Luvisol. Like for the Luvic Chernozems-Vertisols, here too, the humus content decreases downward and this is a typical feature for natural soils. Noteworthy, the humus content is significantly higher in these soils. The largest accumulation of Pb is in the topsoil and it is still below the admissible limit values. Downward migration is meager. The lead content excess in horizon "A" over the horizon "B" is 101%, indicating the probability of its being due to the intensive traffic at the boulevard. Here again an increase in content was recorded over a 10 year period since 1984, along with a decrease in pH values. No significant difference was found between 1994 and 1999. The content of Pb remained below the admissible limit values but is of constantly growing chronic character and can provoke physiological and phenological changes in the vegetation.

Our results show a clearly expressed trend for increasing lead accumulated in soils closer to the highway (Table 2).

Table 2. Content of lead in soil at different distances from the highway.

Experimental site	**Year**	**Pb content in soils (in ppm)** 5 m	10 m	20 m	100 m	200 m
No 1	1984	88,5	82,7	67,3	52,9	41,0
	1994	107,5	97,5	87,9	74,2	70,3
	1999	107,8	99,7	89,9	72,1	65,9
No 2	1984	74,9	66,8	48,1	48,0	41,6
	1994	87,1	77,2	68,7	50,2	44,3
	1999	88,5	78,6	67,3	50,5	43,9

Thus, compared to the controls, lead contents close to highways increased by 1.5 to 2 times. Even at a great distance from the source, the amount of lead accumulated in soil was above the average for the country, which is due to the overall pollution of air above the city. A steady, though gradual increase of lead content had been observed during the period of the study.

The amount of lead found in the topsoil at different distances from the highway were subjected to a correlation analysis. This correlation model is used as follows:

$$\log y = a + b \log x + c \log x^2,$$

where:
y – distance from the boulevard in meters;
x – lead content in the soil in *ppm*.
Models produced correlation coefficients between 0,971 and 0,997.

Litter

Data on the lead content in the litter, which serves as a bridge between the atmosphere, the vegetation and the soil confirms the assumption that lead enters the soil mainly as an aerosol. The amount of lead measured in an average sample in which the percentage ratio of twig, bark, leaf, needle, and fruit contents were used as is shown in Table 3.

Table 3. Content of lead in litter at different distance from the highway.

Experimental site	Years	Pb content in litter (in ppm)		
		5 m	20 m	200 m
No 1	1984	211,1	184,4	44,2
	1994	300,1	261,11	52,8
	1999	311,28	291,13	50,3
No 2	1984	235,55	85,8	40,8
	1994	283,6	124,0	50,6
	1999	287,1	164,6	52,1

Compared to the topsoil, this amount is substantially higher. For the 15-year period a considerable increase in the amount of accumulated lead was recorded, especially close to the highways, between 1.2 and 1.5 times. The litter seems to delay the heavy metal penetration in soil until it becomes fully decomposed. In recent years, researchers have shown great interest in the litter capacity of heavy metals, as it is considered that they suppress its decomposition. Tyler (1972) assumed that the decomposition of litter and the consequent return of nutrients into the ecosystem's trophic cycle progresses at a slower rate and is rather incomplete when heavy metal ions are tied up into the organic matter colloids, and increase the resistance to decompositon and exert a direct toxic effect on reducers.

Data on lead content in soil and litter allowed for a regression analysis to determine the connection between the two components. Maximum approximation was obtained using the following equation:

$$Y = K_1 x + K_2 x + K_3,$$

where:

Y – lead content in litter in *ppm*

x – lead content in soil in *ppm*.

Mathematical models of a high degree of correlation ($r > 0,95$) and reliability ($F > 5,7$) were obtained.

Grass floor

Pollution of the air and soil with lead causes lead to accumulate in plants. The grass floor has been studied only in samples from **Experimental Site No. 1**, as there is no such vegetation in Experimental Site No. 2. Results of the lead content in the Meadow Fescue Grass (*Festuca elatior*) are shown in Table 4.

Table 4. Content of lead in *Festuca elatior* at different distance from the highway.

Distance from the highway (in meters)	Pb (ppm)		
	1984	**1994**	**1999**
5 m at the open	311,2	311,2	312,0
5 m under the forest canopy	211,1	213,4	214,9
10 m	193,8	193,2	196,2
20 m	184,4	187,4	187,0
100 m	55,6	56,6	56,5
200 m	44,9	45,1	44,4

It is interesting to juxtapose the results of the lead content in grass growing under the forest canopy and in an open area. Lead content in the grass growing in an open area was about 1.5 times as high as that found in the grass growing under the forest canopy, confirming the aerosol character of lead pollution. The data showed a great increase in the Pb content compared to the amounts tolerated by plants. These high values tend to change, substantially, the ratio of other elements in the plant tissues, thus leading to physiological and phenological modifications.

Here again, data show that there was a decrease in Pb content with distance, well demonstrated for 5 and 20 m from the highway. Significant differences in lead content between years were not found. A regression analysis revealed the connection between lead content in the soil and in the forest grass floor. The parabolic function found in other components was studied. According to the regression coefficients obtained, there was a strong correlation between the lead content in the soil and in the grass floor ($r > 0,96$; $F > 5,37$).

Tree floor

Numerous studies have found that atmospheric lead causes an increase of lead content in vegetation both through lead particles deposited on the plant surface via the so-called aerial feeding, and through its migration from the soil and entering the plant metabolism.

Three types of tree material: xylem, bark and leaves from seven species of trees taken from specimens located at different distances from the highway during the period of 15 years were studied. Plant species differed in their capacities to absorb and accumulate lead in their organs, thus contributing to cleaning the atmosphere and soil. The amount of Pb in all fractions from trees growing in **Experimental Site No. 1** was significantly higher than in fractions taken from trees growing in **Experimental Site No. 2** (Table 5). Results from our studies point out that bark has the highest amount of lead (bark > leaves > xylem). This is true for both coniferous and broad-leaved species at any distance from the highways. The only exception is Red Oak (*Quercus rubra*), which accumulated lead mostly in its leaves. It is evident that trees, which grow closer to the boulevards, had higher greater amounts of lead, which was assessed by the accumulation coefficient. Lead content in any type of plant material (fractions) is at least twice as high as the limit of tolerance for trees. For the 15-year period, the content of lead in leaves remained almost constant: from 17.8 to 29.93 *ppm*. For coniferous species the amounts were

Table 5. Lead content in different parts of plants from various tree species in Boris' Garden.

Tree Species	Material from different parts of the Tree (fractions)	Pb ppm												Coefficient of accu-mulation
		5 m		10 m		20 m		100 m		200 m		300 m		
		1984	1999	1984	1999	1984	1999	1984	1999	1984	1999	1984	1999	
Pinus nigra	xylem	21,4	23,1	12,8	13,1	12,6	12,8	11,6	11,8	11,5	11,8	11,5	12,1	1,86
Austrian pine	bark	161,8	165,3	142,3	151,3	140,8	141,2	100,0	101,9	40,8	45,6	38,7	40,2	4,18
	leaves	34,6	40,1	25,6	26,1	23,8	24,0	11,7	15,8	10,3	11,1	10,7	11,2	3,23
Pinus silvestris	xylem	26,0	27,1	24,8	26,1	20,1	23,2	12,2	12,3	11,9	11,8	11,6	11,9	2,24
Scots pine	bark	68,3	76,2	51,3	61,2	42,8	44,4	34,3	37,3	26,4	28,2	25,1	27,9	3,72
	leaves	29,6	31,2	28,4	28,8	24,3	25,1	21,6	19,7	18,6	18,7	18,7	18,9	1,58
Tilia parvifolia	xylem	20,1	22,1	18,3	19,2	17,5	17,9	11,0	13,2	11,0	13,6	11,2	11,5	1,79
Small-leafed	bark	47,3	51,3	45,8	46,0	39,7	42,1	25,0	25,9	24,8	25,3	20,5	24,9	2,31
Lime	leaves	28,3	29,0	26,0	26,5	25,3	26,2	19,6	19,6	18,8	17,8	8,3	15,4	3,41
Fraxinus	xylem	10,4	10,4	7,8	8,1	7,8	8,7	7,47	8,6	5,98	6,6	5,82	6,2	1,79
excelsior	bark	30,1	32,9	29,2	30,2	27,8	27,9	16,7	16,9	8,16	11,3	7,8	11,2	3,86
	leaves	26,8	28,1	25,6	26,6	26,1	26,7	26,6	27,8	11,43	10,5	9,8	10,5	2,73
Quercus rubra	xylem	27,8	28,3	26,3	27,1	24,2	25,3	19,9	20,1	13,5	15,4	12,3	12,3	2,26
Red oak	bark	25,6	28,1	23,3	24,2	13,2	14,6	20,3	19,8	20,1	21,3	20,2	19,9	1,26
	leaves	29,3	30,1	27,1	28,1	26,3	27,9	20,8	23,1	20,1	24,3	19,8	22,2	1,48
Acer pseudoplatanus	xylem	14,8	15,1	13,9	14,1	13,3	13,6	11,7	13,0	10,6	11,7	10,2	11,6	1,45
Sycamore (Great	bark	45,3	48,3	42,3	45,2	40,1	43,2	36,7	38,9	30,8	35,2	25,2	26,3	1,8
Maple)	leaves	29,9	31,7	26,7	26,8	25,9	26,0	20,8	21,7	18,8	18,9	18,4	17,9	1,63
Robinia pseudacacia	xylem	15,2	15,9	13,1	14,0	10,7	12,3	8,5	9,6	10,4	10,2	10,7	11,9	1,42
Black or Yellow	bark	71,3	72,1	66,3	67,2	59,4	60,2	25,1	27,2	21,8	26,2	20,1	31,5	3,55
Locust	leaves	17,3	18,2	17,6	17,8	17,8	17,9	16,7	16,1	13,6	15,8	11,2	12,5	1,54

higher due to the longer life of the leaves (the needles) and the longer time of accumulation. Especially worrying is the increase of lead content in the xylem as this means that the lead has already been assimilated by the plant.

The most important consequence of the impact of the polluted air on plants is the change in the ratio of chemical elements in the plant tissues. This most likely is the cause of physiological and phenological modifications in the plant organism, which in turn reduce the trees resistance to adverse factors and cause stress.

It has been found that the increase of lead content in soil above 50 *ppm* causes the lead content in different parts of plants to grow too (Grigoryeva, 1983). This means that there is a very close correlation between the lead content in plants and lead content in soil. Empirical dependencies we have obtained between the quantities of Pb in the soil substrate and its accumulation in the tree parts above the ground can be approximated by the following equation:

$$Y = K_1 x + K_2 x + K_3,$$

where:

Y – lead content in the plant sample, in *ppm*

x – lead content in the soil, in *ppm*.

The high values of the correlation coefficient ($r > 0,9$) and of Fisher's criterion ($F > 5,73$) show how strongly the two components correlate.

CONSLUSIONS

An increased lead content in most of the components of the studied plantations in Boris' Garden was recorded. This increase was better demonstrated for the 10 years period 1984-1994. Differences in lead accumulation between 1994 and 1999 were not significant. The lead was of anthropogenic origin and was introduced in the form of an aerosol.

Lead pollution of soils in the two experimental sites was quite significant, between 227% and 105%, as compared to the average for the country. The ratio between different microelements was disrupted, bearing evidence of a human-induced geochemical anomaly, which together with increased acidity, may cause an enhanced migration ability of lead followed by substantial changes in the soil-plant complex and reducing of the vegetation's overall resistance to stress and adverse influence.

Analyses of grass from experimental sites have shown the presence of significant amounts of lead, about 80 times as much as its content in non-polluted grass. The amount of lead found in all types of tree material (fractions) of the studied trees from both sites was above the limits of tolerance. Generally, the coniferous trees retained greater amounts of lead in their tissues compared to broad-leaved trees. The highest amounts of lead were found in the tree bark. The only exception was the Red Oak (*Quercus rubra*). Necroses on the tree leaves were observed as well as changes in the phenological phases. Lime (*Tilia* sp.) was the most sensitive species, while the Red Oak was the most resistant to aerosol pollution.

Vertical lead distribution within the plantations was as follows: **litter > grass > soil > bark of coniferous trees > bark of broad-leaved trees > coniferous trees needles > leaves > xylem**.

This distribution shows that aerosol pollution takes place predominantly close to the ground. The clearly expressed horizontal distribution shows an increase in lead content in all plant components close to the highways (boulevards) and confirms that pollution is mostly due to the busy automobile traffic.

Finally, it should be underlined that Boris' Garden needs special management. This includes: management of the soil (maintaining pH around the neutral value in order to prevent lead from migrating); management of tree resistance; maintaining tree health and regulating the processes of plant reproduction, including the planting of tree species, resistant to worsened environmental conditions, where and when necessary. This forest park is of importance for maintaining a normal ecological and aesthetic environment within the city limits and we are obliged to secure it with all of the abovementioned management.

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Animals

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Distribution Patterns of Nematode Communities in an Urban Forest in Sofia, Bulgaria

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Abstract

Diversity and functional parameters of nematode communities were studied at "Knyaz Borisova Gradina" City Park. The study site was a 60-90 year-old mixed forest. Litter and soil samples at four depths were collected. Ninety nematode genera were identified. Bacterial feeders were the most common, abundant and diverse group (36 genera), followed by plant feeders (22). Significant differences between litter and soil nematode assemblages parameters were revealed. Nematode communities in litter exhibited high diversity with a very low abundance. Nematodes from different soil depths were similar in taxonomic and trophic group structure. In soil layers, plant feeding nematodes prevailed and omnivores were well represented, whereas bacterial feeders decreased with depth. Maturity indices of soil communities increased gradually with sampling depth. The high diversity and maturity of nematode assemblages could be related to the age, heterogeneity and size of the forest.

Key words

Bioindication, Bulgaria, nematodes, Sofia, urban ecology, vertical distribution.

INTRODUCTION

The establishment of park zones in urban areas involves planting of various species, which change the initial flora and fauna. Also, various localised disturbances occur in large conurbations, such as an increase in temperature ('heat island' effect) and precipitation, higher depositional fluxes of atmospheric chemicals, human-built structures, etc. (Poyat *et al.*, 1995). These can potentially influence animal and plant species composition and their relationships, thus forming highly specific communities. Nematodes play a significant role in soil food webs and take an important part in ecological processes (e.g. nutrient cycling, plant growth, etc. Ingham *et al.*, 1985; Mishra & Mitchell, 1987; Bouwman *et al.*, 1994; Ekschmitt *et al.*, 1999). They possess several biological features that make them useful

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 281-297

as indicators of soil quality and soil perturbance, both at species (taxonomic) and community levels. The potential of using nematodes and their communities as bioindicators has been reviewed in several articles (Wasilewska, 1997; Niles & Freckman, 1998; Bongers & Ferris, 1999; Ritz & Trudgill; 1999; Neher, 2001). Although numerous studies on disturbance effects have been undertaken, only a few deal with nematode assemblages of urban areas in cities (Pouyat *et al.*, 1994; Steiner, 1994a,b,c).

The present study is part of an investigation of nematode communities in mixed forests along an urban-rural gradient in the Sofia region. The objective is to describe the taxonomic and functional diversity of nematode communities in litter and soil from a forest in "Knyaz Borisova Gradina" park, which represents the urban end of an urban-rural gradient studied.

MATERIALS AND METHODS

Site description

The study site is located at the northeastern part of "Knyaz Borisova Gradina" City Park, along "Tzarigradsko shosse" blvd., 30 m apart, 575 m above sea level, slope 4°.

The sampling site was a 60-90 yr old artificial deciduous-coniferous forest dominated by *Quercus pedunculiflora* C. Koch. (plant association *Querceta pedunculiflorae*). Other tree species occurring were *Quercus cerris* L., *Fraxinus exelsior* L., *Pinis nigra* Arn., rarely *Tilia tomentosa* Moench., *Prunus cerasifera* Ehrh.; shrubs were represented mainly by *Rosa canina* L., *Hedera helix* L., *Clematis vitalba* L. The grass cover consisisted of *Dactylis glomerata* L., *Elymus hispidus* (Opiz) Meld., *Geum urbanum* L., *Prunella vulgaris* L.

Three sampling plots representing the main plant communities were selected in the study area: (1) tree vegetation dominated by *Q. cerris*, with a lower occurrence of *Quercus rubra* L., *Pinus nigra* and *P. sylvestris* L.; undergrowth and grass cover consisting of *Ligustrum vulgare* L., *T. tomentosa, F. exelsior, Acer platanoides* L., *R. canina*, *H. helix*, *Ranunculus ficaria* L., *Viola* sp.; litter was heterogeneous, variable in thickness (3-4 cm at maximum) and degree of destruction, consisting mainly of oak leaves, pine needles and branches; (2) tree vegetation dominated by *P. nigra*, with some *P. silvestris* and *Q. rubra*; undergrowth was mainly *F. excelsior* and *T. tomentosa*; *H. helix* prevailed in the grass layer and also some scarce mosses occurred; litter with different thickness (1-3 cm), consisted of branches, pine needles and red oak leaves; (3) tree composition was *Q. pedunculiflora*, *F. exelsior*, *T. tomentosa*, *P. nigra* and less *P. sylvestris*; undergrowth consisted of *L. vulgare*, *Q. rubra*, *T. tomentosa*, *Rubus sp.*; *H. helix* dominated in the grass floor; litter 1- 4 cm thick, composed of a mixture of branches, leaves and pine needles.

Soil type is Chromic Livisol, moderately loamy: physical and chemical properties for 0-10 cm and 10-30 cm depth, respectively, were: relative weigth 2.46 and 2.57, hygroscopic humidity 4.56% and 3.08%, humus content 5.83 and 3.26, clay 31.9% and 30.2%, pH 6.50 and 5.75, N 0.18% and 0.07%.

For further details see Penev *et al.*, this volume.

Sampling, nematode extraction and identification

A total of 45 litter (L) and soil (S1-S4) samples were collected on 31 October 1998 (U1) and 1999 (U3), and 1 April 1999 (U2). From each plot 3 samples were taken using a spade. Each sample was divided into 5 samples along a soil profile: after collecting the organic layer (litter- L), the mineral soil was sampled at four depths: S1, 0-1 cm; S2, 2-6 cm, S3, 7-11 cm and S4, 12-25 cm. Each sample was placed in a plastic bag and stored at 4ºC until analyzed.

Nematodes were extracted from 100 g soil by a sieving and decanting technique (using two sieves with apertures of 1 mm and 63 μm), with final separation on a small-sized sieve (aperture c. 250 μm) placed in a water-filled Baerman funnel for 48 hours. To isolate nematodes from the litter, 10 g of each sample were cut into narrow bands (c. 1-5 cm), then the procedure described above was applied. Extracted nematodes were heat-killed at 70°C, fixed in TAF and counted. A maximum of 200 specimens per sample were processed in anhydrous glycerine and studied on permanent slides (Seinhorst, 1959).

The nematodes were identified to genus level under a high magnification microscope using the keys by Andrássy (1984), Bongers (1988), Jairajpuri & Ahmad (1992), Hunt (1993) and Siddiqi (2000). The allocation of the genera into feeding types and colonizer-persister (*c-p*) groups followed Yeates *et al.* (1993) and Bongers & Bongers (1998). In some of the analyses, plant-feeding nematodes belonging to the sub-groups b-f were considered separately (see Yeates *et al.*, 1993).

Indices and analyses

The maturity indices, MI, PPI (see Bongers, 1990) and MI 2-5 (based on *c-p* groups 2-5), and the following diversity measures: generic richness (S), Shannon-Wiener index for generic diversity (H‘) and Simpson's "concentration of dominance" index (C), were calculated for each sample as community parameters (Krebs, 1989). The taxonomic similarity was assessed using the percentage similarity index (Ics) and dendrograms were obtained by the agglomerative unweighted pair-group clustering method using arithmetic averages (UPGMA, Krebs, 1989). The diversity parameters, similarity measures and cluster analysis were performed using the programme BIODIV 5.2 (Baev & Penev, 1995). Correspondence Analysis (CA) based on the relative generic abundance data and downweighting of the rare taxa was applied. For the CA ordination diagram Hill's scaling focusing on inter-sample distance was used. The analysis was carried out using CANOCO 4.0 (Ter Braak & Smilauer, 1998). As most of the data were not normally distributed, multiple comparison of samples was performed with the non-parametric Kruskal-Wallis *H* test. Subsequently, significant differences were localised using the Mann-Whitney *U* test, M-W (Sokal & Rohlf, 1981). Only differences significant at $p<0.05$ were discussed. Statistical analyses were performed with Statistix 4.0 and Excel 97.

RESULTS

Generic composition: abundance, occurrence and dominance

Ninety nematode genera belonging to 10 orders were recorded from the litter and soil layers studied. The most diverse group was the order Tylenchida (22 genera) followed by orders Dorylaimida (14) and Rhabditida (7). Mean relative abundance (expressed as a percentage) and frequency of occurrence of the nematode taxa recorded are shown in Table 1. The nematode

Table 1. Mean relative abundance, (D per 100 g, %,) and frequency (F, samples number) of nematode taxa present in the litter and soil layers (S1-S4) of a mixed forest in 'Knyaz Borisova Gradina' City Park.

Genera/trophic groups	Layers									
	Litter		S1		S2		S3		S4	
	D	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*
Bacterial-feeders										
Acrobeles	0,0	-	0,4	1	0,0	-	0,6	3	0,0	-
Acrobeloides	0,0	-	0,6	4	0,9	3	0,3	3	1,0	3
Alaimus	0,3	1	2,8	8	4,0	3	1,0	2	1,4	3
Anaplectus	0,3	1	0,2	2	1,8	2	0,7	2	0,4	1
Aphanolaimus	0,0	-	0,0	-	0,0	-	0,0	-	0,1	1
Aulolaimus	0,0	-	0,0	-	0,1	1	0,0	-	0,0	-
Bastiania	0,3	1	1,2	4	5,2	7	5,2	6	0,6	4
Bunonema	0,0	-	0,1	1	0,0	-	0,0	-	0,1	1
Ceratoplectus	0,0	-	1,2	3	0,4	2	0,1	1	0,0	-
Cervidellus	0,0	-	0,2	1	0,0	-	0,3	2	0,0	-
Cylindrolaimus	0,0	-	1,7	3	0,2	2	0,3	1	0,1	1
Domorganus	0,0	-	0,5	2	0,2	1	0,6	2	0,1	1
Drilocephalobus	0,0	-	0,2	2	0,0	-	0,1	1	0,4	2
Eucephalobus	0,0	-	6,6	9	2,6	4	0,9	4	1,2	4
Eumonhystera	0,6	1	0,2	2	0,0	-	0,4	1	0,0	-
Geomonhystera	1,7	3	0,2	2	0,0	-	0,1	1	0,0	-
Goffartia	0,0	-	0,0	-	0,0	-	0,0	-	0,1	1
Halaphanolaimidae	0,0	-	0,1	1	0,2	1	0,0	-	0,3	1
Heterocephalobus	0,0	-	0,3	2	0,0	-	0,0	-	0,1	1
Mesorhabditis	0,0	-	1,5	5	2,0	5	0,4	1	0,6	1
Metateratocephalus	0,0	-	0,2	-	0,1	1	0,0	-	0,1	1
Monhystera	0,0	-	0,0	-	0,0	-	0,0	-	0,1	1
Odontolaimus	0,0	-	0,1	1	0,1	1	0,0	-	0,0	-
Panagrolaimus	15,3	7	0,1	1	0,1	1	0,2	2	0,6	3
Paramphidelus	0,0	-	2,8	2	1,1	3	0,4	2	0,5	1
Plectus	29,4	9	4,3	8	2,2	8	1,8	6	2,9	6
Prismatolaimus	0,0	-	1,1	4	0,5	2	3,0	3	0,6	4
Pristionchus	0,0	-	0,1	1	0,0	-	0,0	-	0,1	1
Prodesmodora	0,0	-	0,1	1	0,4	2	0,0	-	0,0	-
Prodontorhabditis	0,0	-	0,2	1	0,0	-	0,0	-	0,0	-
Protorhabditis	0,6	1	0,1	1	0,0	-	0,0	-	0,0	-
Rhabditidae	0,0	-	0,0	-	0,6	1	0,0	-	0,0	-
Rhabditis	0,3	1	0,2	1	0,0	-	0,1	1	0,1	1
Teratocephalus	0,3	1	0,2	2	0,0	-	0,0	-	0,0	-
Tylocephalus	0,0	-	0,0	-	0,1	1	0,0	-	0,1	1
Wilsonema	0,6	1	2,2	3	0,1	1	0,2	2	0,4	1
Fungal-feeders										
Aphelenchoides	21,8	9	0,6	5	0,0	-	0,3	3	0,4	2
Aphelenchus	0,0	-	0,0	-	0,1	1	0,0	-	0,3	1
Diphtherophora	0,0	-	0,7	2	0,3	1	1,4	5	0,6	2
Ditylenchus	7,6	3	3,6	6	0,7	5	1,2	4	0,9	5
Hexatylus	2,3	2	0,0	-	0,0	-	0,0	-	0,0	-
Leptonchus	0,0	-	0,1	1	0,0	-	0,1	1	0,1	1
Nothotylenchus	0,0	-	0,0	-	0,0	-	0,0	-	0,1	1
Paraphelenchus	1,4	1	0,0	-	0,0	-	0,0	-	0,0	-
Pseudhalenchus	0,0	—	1,5	3	0,3	2	0,0	-	0,1	1
Tylencholaimellus	0,0	—	0,7	2	0,3	2	0,1	1	0,3	2
Tylencholaimus	0,0	-	1,1	3	2,3	4	4,2	5	0,9	2
Tylolaimophorus	0,0	-	1,4	1	0,0	-	4,4	1	3,0	2

Table 1. Continued.

Genera/trophic groups	Layers									
	Litter		S1		S2		S3		S4	
	D	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*
Omnivores										
Aporcelaimellus	0,3	1	1,7	6	8,4	8	16,2	7	12,6	8
Aporcelaimus	0,3	1	0,1	1	0,1	1	0,3	2	0,3	2
Enchodelus	0,0	-	0,6	2	0,1	1	0,0	-	0,0	-
Epidorylaimus	0,0	-	2,3	4	0,4	4	1,4	2	0,5	2
Eudorylaimus	0,3	1	5,1	5	3,3	3	0,1	1	0,3	2
Mesodorylaimus	4,8	3	0,2	2	0,1	1	0,0	-	0,0	-
Microdorylaimus	0,0	-	0,6	3	0,1	1	0,1	1	0,0	-
Prodorylaimus	0,0	-	3,8	5	4,6	5	1,7	5	2,7	4
Thonus	0,6	2	3,8	5	0,7	3	0,9	2	0,8	2
Predators										
Clarkus	1,1	1	2,2	6	2,5	4	1,1	3	2,9	8
Discolaimus	0,0	-	0,0	-	0,1	1	0,9	1	0,6	1
Mylonchulus	0,0	-	0,1	1	2,4	3	0,0	-	0,3	2
Nygolaimus	0,0	-	0,0	-	0,1	1	0,4	1	0,4	1
Paravulvus	0,0	-	0,5	2	0,3	2	0,0	-	0,0	-
Prionchulus	6,2	3	1,2	6	0,1	1	0,0	-	0,1	1
Seinura	0,0	-	0,2	1	0,0	-	0,1	1	0,0	-
Stenonchulus	0,0	-	0,0	-	0,3	1	0,9	1	0,5	2
Tripyla	0,0	-	0,2	2	1,7	3	0,7	2	0,6	1
Plant feeders										
Heteroderidae	0,0	-	0,0	-	1,3	2	0,1	1	0,0	-
Meloidogyne	0,0	-	0,0	-	0,3	1	0,2	1	0,0	-
Pratylenchus	0,0	-	0,5	2	1,2	1	1,2	1	0,0	-
Rotylenchus	0,0	-	0,9	3	1,1	3	0,6	1	0,1	1
Cephalenchus	0,6	1	1,6	7	9,7	8	11,8	9	24,6	9
Criconema	0,0	-	0,1	1	0,0	-	0,0	-	0,1	1
Longidorus	0,0	-	0,1	1	0,5	1	5,6	1	3,5	1
Mesocriconema	0,0	-	0,3	1	1,8	4	1,6	5	2,3	6
Paratylenchus	0,0	-	2,1	3	6,6	3	3,5	4	4,2	4
Tremonema	0,0	-	0,0	-	0,0	-	0,2	1	0,0	-
Trichodorus	0,0	-	0,0	-	0,0	-	0,1	1	1,2	3
Xenocriconemella	0,0	-	0,0	-	0,2	1	0,0	-	1,0	1
Basiria	0,0	-	4,7	4	2,5	3	0,3	2	0,0	-
Boleodorus	0,0	-	5,2	4	2,6	4	4,0	3	1,4	2
Discotylenchus	0,0	-	0,0	-	0,9	1	0,0	-	0,0	-
Dorylaimellus	0,0	-	0,0	-	0,0	-	0,3	1	1,2	2
Filenchus	2,0	3	15,7	9	12,4	8	6,3	7	6,2	6
Lelenchus	0,0	-	0,0	-	0,1	1	0,0	-	0,0	-
Malencus	0,3	1	0,2	1	0,4	1	0,3	2	0,3	2
Polenchus	0,0	-	0,1	1	0,0	-	0,0	-	0,3	1
Laimaphelenchus	0,8	2	0,0	-	0,0	-	0,0	-	0,0	-
Tylenchus	0,0	-	0,2	2	0,1	1	0,0	-	0,1	1
Dispersal stages										
Dauer larvae	0,3	1	3,8	5	5,5	9	6,6	8	7,8	8
Steinernema	0,0	-	2,7	2	1,1	1	4,7	2	3,9	2

abundance varied greatly between samples (70-1160 individuals/100 g, Table 2). The relative abundance of nematodes of the litter (L) and the first soil layer (S1) were significantly higher as compared to the nematode assemblages of the deeper soil layers (S2-S4) (M-W $p<0.05$, Table 2). However, there was no statistically significant difference between the L and the S1 layer or between the S2, S3 and the S4 layers (M-W $p>0.05$).

Sixteen genera (17.8%) were common to all layers, but only two of them (*Plectus* (29.4%) and *Panagrolaimus* (15.3%, Table 1) prevailed significantly in the litter. Among the nematode genera not found in all layers, *Aphelenchoides* spp. dominated (21.8%). Two genera (*Paraphelenchus* and *Laimaphelenchus*) were restricted to litter and were found in low abundance and frequency (1.4%, 1 and 0.8%, 2, respectively). Most of the nematode taxa recovered from this layer were present at low frequency (1-2 samples) and abundance (<2.5%), while others, *Ditylenchus*, *Prionchulus, Mesodorylaimus*, *Hexatylus, Filenchus, Geomonhystera*, occurred rarely (2-3 samples) but at high abundance (Table 1).

The nematode genera recovered in soil layers exhibited diverse patterns of distribution along the soil profile (S1 to S4). Some genera (*Filencus, Eucephalobus*, *Plectus, Boleodorus*) prevailed in the upper (S1) layer and decreased gradually with depth. Conversely, others (*Aporcelaimellus*, *Clarkus*, *Cephalenchus*, *Mesocriconema*) gradually increased and were most abundant in the deepest layers (S3 and/or S4). Furthermore, some genera prevailed in one (*Thonus*, *Prionchulus, Wilsonema* and *Cylindrolaimus*, S1) or two (*Mesorhabditis*, *Eudorylaimus* and *Basiria,* S2 and S3; *Bastiania*, S3 and S4) soil layers. The genera *Prodorylaimus* and *Paratylenchus* had almost equal distribution in the S1 to S4 layers, but with the latter being slightly more aggregated in the S2 layer. *Longidorus* sp. was recovered in low occurrence and high abundance and showed a strong aggregation at the deepest layers (S3 and S4) (Table 1).

Generic richness and diversity

Compared with the total number of genera detected (90), the number of genera per sample was relatively low and varied greatly between layers (3-33, Table 2). Soil (S1-S4) was characterised by a higher generic richness compared to the litter (67-56 *vs.* 27 genera, Table 1). The nematode communities of litter showed significantly lower generic richness (S=3-10, M-W $p<0.002$, Table 2) and diversity (H'=0.66-1.89, M-W $p<0.01$), coupled with the highest values of Simpson's dominance index (C=0.20-0.64) caused by the dominance of one and/or two taxa. Conversely, the nematode communities in the soil layers had a higher generic richness and diversity, and significantly lower dominance (C=0.07-0.37). The highest values for generic richness and diversity were calculated for the nematode communities in the S1 layer, followed by those in the S2, S4 and S3 layers (Table 2).

Trophic and life-history group structure, and maturity indices

Trophic and colonizer-persister (*c-p*) groups distribution, and MI and PPI values for each layer are presented in Table 2. Generally, bacterial- and fungal-feeding nematodes prevailed significantly in litter communities (M-W $p<0.002$ and $p<0.004$, respectively) as compared to the soil layers (S1-S4), except for nematode communities in the S1 and L layers, where the abundance of

Table 2. Relative abundance (numbers per 100 g fresh substrate), diversity measures, relative abundances of trophic and colonizer-persister groups, fungivores-bacterivores ratio and the maturity indices (MI, MI(2-5), PPI) for nematode communities of litter and soil layers (S1-S4).

		Layers									
		Litter		**S1**		**S2**		**S3**		**S4**	
	Kruskal-Wallis Test	AV ± SD Range	M-W	AV ± SD Range	M-W	AV ± SD Range	M-W	AV ± SD Range	M-W	AV ± SD Range	M-W
Mean abundance	H=12.26 p=0.02	393.3 ± 380.3 70-1160	*a*	188.1 ± 6.1 52-470	*a*	112.1±92.4 36-314	*bc*	114.7±104.9 31-314	*c*	85.7±62.7 13-170	*c*
Mean generic richness	H=19.84 p=0.0005	6.9±2.4 3-10	*a*	22.2±6.1 13-33	*bc*	18.1±7.4 9-27	*cd*	16.1±7.7 7-27	*d*	17.0±8.4 7-32	*d*
Shannon's diversity index	H=16.29 p=0.0026	1.51±0.37 0.66-1.89	*a*	2.41±0.40 1.77-2.96	*b*	2.32±0.42 1.76-2.88	*b*	2.08±0.53 1.09-2.71	*b*	2.12±0.42 1.56-2.79	*b*
Simpson' dominance index	H=12.58 p=0.0135	0.30±0.14 0.20-0.64	*a*	0.15±0.09 0.07-0.37	*b*	0.15±0.06 0.07-0.24	*b*	0.21±0.15 0.10-0.57	*b*	0.20±0.08 0.10-0.31	*b*
Trophic groups											
Bacterial feeders	H=19.98 p=0.0005	194.4±221.8 30-640	*a*	55.6±47.3 7-155	*ab*	25.4±28.1 5-93	*bc*	19.0±26.8 0-87	*c*	10.7±8.1 2-23	*c*
Fungal feeders	H=19.21 p=0.0007	130.0±134.7 10-420	*a*	18.1±18.2 0-46	*bcd*	4.4±4.2 0-12	*c*	13.2±15.2 1-50	*d*	5.8±23 0-26	*bcd*
Plant feeders, Sum	p>0.05	14.4±16.7 0-40	*a*	59.7±51.2 10-144	*b*	46.7±46.5 13-129	*ab*	41.3±44.2 3-115	*ab*	39.9±41.6 6-111	*ab*
PF a						1.8±3,6 0-11.0		0.3±0.7 0-2			
PF b				1.0±2.6 0-8		1.3±4.0 0-12.0		1.3±4.0 0-12			
PF c				1.8±43 0-13		1.2±2.2 0-5.0		0.7±2.0 0-6		0.1±0.3 0-1	
PF d		2.2±6.7 0-20		8.0±43 0-34		21.1±29.5 2-76.0		26.2±30.3 2-77		31.7±33.4 6-89	
PF e		8.9±14.5 0-40		48.6±42.2 6-120		21.1±24.5 0-65.0		12.8=15.6 0-37		8.0±8.7 0-22	
PF f		3.3±7.1 0-20		0.3±0.7 0-2		0.1±0.3 0-1.0				0.1±0.3 0-1	
Omnivores	p>0.05	24.4±37.5 0-110		34.2±37,6 0-99		19.9±23.3 0-76		23.7±26.7 0-76		14.7±14.9 0-40	
Predators	p>0.05	28.9±47.0 0-140		8.3±8.0 0-25		8.3±10.5 0-27		4.6±6.5 0-16		4.7±4.7 1-14	
Others		1.1±3.3 0-10		12.2±19.2 0-55		7.3±6.8 2-25		12.9±16.0 0-50		10±12.2 0-30	

Table 2. Continued.

		Layers									
		Litter		**S1**		**S2**		**S3**		**S4**	
	Kruskal-Wallis Test	AV ± SD Range	M-W	AV ± SD Range	M-W	AV ± SD Range	M-W	AV ± SD Range	M-W	AV ± SD Range	M-W
FF/BF ratio	H=12.2 p=0.0172	1.0±1.1 0.2-3.7	*a*	0.3±0.2 0.0-0.6	*b*	0.2±0.2 0.0-0.6	*b*	1.9±3.3 0.1-10	*ac*	0.6±0.8 0.0-2.6	*bc*
Maturity Index (MI)	H=16.07 p=0.0029	2.16±0.56 1.57-3.43	*a*	3.12.±0.64 2.31-3.89	*b*	3.31±0.95 1.55-4.26	*b*	3.52±0.59 1.55-4.26	*b*	3.57±0.70 2.33-4.51	*b*
MI (2-5)		2.42±0.47 2.00-3.43		3.19±0.63 2.45-3.97		3.51±0.85 2.00-4.53		3.61±0.54 2.67-4.17		3.72±0.76 2.39-4.61	
Plant Parasite Index	H=10.36 p=0.0348	2.00±0.00 2.00-2.00	*a*	2.09±0.12 2.00-2.38	*b*	2.33±0.35 2.00-2.86	*bd*	2.34±0.52 2.00-3.61	*bd*	2.39±0.43 2.00-3.31	*cd*
Colonizer – persister groups											
c-p 1	H=19.58 p=0.0006	63.3±76.6 0-210	*a*	4.1±4.0 0-12	*b*	3.0±4,7 0-13	*bd*	0.8±1.6 0-5	*cd*	1.6±1.4 0-5	*b*
c-p 2	H=25.81 p=0.0000	257.8±293.8 30-850	*a*	42.3±39.0 4-121	*b*	10.2±10.9 1-34	*c*	8.0±5.1 2-19	*c*	7.2±6.0 1-19	*c*
c-p 3	H=11.69 p=0.0198	2.2±6.7 0-20	*a*	13.9±18.1 1-53	*b*	10.3±11.6 0-27	*b*	18.8±24.1 0-68	*b*	5.9±7.0 1-20	*b*
c-p 4	p>0.05	33.3±45.6 0-140	*ac*	44.2±50.7 6-165	*ab*	19.2±29.6 0-90	*c*	10.6.±13.7 0-40	*c*	6.9±7.0 1-20	*c*
c-p 5	p>0.05	21.1±35.2 0-100		11.7±13.2 0-42		15.3±15.7 0-51		22.3±24.3 0-70		14.2±14.2 0-39	
Plant-parasite groups											
p-p 2	p>0.05	14.4±16.7 0-40	*a*	55.9±49.3 9-135	*b*	39.6±47.3 4-129	*ab*	30.2±32.6 6-102	*ab*	31.8±35.4 4-106	*ab*
p-p 3	H=12.27 p=0.0155	-	*a*	3.6±4.7 0-13	*b*	6.6±5.9 0-14	*b*	4.2±5.0 0-12	*b*	3.1±4.5 0-14	*b*
p-p 4	-	-						0.1±0.3 0-1		1.0±1.6 0-4	
p-p 5	p>0.05	-		0.2±0.7 0-2		0.6±1.7 0-5		6.8±20.3 0-61		4.0±0.9 0-30	

Abbreviations: Kruskal-Wallis *H* (K-W) and Mann-Whitney *U* (M-W) tests; Note: in a given line numbers followed by different letters differ significantly ($p<0.05$, M-W test);

bacterial feeders showed similar ranges (M-W p>0.005). Moreover, the proportion of bacterial and fungal feeders was more than 80% in the litter layer. The ratio of fungal to bacterial feeders (FF/BF) decreased in the following order L-S3-S4-S1-S2. Differences revealed within the nematode communities of the soil layers for both trophic groups are presented in Table 2.

Analysis of plant-feeding, omnivorous and predatory nematode abundances revealed significant differences only in the group of plant feeders between the L and S1 layers. In general, the proportion of bacterial- and fungal feeders decreased with depth, whereas the proportion of plant-feeders increased (Fig. 1). The generic richness and dominant genera of each trophic group differed between the layers, showing the highest specificity in the nematode communities of litter (Table 1).

The distribution of the sub-groups of plant-feeding nematodes in soil revealed a relative abundance of ectoparasites (PFd) that increased while epidermal cell and root hair feeders (PFe) decreased significantly with depth (Table 1). The group of nematodes feeding on lower plants (PFf) prevailed in the litter.

Both MI and PPI values, characterising the maturity of nematode communities in litter, were significantly lower as compared to all soil layers (M-W, p<0.05, Table 2). Further comparisons revealed a significant difference only for PPI between nematode communities in the S1 and S4 layers. MI and MI (2-5) values differed substantially, caused by the relatively higher proportion of

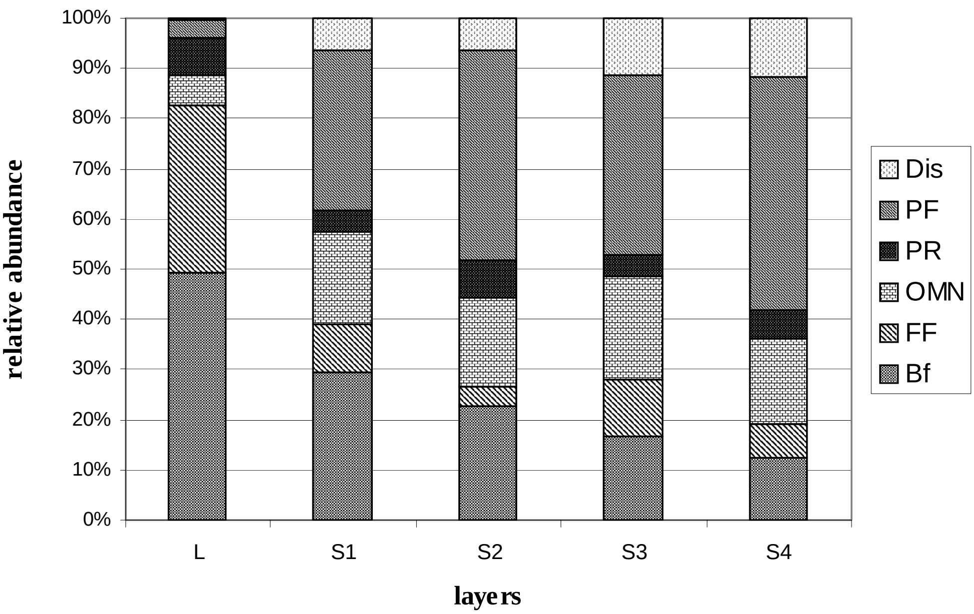

Fig. 1. Trophic structure of nematode communities along the litter-soil (L-S4) gradient. Trophic groups are presented with their relative abundances. Abreviations of the feeding types: bacterial feeders (Bf), fungal feeders (FF), omnivores (OMN), predators (PR), Plant feeders (PF), dispersal stages of animal parasites and dauer larvae (Dis).

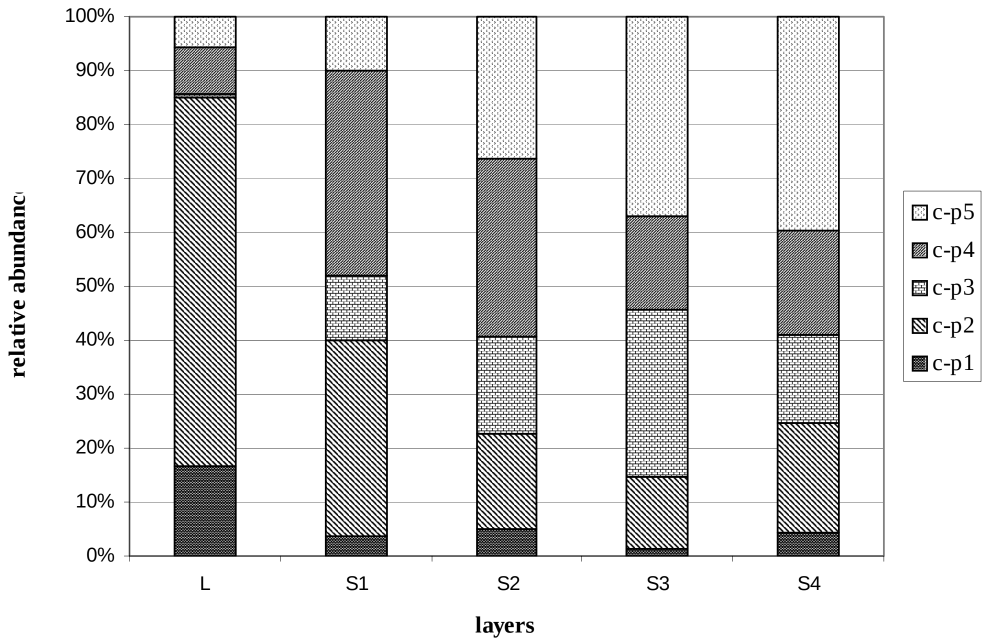

Fig. 2. Colonizer-persister (*c-p*) group distribution along the litter-soil (L-S4) gradient. Abreviations: c-p1, enrichment colonizers; c-p2, general colonizers; c-p3-5, persisters.

enrichment opportunists (*c-p*1 group) in the litter. In addition, the colonizer-persister ratio of nematode communities inhabiting litter was the most distinctive (Fig. 2) caused by the higher proportion of colonizers (*c-p*1 and *c-p*2 groups) and a lower proportion of the *c-p*3 group (M-W $p<0.02$). Further comparisons revealed some other differences in the distribution of colonizer-persister groups along the soil layers (Table 2), while plant-parasite groups showed equal distribution within the different soil depths.

Classification of assemblages and gradient analysis

The classification analysis based on the percentage similarity index distinguished two main groups: (i) nematode communities of litter (L) (cluster 1 in Fig. 3), and (ii) nematode communities of mineral soil (S1-S4) (cluster 2). Furthermore, within the second group two sub-groups were classified; (iii) nematode communities inhabiting the first soil layer (S1) (cluster 2') and (iv) nematode communities of the S2 to S4 layers (cluster 2''). Similarly, the first axis of the CA (eigenvalue 0.67, Fig. 4) clearly separated nematode communities inhabiting soil layers (S1 to S4) from those inhabiting litter (L). However, along the second ordination axis (eigenvalue 0.38) soil samples showed a gradient associated with the month of collection, thus clearly separating Autumn and Spring samples (U1 and U3 *vs* U2). In addition, the dominant genera are presented on the same ordination diagram (Fig. 4). The first two axes of the CA biplot explain 42.9% of the variance of the generic data.

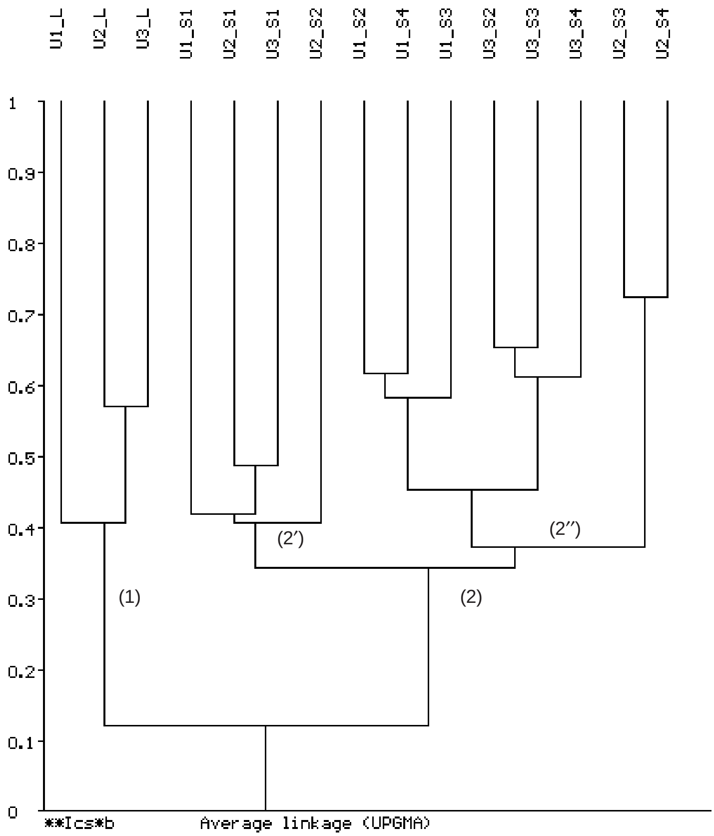

Fig. 3. UPGMA dendrogram based on Czekanovski–Sørensen similarity index (Ics*b), showing the classification of the nematode communities of litter (L) and soil layers (S1-S4). Numbers in brackets specify groups of: 1, litter; 2, mineral soil; 2' composed mainly of nematode communities of the first layer (S1) and 2" deeper soil layers (S2-S4). Abbreviations of collection dates: 31 October 1998 (U1) and 1999 (U3), and (U2) April 1999.

DISCUSSION

All analyses applied in the present study identified variation in the abundance, diversity and structure of nematode communities along the litter-soil gradient. The decrease in the relative nematode abundance with depth and the greatest diversity attributed to the superficial soil layers were general patterns observed for nematode vertical distributions in other forest habitats in Europe (Scotto la Massèse & du Merle, 1978; Popovici, 1980; Vinciguerra & Gianetto, 1987; Peneva & Nedelchev, 1994; Armendariz & Arpin, 1996). However, the relative abundance of nematodes in the organic layer of the studied site was very low (391±380 specimens/100 g fresh litter) and differed considerably from data obtained for other oak forests: e.g. 3606 and 3622

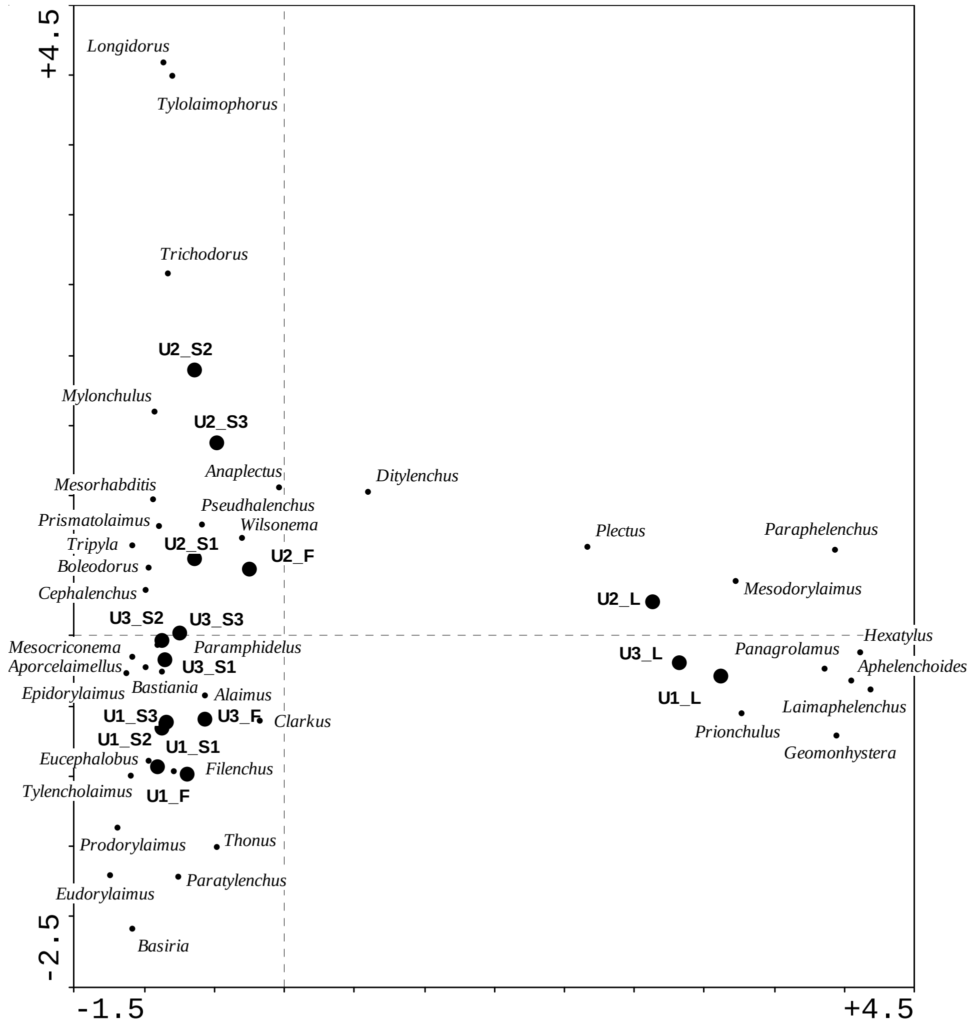

Fig. 4. Correspondence Analysis (CA) based on relative generic abundance data and downweighting of rare taxa. Most abundant genera are presented on the diagram. Abbreviations of the samples as in Fig. 1.

specimens /100 g litter (Vinciguerra & Gianetto, 1987); 973 ± 671 and 16656 ± 16980 specimens/100 g litter for sub-urban and rural forests, respectively (Mladenov *et al.*, *in litt.*); 11730 ± 14673 specimens/100 g, (Lazarova *et al.,* 2004).

Long-term studies on lead (Pb) deposition in soil-plant system from the study site revealed a high concentration of Pb in litter and the A1 soil horizon (291.13 *ppm* and 89.99 *ppm*, respectively; average Pb content for Bulgarian soils = 39.0 *ppm*; Bratanova-Doncheva, this volume). Thus, the impact of the city air pollution and emissions produced by the heavy traffic of the highway nearby diminished with depth, the litter and upper soil layers being the most exposed surfaces and, subsequently, most altered by the highest concentrations of pollutants. Similar results have been obtained from an extended study on ecosystem processes along an urban-rural gradient in oak forests in the USA (Pouyat *et al.*, 1994; Pouyat *et al.*, 1995; McDonnell *et al.*, 1997). Both fungivorous microinvertebrates (including nematodes) and litter fungi biomass were inversely correlated with soil heavy metal concentrations (Pouyat *et al.*, 1994). The results of these studies indicated increased litter decomposition and nitrification rates in urban forests (Pouyat *et al.*, 1995; McDonnell *et al.*, 1997). These authors hypothesized that poorer leaf litter quality is one of the reasons for the changes observed in C and N dynamics. The uptake of airborne heavy metals and harmful gases by mosses is well known and their influence on moss microfauna has been shown (Steiner, 1994b). Furthermore, when taken up by bacteria and fungi, Pb and Cd have an inhibitory effect on the reproductive rate of fungal- and bacterial-feeding nematodes (cited by Steiner, 1994b). Similarly, Popovici (1992) reported a significant decrease in nematode abundance, correlated with very high concentrations of Pb and Cu in forest litter. This was accompained with a decrease in diversity and MI together with changes in the functional structure of nematode communities. A feature of the litter nematode communities in the urban forest studied was the high generic richness (27 genera recovered) as compared to 13-29 genera reported for litter of native oak forests (Popovici, 1995, Lazarova *et al.*, 2004).

Nematode abundance in the studied soil layers was comparable with nematode densities reported for the same types of habitats (between 1780 and 2775 specimens/100 g in 0-3cm soil layer and between 1845 and 1990 specimens/100 g from 4-6cm soil depth, Vinciguerra & Giannetto 1987; 103-212 specimens/100 g soil, Lazarova, 2000). However, soil nematode communities appeared to be very rich compared to other oak forests in Europe. Overall, 86 genera were detected in the four soil layers *vs* 46-64 genera registered in similar habitats in the Czech Republic, Romania and Bulgaria (Bartošová & Háněl, 1994; Háněl 1996a, 2000; Lazarova *et al.*, 2004). This finding is in contradiction with studies on the impact of different disturbances on nematode communities. A reduced taxonomic richness and/or functional diversity of soil nematode communities have been observed with increased heavy metal contamination (Popovici, 1992, Popovici & Korthals, 1995; Trett *et al.*, 2000; Georgieva *et al.*, 2002) and acidity (Dmowska, 1993; Ruess *et al.*, 1996; Wassilewska, 1996). We relate the high nematode diversity to be influenced by human management and the peculiarities of the forest. The previous landscape of this park is known to be arable land with scattered single oak trees (Kovachev, 2001). Subsequently, numerous non-native tree species have been planted and thus new plant parasite nematodes species were probably introduced. Consequently, the recent nematode fauna of the studied site is probably formed by mixing of autochthonous and allochthonous species. For example, nematodes of the genus *Cephalenchus*, one of the dominant genera in the mineral soil, is known as a pest in forest nurseries (Gowen, 1971). Furthermore, the patchiness of the above-ground plant communities affect the spatial and temporal heterogeneity in the organic layer, which would result in different microhabitats (e.g. leaf litter types, twigs, etc.) being colonized by specific communities (Beare *et al.*, 1995). The large size of the park area and its age (more than 90 yr) could be additional factors that possibly influence the nematode diversity positively.

The distribution of nematodes based on their life-history strategy (*c-p*) groups and the maturity indices (MI and PPI) characterise the maturity of nematode communities. There are no data available presenting the variability of these community parameters along litter-soil gradients. Our study revealed prominent differences in almost all parameters when comparing litter and soil nematode assemblages, while within soil depth differences were more pronounced in the distribution of colonizers (*c-p* 1 and 2), persisters belonging to the *c-p* 4 group, and Plant Parasite Index.

The average MI values for soil were comparatively higher (3.12-3.57) than those recorded for other European forests (e.g. The Netherlands, 2.01-2.36 (de Goede & Dekker, 1993); Czech Republic, 2.00-2.62 (Háněl, 1996a,b,c; 1998), Poland, 2.10-2.70 (Wasilewska, 1996) and Germany, 2.16-2.58 (Ruess, 1995) but similar to those recorded for several natural Bulgarian forests (average value 3.48, Lazarova, 2000). Ruess (1995) recorded a high MI value for a relatively undisturbed forest in Germany. The percentage of persistor nematodes (*c-p* 4-5 groups), which are most sensitive to environmental stress, was also higher (> 49%) as compared to those of coniferous forests in The Netherlands and Scandinavia (0.8-8.1% and 11.7-24.4%, respectively (de Goede & Dekker, 1993) and Poland (5-9% (Wasilewska, 1996). Again, the proportion of nematodes with a K-life history strategy (*c-p* 4-5) was comparable to data from Bulgarian forests (average value 61% ± 11.9, Lazarova, 2000).

It appeared that urbanisation mostly affected the nematode communities in the litter. Nematode abundance and proportion of general colonizers (*c-p*2) proved to be the most suitable parameters for assessing disturbance in urban forests.

AKNOWLEGMENTS

The authors thank Dr M. Grozeva, Institute of Forestry, Sofia for helpful consultations, D. Gradinarov, Faculty of Biology, Sofia University for consulting materials of entomopathogenic nematodes, and Prof. D.J.F. Brown, Central Laboratory of General Ecology, Sofia for critical reading of the manuscript. The work was supported by the Bulgarian Academy of Sciences. The work is supported by National Scientific Research Fund (grant No: B-1305/03).

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Myriapoda (Chilopoda, Diplopoda) in Urban Environments in the City of Sofia

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Abstract

This is a first attempt at studying myriapods in urban environments in the city of Sofia. It resulted in the discovery of 21 centipede and millipede species, representing 15 genera and 10 families. All records are from highly disturbed urban habitats like city parks, yards and houses. The most numerous myriapod species in Sofia are: *Megaphyllum bosniense*, *Lithobius forficatus*, *L. lucifugus* and *Polydesmus complanatus*. The diversity of centipedes is much higher in urban environments in Sofia compared to millipedes. In the Chilopoda, Lithobiomorpha is represented by a high number of specimens and a high species diversity. *Oxidus gracilis* (C.L. Koch, 1847) is a new species to the fauna of Bulgaria.

Key words

Chilopoda, Diplopoda, faunistics, synanthropes, Sofia.

INTRODUCTION

The myriapods are an object of recent investigations in suburban and urban environments of some big European cities. Most authors, however, only deal with either centipedes or millipedes. Enghoff (1973) and Davis (1979) provided information for the myriapods of Copenhagen and London, respectively. Andersson (1983) studied the centipede communities of Göteborg, Zapparoli (1992) of Rome, Wytwer (1995) of Warzaw and Lesniewska (1996) of Poznan. The myriapod fauna of many other cities in Europe, and particularly that of the Balkan peninsula remains, until now, unknown.

Information on the Myriapoda found in urban environments in Bulgaria is scarce and concerns mainly some man-made habitats, i.e. artificial galleries, vineyards and Botanical Gardens outside big cities (Table 1). Ribarov (1985, 1986a,b, 1989) recorded centipedes collected in city parks and houses from the city of Yambol (south-eastern Bulgaria). Records on millipedes in

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Table 1. Myriapoda in suburban and urban environments in Bulgarian cities.

Species	City: Environments/ Author
Chilopoda	
Eupolybothrus transsylvanicus (Latzel, 1882)	Yambol: basement of a house (Ribarov, 1985, 1986a)
Lithobius erythrocephalus (C.L. Koch, 1847)	Balchik: Botanical Gardens (Negrea, 1965); Yambol: city park (Ribarov, 1985)
L. forficatus (Linnaeus, 1758)	Yambol: city park (Ribarov, 1985)
L. latro Meinert, 1872	Yambol: city park (Ribarov, 1985, 1986a)
L. lucifugus L. Koch, 1862	Yambol: city park, house (Ribarov, 1985)
L. muticus C.L. Koch, 1847	Yambol: city park (Ribarov, 1985, 1986a)
L. nigripalpis L. Koch, 1867	Yambol: quarry in a city park (Ribarov, 1985, 1986a)
L. peregrinus Latzel, 1880	Yambol: city park (Ribarov, 1985, 1986a)
L. viriatus Sselivanoff, 1878	Yambol: city park (Ribarov, 1985, 1986a)
L. (Monotarsobius) crassipes L. Koch, 1862	Yambol: bathroom of an apartment, city park (Ribarov, 1985, 1986a); Balchik: Botanical Gardens (Negrea, 1965)
L. (M.) curtipes C.L. Koch, 1847	Panagyurishte: the Museum's yard (Ribarov, 1989)
L. (Sigibius) burzenlandicus Verhoeff, 1931	Yambol: city park (Ribarov, 1985)
Lamyctes emarginatus (Newport, 1844)	Yambol: city park (Ribarov, 1985, 1986a)
Scutigera coleoptrata (Linnaeus, 1758)	Sofia: City Bath (Chritovich, 1892); Kazanlak (Jurinich, 1904); Yambol: city park (Ribarov, 1985)
Cryptops anomalans Newport, 1844	Yambol: city park (Ribarov, 1985)
C. croaticus Verhoeff, 1931	Yambol: city park (Ribarov, 1985)
C. hortensis (Donovan, 1810)	Sofia: Botanical Gardens of the University of Sofia (Matic & Golemansky, 1969)
C. parisi Brolemann, 1920	Yambol: city park (Ribarov, 1985)
Geophilus linearis C.L. Koch, 1835	Panagyurishte: City Park (Ribarov, 1989)
Clinopodes flavidus C.L. Koch, 1847	Yambol: city park (Ribarov, 1985)
Pachymerium ferrugineum (C.L. Koch, 1835)	Yambol: city park (Ribarov, 1985, 1986b)
P. folkmanovae (Dobroruka, 1966)	Yambol: city park (Ribarov, 1985, 1986b)
Dignathodon microcephalus (Lucas, 1846)	Yambol: city park (Ribarov, 1985, 1986b)
Henia illyrica (Meinert, 1870)	Yambol: city park (Ribarov, 1985)
Strigamia acuminata (Leach, 1815)	Yambol: city park (Ribarov, 1985, 1986b)
Strigamia crassipes (C.L. Koch, 1835)	Yambol: city park (Ribarov, 1985, 1986b)
Himantarium gabrielis (Linnaeus, 1767)	Yambol: city park (Ribarov, 1985, 1986b)
Diplopoda	
Glomeris hexasticha Brandt, 1833	Sofia: Knyazhevo (Strasser, 1966)
Polydesmus renschi Schubart, 1934	Sofia: Knyazhevo (Strasser, 1966)
Leptoiulus trilineatus (C.L. Koch, 1847)	Sofia: Knyazhevo (Strasser, 1966)
Leptoiulus borisi Verhoeff, 1926	Sofia: Knyazhevo (Strasser, 1966)
Cylindroiulus boleti (C.L. Koch, 1847)	Sofia: Knyazhevo (Strasser, 1966)
Cylindroiulus arborum Verhoeff, 1928	Sofia: Knyazhevo (Strasser, 1966)
Cylindroiulus horvathi (Verhoeff, 1897)	Sofia: Knyazhevo (Strasser, 1966)
Megaphyllum unilineatum (C.L. Koch, 1838)	Sofia: Knyazhevo (Strasser, 1966)
Megaphyllum bosniense (Verhoeff, 1897)	Sofia: Knyazhevo (Strasser, 1966)
Pachyiulus hungaricus (Karsch, 1881)	Sofia: Knyazhevo (Strasser, 1966)
Nopoiulus kochii (Gervais, 1847)	Sofia: Knyazhevo (Strasser, 1966)

suburban and urban habitats are, however, much less known and are derived chiefly from Strasser (1966) for some of the outskirts of Sofia.

The present study records the myriapods, recently collected from the city parks of Sofia by Ivaylo Dedov and Ivaylo Stoyanov (Central Laboratory of General Ecology, Bulgarian Academy of Sciences), as well as some earlier collections from the National Museum of Natural History (NMNH). This forms part of a project aiming at inventorying the invertebrate fauna of Sofia (National Science Fund, Grant No. B-808), within the framework of GLOBENET - a global network for monitoring biodiversity changes across urban-rural landscapes (Niemelä *et al.*, 2000).

MATERIALS AND METHODS

Most of the material was collected using Barber pitfall trapping in four of the main city parks in 1998 and 1999. The parks lie along four axes passing through the city centre: north (Severen park), south (Loven park), west (Zapaden park) and east (Knyaz Borisovata gradina) (Dedov & Penev, 2000). For details on the sampling sites and the general project model see Penev *et al.* (this volume).

Additional hand collecting was carried out in these parks as well as in some yards and open landscapes between buildings. Myriapod material from the NMNH, which were gathered in Sofia and its suburbs at the beginning of the twentieth century were also examined. All centipedes are preserved in 70% ethanol. Damaged and/or juvenile specimens, that could not be reliably determined, were excluded from this study. The entire collection is preserved in the Department of Non-Insect Invertebrates in the NMNH.

STUDY AREA

Sofia lies in the Sofia Plain, which is situated between the Stara planina and Vitosha mountains. A ring motorway around the city delineates its boundaries, although rural habitats beyond this road are also influenced by human activities. The average altitude of the city is 500 m a.s.l. The city maintains many green territories linked through green "corridors" to the natural forests of the suburbs, i.e. Vitosha, Stara planina, Lozenska and Luylin mountains.

RESULTS

Overall, 476 specimens belonging to 21 species, 15 genera and 10 families were identified (Table 2). Sixteen species belong to the Chilopoda and 5 to the Diplopoda. Three diplopod species (two Julidae and one Chordeumatida) could not be identified due to the scarcity of samples. Among the Chilopoda, Lithobiidae is represented by the highest number of specimens and species (241/7, respectively). In the Diplopoda, Julidae was most often collected in urban habitats (178/2). The most abundant species were: *Megaphyllum bosniense* (175 individuals), *Lithobius forficatus* (131), *L. lucifugus* (79) and *Polydesmus complanatus* (31). The next nine species were represented by more than one individual: *L. nigripalpis* (10), *L. beroni* (10), *E. transsylvanicus* (9), *Oxidus gracilis* (6),

Table 2. Myriapoda species collected in Sofia. Abbreviations: U1-Knyaz Borisovata gradina, U2-Zapaden park, U3-Severen park, U4-Loven park.

Family	Species	No	Locality
Chilopoda			
Lithobiidae	*Lithobius* (s.str.) *agilis* C.L. Koch, 1847	2	Sofia; Mladost
	Lithobius forficatus (Linnaeus, 1758)	131	U1-U4
	Lithobius lucifugus L. Koch, 1862	79	U1-U4; Seminariyata
	Lithobius nigripalpis L. Koch, 1867	10	U1
	Lithobius (Sigibius) beroni Negrea, 1965	10	U1
	Pleurolithobius patriarchalis (Berlese, 1894)	1	U1
	Eupolybothrus transsylvanicus (Latzel, 1882)	9	U4; Lozenets: buncker; Knyazhevo: house yard
Geophilidae	*Clinopodes polytrichus* (Attems, 1903)	2	U3; Knyazhevo
	Pachymerium ferrugineum (C.L. Koch, 1835)	2	Sofia
	Geophilus sp.	1	U1
Dignathodontidae	*Henia illyrica* (Meinert, 1870)	2	U1
Schendylidae	*Schendyla nemorensis* (C.L. Koch, 1836)	1	U4
Scolopendridae	*Cryptops anomalans* Newport, 1844	3	U3; Knyazhevo: house yard
	C. hortensis (Donovan, 1810)	1	Botanical Gardens of the University of Sofia
	C. parisi Brolemann, 1920	1	U4
Scutigeridae	*Scutigera coleoptrata* (Linnaeus, 1758)	4	Sofia
Diplopoda			
Polydesmidae	*Polydesmus complanatus* (Linnaeus, 1761)	31	U1, U2, U4
Paradoxosomatidae	*Oxidus gracilis* (C.L. Koch, 1847)	6	Botanical Gardens of the University of Sofia
Julidae	*Megaphyllum bosniense* (Verhoeff, 1897)	175	U1, U3, U4
	Cylindroiulus sp.	3	U1
Chordeumatidae	*Melogona broelemanni* (Verhoeff, 1897)	2	U2
Total	**21 species**	**476**	**individuals**

Cryptops anomalans (3), *Cylindroiulus* sp. (3), *Melogona broelemanni* (2), *Lithobius agilis* (2) and *Clinopodes polytrichus* (2). Five species: *Pleurolithobius patriarchalis*, *Schendyla nemorensis*, *Cryptops hortensis*, *C. parisi* and *Geophilus* sp. were collected only once.

Seven species were identified among the materials sampled in Sofia during the 1930's. These are: *Clinopodes polytrichus*, *Pachymerium ferrugineum*, *Henia illyrica*, *Scutigera coleoptrata*, *Lithobius forficatus*, *L. lucifugus* and *L. agilis*. Of these, *P. ferrugineum*, *H. illyrica* and *S. coleoptrata* have not been recollected recently, although their occurrence in Sofia is quite probable.

DISCUSSION

The occurrence and dynamics of the local fauna of Sofia is directly linked to the impacts humans have on the environment. These include: (a) fragmentation of the natural ranges of autochthonous species that occurred in the region prior to urbanisation; (b) introduction of allochthonous species; (c) expansion of xerophilic species from the environs of Sofia into free ecological spaces "opened" due to the fragmentation of forested habitats; and (d) penetration of mesophilic species from deciduous forests situated around Sofia into city parks (Dedov & Penev, 2000).

Present data are only an attempt for an analysis of the distribution, and possible reasons for it, of the local myriapod fauna. More intensive collecting through different sampling methods like sifting of leaf litter, Berlese funnels, light traps and hand collecting could result in increasing the species list. Sampling should also take place in various micro and macro habitats like forests, open and rocky terrain, buildings, artificial galleries, under stones and logs. Characteristics of some of the species collected are given below.

Lithobius nigripalpis L. Koch, 1867

This eastern Mediterranean species is widespread in Bulgaria, known also to exist in urban habitats (Ribarov, 1985, 1986a). Until recently, *L. nigripalpis* has only been found in the Knyaz Borisovata gradina, although it is also widespread in rural habitats near Sofia: Boyana (Vitosha Mts) and Belidie Han (Stara planina Mts). Therefore, the populations in Sofia are either autochthonous, or a result of a recent invasion from the neighbouring mountains through city greens.

Lithobius (Sigibius) beroni Negrea, 1965

This species is widespread in Bulgaria and was recently discovered in Northern Greece. It is morphologically similar to *L. micropodus* (Matic, 1980) but differs in having accessory apical claws on the penultimate legs and also a quite different spinulation pattern. Like *L. nigripalpis*, it has been found in the Knyaz Borisovata gradina and in the Lozenska planina Mountain, near Sofia. *L. beroni* is probably representing an autochthonous element in the terrestrial fauna of Sofia.

Pleurolithobius patriarchalis (Berlese, 1894)

This eastern Mediterranean species is widespread in the southern regions of Bulgaria with the northern border of its range passing through the Stara planina Mts (Klisura). *P. patriarchalis* is rare in the city fauna of Sofia, as only one specimen has hitherto been caught in the Knyaz Borisovata gradina. Its presence in Sofia is probably due to an introduction, as it might have been brought with soil or plants from more southern regions of the country. No natural populations of this species have yet been found in or near Sofia.

Eupolybothrus transsylvanicus (Latzel, 1882)

Widespread in Bulgaria, this species has been reported to exist also in urban habitats (Ribarov, 1985, 1986a). It was collected with a pitfall trap in the Loven park and seems to be absent from the other three city parks. There are other records as well, for example from a yard and a bunker. Natural populations of *E. transsylvanicus* occur in the forests surrounding Sofia, i.e. in Vitosha and Lozenska planina mountains, and its presence in urban environments is probably due to natural dispersion.

Scutigera coleoptrata (Linnaeus, 1758)

Mediterranean by origin, this species has been introduced to many regions of the world. In Bulgaria, it inhabits natural and urban habitats like caves, artificial galleries, rock crevices, buildings and different open landscapes in especially southern regions. It is a common synantrope in almost every human settlement.

Clinopodes polytrichus (Attems, 1903)

This species resembles *C. flavidus* C.L. Koch and differs chiefly in the presence of dense hair on the first sternites. Although only two specimens of this species were found in Severen park and Knyazhevo, natural populations do exist in the environs of Sofia, i.e. Belidie Han (Stara planina Mts), Mecha polyana (Vitosha Mts) and Shtarkelovo gnezdo and Polovrak Peak (Lozenska planina Mts). *C. polytrichus* appears to be an indigenous element in the fauna of Sofia.

Henia illyrica (Meinert, 1870)

This species is widespread in Bulgaria, known also to exist in urban habitats like artificial galleries and the city park of Yambol (Ribarov, 1985). Two specimens were hand collected from Knyaz Borisovata gradina some 60 years ago, but not again. Natural populations of *H. illyrica* exist in the environs of Sofia, i.e. Dragalevtsi and Zheleznitsa (Vitosha Mt), so the finds from Sofia are probably of autochthonous origin.

Pachymerium ferrugineum (C.L. Koch, 1835)

Only two individuals of this species, collected 60 years ago, were discovered among the materials kept in the NMNH. The species is widespread in Bulgaria, known to also exist in urban habitats (Ribarov, 1985, 1986b).

Geophilus sp.

A single specimen with 39 pairs of legs was found in the Knyaz Borisovata gradina. Although undoubtedly representing a mature individual, due to the scarcity of the material, and its small size I was unable to identify this individual to species level.

Schendyla nemorensis (C.L. Koch, 1836)

It is the second finding of this widespread European synantrope in Bulgaria since Kaczmarek (1969). Only one specimen was hand collected in Loven park but it is likely that more individuals are to be found here and elsewhere in Sofia.

Megaphyllum bosniense (Verhoeff, 1897)

This is the most numerous species collected, occurring in the Knyaz Borisovata gradina, in Severen and Loven parks but not in Zapaden park. As Strasser (1966) and Golovatch & Kondeva (1992) have registered its existence in various localities in the Vitosha and Lyulin mountains, the Sofia populations are most likely of indigenous origin.

Cylindroiulus sp.

Only three premature specimens were found among the examined samples. They probably belong to the ubiquitous *C. boleti*.

Oxidus gracilis (C.L. Koch, 1847)

Probably eastern Asiatic in origin, this species has largely been introduced into Europe through cargo from that region. It is widespread in hot houses in Europe, but is also found in natural habitats around cities. Our material is only from the Botanical Gardens of the Sofia University, and could hardly be considered a native inhabitant of the terrestrial fauna of Sofia. It has never been registered in Bulgaria and is, therefore, considered a new species to the region.

CONCLUSIONS

The following primary results are subtracted from the present study.

Presently, the diversity of centipedes is much higher in urban environments in Sofia compared to millipedes. This relationship might change in the future when more habitats and regions of the city are sampled.

Similar to results from Zapparoli (1992) for the city of Rome, Lithobiomorpha (Chilopoda) were most abundant and species rich in urban environments in Sofia.

The most abundant myriapod species in the city parks of Sofia were: *Megaphyllum bosniense*, *Lithobius forficatus*, *L. lucifugus* and *Polydesmus complanatus*.

According to Zapparoli (1992) the geophilomorphs are more sensitive to habitat transformation than other groups of centipedes. This is reflected in our data because only 7 geophilomorph individuals, out of a 474 myriapod individuals examined were found in the city greens. Another possible explanation for the scarcity of this group is in the sampling methods used. Many geophilomorphs, cryptopsids and some small sized millipedes are poorly collected by pitfall traps, while sifting of leaf litter and hand picking are better techniques for their discovery.

At least two species, *Oxidus gracilis* and *Pleurolithobius patriarchalis* are introduced from other regions. While the latter species maintains rural populations in the southern parts of Bulgaria, *O. gracilis* is a clear anthropochore, which has been transported with soil and plants from other hothouses in Europe or America. *Cryptops hortensis* was only found in the Botanical Gardens at the University of Sofia although rural populations near Sofia also exist.

Two gelophilomorphs, *H. illyrica* and *P. ferrugineum*, together with the house centipede (*Scutigera coleoptrata*) are represented in the city fauna by materials gathered some 60 years ago. The current inventory failed to trace them within the city boundaries.

ACKNOWLEDGMENTS

I thank Dr Ivaylo Dedov and Ivaylo Stoyanov for allowing me to study their collection of myriapods from the parks of Sofia. Ms Rouzha Spasova, student of Ecology at the Sofia University sorted the myriapods from all other trapped invertebrates. For editing the English I extend my best thanks to Dr Johan Kotze. This work was partly supported by the National Scientific Research Fund (grant No. B-808/1998).

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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-

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 307-318

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).

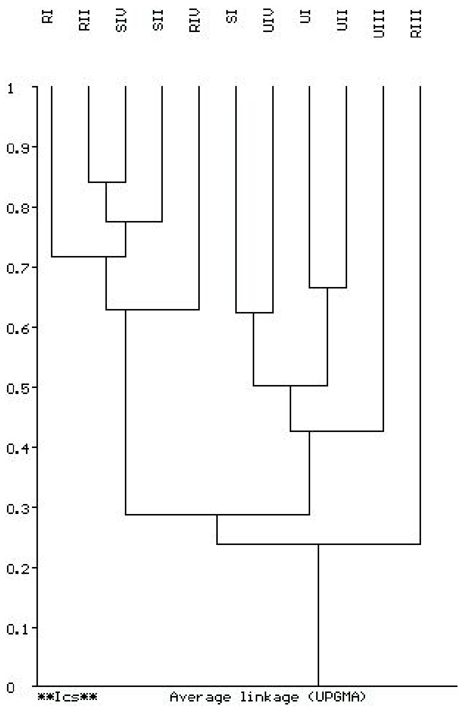

Fig. 1. Group average clustering dendrogram of the terrestrial snail assemblages based on the Czekanowski-Sörensen similarity index for presence-absence data. For abbreviations of site names see **Material and methods**.

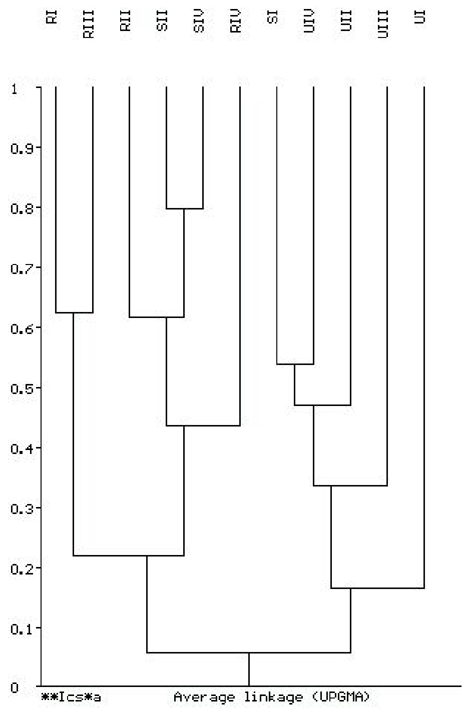

Fig. 2. Group average clustering dendrogram of the terrestrial snail assemblages based on the Czekanowski-Sörensen similarity index for abundance data. For abbreviations of site names see **Material and methods**.

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

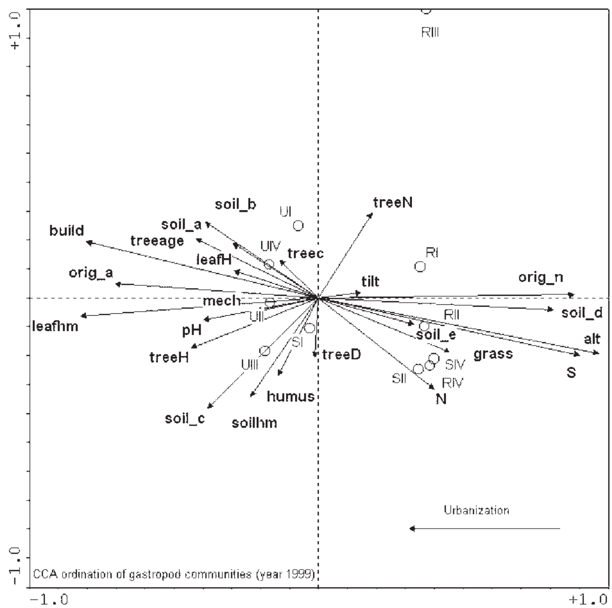

Fig. 4. Correspondence analysis (CCA) ordination diagram of the species and localities. (Forward selection of environmental variables was used to select the factors with best possible explanatory value). For abbreviations of environmental variables see **Environmental data set**.

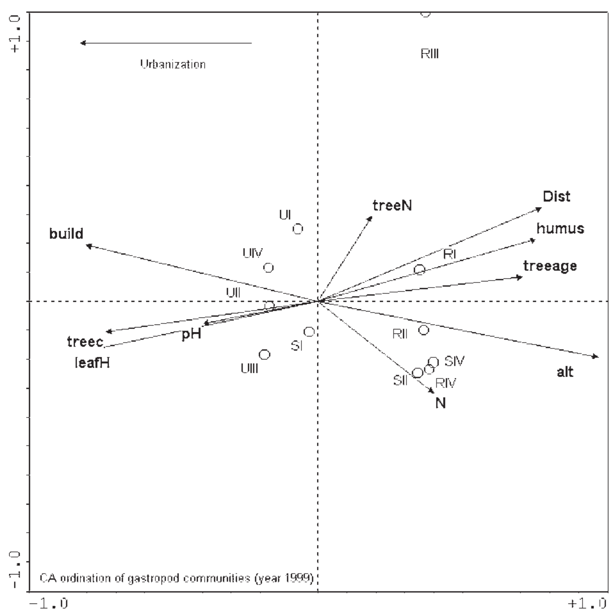

Fig. 5. Correspondence analysis (CA) ordination diagram of the localities and environmental factors. For abbreviations of environmental variables see **Environmental data set**.

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.

AKNOWLEDGEMENTS

We would like to thank Mr. Ivailo Stoyanov for his help during the field work and to Dr. D.J. Kotze for editing the English text. This work was partly supported by the National Scientific Research Fund (grant No. B-808/1998).

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The Harvestmen Fauna (Opiliones, Arachnida) of the City of Sofia (Bulgaria) and its Adjacent Regions

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Abstract

This is the first paper dealing with the opilionid fauna of urban park-areas (located in the city of Sofia) in Bulgaria. In addition, the harvestmen fauna of the regions surrounding the city of Sofia is summarized. The faunistic list presents data on the 32 species hitherto found in the covered area. Two of them (*Trogulus closanicus* and *Rilaena serbica*) are new to the Bulgarian fauna, and a further one, referred herein as *Rilaena* cf. *serbica*, is currently of unclear taxonomical status. A detailed analysis of the opilionid assemblages (both local and regional) under study is provided, and hypotheses concerning the genesis and development of the urban fauna are presented.

INTRODUCTION

Although the opilionid fauna of Bulgaria is relatively well known as being represented by 57 species belonging to 31 genera and 6 families (Staręga, 1976, Juberthie, 1991, Beron & Mitov, 1996, Mitov, 1994, 1995a, 1997b, 2001, 2002, 2003a,b, and present study), data concerning the chorology and ecology of this animal group in Bulgaria are still very scarce.

With increasing anthropogenic pressures, caused mainly by the migration of rural populations towards the heavily developed cities of Bulgaria and the parallel process of increasing the level of anthropogenic stressors (especially during the last ten years), the need for specialized urban-faunistic and urban-ecological investigations of the Opiliones has increased. The results of such research could be used in the future as a baseline for comparison and analysis of the anthropogenic impacts and for determining the change in status of these animals.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 319-354

Despite the fact that Sofia is the largest city (with more than 1 million inhabitants and covering an area of more than 190 km^2) and the capital of Bulgaria, its opilionid fauna has not been investigated until now. In the literature there are only scarce and scattered data available – only four harvestmen species were recorded – *Carinostoma ornatum* and *Phalangium opilio* (see Staręga, 1976), *Opilio saxatilis* (Šilhavý, 1956) and *Opilio parietinus* (Šilhavý, 1956; Staręga, 1976). Moreover, the territory of the Sofia Kettle that surrounds the city has been even less investigated – only *Zachaeus crista* was mentioned (sub *Zacheus crista*) by Staręga (1976).

Keeping this in mind, the first aim of the present paper is to contribute to the knowledge of the opilionid fauna of the city of Sofia and its surroundings (referred to here as the Sofia Kettle, and the bordering mountains). Our second aim will be to present an analytical overview of the urban and non-urban opilionid assemblages, and subsequently to present hypotheses on the origin of the fauna of the city of Sofia on the basis of the faunal similarities found.

MATERIAL AND METHODS

This study is based on all the available up-to-date Opiliones material, collected within the borders of the city of Sofia, and in the regions surrounding it.

To complete the faunistic list, literature data on harvestmen species previously recorded, but left unsampled throughout the intensive sampling programme were also included. Due to the comparative aims pursued with the present research, all records from caves (including both endemic and widespread species) were not included neither in the list, nor in the analyses.

The sites

A significant part of the collected Opiliones originate from a set of permanent sampling sites (coded as: R1, R2, R3, R4 (Rural sites), S1, S2, S4 (Suburban sites), U1, U2, U3, and U4 (Urban sites)) where the main sampling activities were concentrated for a period of two years (1998-1999). All these were chosen as to be positioned in *Quercus*-formations, mainly because this vegetation type was characteristic for the geographic region of interest, but as a result of the strong anthropogenic influence during the last 300 years, it has almost vanished or has been strongly degraded (see Stoyanov, 1937; Kunchev & Koseva, 1990). For a brief description of these sites see Niemelä *et al.* (2002), a more detailed review is published by Penev *et al.* (this volume). Additionally, many Opiliones were less systematically collected by hand in various parts of the city – in the great parks, and in the smaller gardens scattered through the highly urbanised city core (as indicated in the faunistic list). Also, much harvestmen material was obtained from the geographical regions (defined by Georgiev, 1991; Nikolov & Yordanova, 1997) surrounding the city of Sofia – i. e. the Sofia Kettle, West Stara Planina range, Zavalska Mt., Lyulin Mt., Vitosha Mt., Plana Mt. and Sredna Gora Mt.

The material examined

Along the material sampled during the main sampling programme, a considerable amount of harvestmen material, originating from their own research (mainly in the surrounding regions), was kindly provided by many colleagues (see Acknowledgements). Material from the collections of the National Museum of Natural History (Sofia) was also studied.

All material, except the latter, is currently in the private collection of the senior author.

The following opilionid material was utilized for diverse comparative needs:

8♂♂, 1♀ *Trogulus closanicus* (Germany, Sonnenberg, Timmenrode, Nördl. Harzvorland, 1995/96, det. Chistian Komposch, in the collection of P.M.), 3♂♂, 5♀♀ *Rilaena serbica serbica* Karaman, 1992 (Yugoslavia, Serbia, Zlatibor Mt.: Tornik, 1300 m, 08.VII.1995, leg. & det. Ivo M. Karaman – 1♂, 3♀♀; Šargan, 800 m, 08.VI.1996, leg. & det. Ivo M. Karaman – 2♂♂, 2♀♀; all in the collection of P.M.) and 2♂♂, 2♀♀ (Paratypes) *R. serbica kopaonica* Karaman, 1992 (Yugoslavia, Serbia, Kopaonik Mt., Sunčana Dolina, 1600 m, 10.VIII.1981, leg. & det. Ivo M. Karaman; in the collection of P.M.).

The classification and nomenclature of harvestmen follow closely Martens (1978). The only exceptions are *Trogulus closanicus* Avram, 1971, treated after Chemini (1984), and the genus *Zacheus*, for which we have adopted the spelling *Zachaeus* (after Crawford, 1992).

For facilitating a future comparative analysis of the phenolocical data, we have also included summarized information (based on the material examined) about body length and the presence of eggs in the egg reservoir (=*uterus internus*).

The collecting techniques

The main sampling sites (see above) were sampled by a set of 12 uncovered and unbaited pitfall traps (plastic cups with mouth diameter of 8.5 cm and a volume of 500 ml), randomly placed at least 10 meters apart, filled with a 4% formaldehyde solution in vinegar, which were emptied approximately every month starting from April and ending in October in 1998 and 1999 (thus obtaining 7 monthly samples). In the concurrent sampling programmes (not especially targeted at Opiliones), carried out by some of our colleagues, the placement of the traps was similar, the main difference being the collecting fluid and/or the bait used (see Abbreviations used and Results).

The analyses

Since we primarily aimed at emphasizing the similarities, instead of the peculiarities when comparing the various fauna, the full faunistic table containing the presence of each taxon at each locality or region (Table 1, 2) was reduced by excluding taxa that appeared only at one locality. The region of Zavalska Mt. was also excluded from the analysis, because its fauna (hitherto only 4 known species) is clearly poorly investigated. Subsequently, this reduced matrix was subjected to a Correspondence Analysis procedure (e. g. Hill, 1974), and the ordination diagram was plotted using its recently described and still little known joint property of reciprocal averaging and dual scaling (Thioulouse & Chessel, 1992). So the species and the sites are plotted at identical scales and permit a convenient interpretation in view of the graphical representation of the species amplitudes and sample diversity (perimeter of stars in the corresponding plot). The analyses were performed with the ADE-4 package (Thioulouse *et al.*, 1997).

Table 1. Summary of the opilionid fauna of the city of Sofia and the surrounding regions. SOF=city of Sofia, SOFK=Sofia Kettle, SPW=Western Stara Planina Mts., Z=Zavalska Mt., L=Lyulin Mt., V=Vitosha Mt., PL=Plana Mt., SG=Sredna Gora Mt.

	SOF	SOFK	SPW	Z	L	V	PL	SG
Nemastoma lugubre			+					
N. bidentatum sparsum			+					+
Paranemastoma radewi			+			+	+	+
P. aurigerum ryla						+		
Pyza bosnica			+		n	+		+
Histricostoma drenskii						n		+
Carinostoma ornatum	+	n	+	+		+		+
Mitostoma chrysomelas			+			+		
Dicranolasma scabrum			+			+		
Trogulus tricarinatus	n	n	+		n	+		+
Trogulus nepaeformis			+					
Trogulus closanicus **					n	n		
Phalangium opilio	+	n	+		+	+		+
Opilio parietinus	+		+			+		+
Opilio saxatilis	+	n	+		+	+		+
Opilio dinaricus	n		n		n	+		n
Opilio ruzickai	+		+		n	+		+
Rilaena triangularis			+					
Rilaena balcanica			n	+	n	+	+	n
Rilaena serbica **			n					
Rilaena cf. serbica **	n		n		n	n		n
Lophopilio palpinalis			+		n	+		+
Rafalskia olympica						+		n
Zachaeus crista	n	+	+		n	+		+
Zachaeus anatolicus		n				+		n
Egaenus convexus		n	+					
Lacinius horridus	n		+	+	n	+		+
Lacinius ephippiatus			+		n	+		
Lacinius dentiger	n	n	+	+	n	+		+
Odiellus lendli	n	n	+		n	+		+
Mitopus morio			+			+		n
Leiobunum rumelicum			+			+		+
S	**12/7***	**9/8***	**27/4***	**4/0***	**15/13***	**26/3***	**2/0***	**22/6***

** = taxon new to the Bulgarian fauna
+ = previous records
* = new records
S = number of species

Table 2. Summary of the opilionid fauna of the city of Sofia and the surroundings - main sampling localities. **Urban habitats:** U1 = Knyaz Borisovata Gradina (Park area); U2 = Zapaden park; U3 = Severen park; U4 = Knyaz Borisovata Gradina (Forest area = "Loven park"). **Non-urban habitats:** *Rural sites:* R1 = near German monastery, Lozenska Mt.; R2 = near locality Bonsovi Polyani, Lyulin Mt.; R3 = near Drenovo Village, Sofia Kettle; R4 = locality "Tikhiya Kat", Vitosha Mt.; *Suburban sites:* S1 = near German Village, Lozenska Mt.; S2 = between r.d. "Gorna Banya" and loc. Bonsovi Polyani, Lyulin Mt.; S4 = above Vladaya Village, Vitosha.

	R1	**R2**	**R3**	**R4**	**S1**	**S2**	**S4**	**U1**	**U2**	**U3**	**U4**
P. bosnica		+		+							
H. drenskii	+										
C. ornatum			+		+			+	+	+	+
T. tricarinatus	+	+	+		+	+	+	+	+	+	+
T. closanicus		+				+					
P. opilio	+			+	+				+	+	+
O. parietinus								+		+	
O. saxatilis					+			+	+	+	+
O. dinaricus	+	+				+			+		+
O. ruzickai	+			+				+	+	+	
R. balcanica	+	+		+	+	+	+				
R. cf. *serbica*		+		+		+		+	+	+	+
L. palpinalis				+							
Z. crista	+	+	+	+	+	+	+	+	+		+
L. horridus	+			+			+	+			+
L. ephippiatus		+				+					
L. dentiger	+			+							+
O. lendli									+	+	
S	**9**	**8**	**3**	**9**	**6**	**7**	**4**	**8**	**9**	**8**	**9**

S = number of species

Abbreviations used

ad. = adultus
Ass. = plant association
C.V. = Coefficient of Variation
d = interocular distance in *Trogulus closanicus*.
EPT = pitfall traps with ethylene glycol (unbaited)
FPT = pitfall traps with formaline (unbaited)
FPT-1 = pitfall traps filled with formaline (baited with tinned fish)
FPT-2 = pitfall traps filled with formaline + vinegar (unbaited)
H = hand-collected
juv. = juveniles
L = body length
l = egg length
LTU = experimental station "Vrazhdebna" (University of Forestry, Sofia).
MNHS = National Museum of Natural History in Sofia
n = number of individuals
v. = village
inv. No = inventory number
I.S. = Ivailo Stoyanov
P.M. = Plamen Mitov
r.d. = residental district
S.S. = Stefanka Subeva
sub. = subadultus
$\overline{x}$ = mean
± = standard error of the mean

RESULTS

A total of 2356 opilionid specimens, pertaining to 28 species, from the investigated area were examined (635♂♂, 984♀♀, 1 ad., 733 juv.). The taxon, here formally named as "*Rilaena* cf. *serbica*", is currently of unclear taxonomical status, but prominently different from all hitherto known Bulgarian *Rilaena*-species, is also marked as being new to the Bulgarian fauna. Seven species are new to the fauna of Sofia, eight are new to the fauna of the Sofia Kettle (referred here as the territory outside of Sofia city), four species are new to the fauna of West Stara Planina Mts., 15 are new to the fauna of Lyulin Mt., three and six are new respectively to the faunas of Vitosha and Sredna Gora Mts.

Systematic list of the Opiliones of Sofia city, the Sofia Kettle and the surrounding areas[1]

The species marked with two asterisks are new records to the Bulgarian fauna.

Family Nemastomatidae Simon, 1879

1. *Paranemastoma (Paranemastoma) radewi* (Roewer, 1926)

Paranemastoma (Paranemastoma) radewi: Staręga, 1976: 330 (West Stara Planina range: "Cerovo", "Gara Thompson", "Iskrec", "Lakatnik", "Paß Petrohan", "Byrzija", "Babkite-Quelle", "Brusen", "Berghütte "Ledenika", "Kloster "Sv. Ivan pusti"; Vitosha Mt.: "Bojana", "Bojanski vodopad", "Dragalevci", "Zlatni mostove"; Plana Mt.: "Kokaljane"; Lozenska Mt.: "Germanski manastir"; Sushtinska Sredna Gora Mt.: "Koprivštica", "Berg Bogdan", "zwischen den Bergen Malyk Bogdan und Bogdan").

Paranemastoma radewi: Mitov, 1988: 484 (Vitosha Mt.: "above Dragalevtsi"); Mitov, 1995b: 70 (Vitosha Mt.:"above Dragalevtsi", "Shoumako"); Mitov, 1996: 483 (Vitosha Mt.: "über Dragalevzi"); Mitov, 1997a: 255 (Vitosha Mt.: "above Dragalevtsi"); Mitov, 1997a: 255 (Vitosha Mt.: "Bay Krustyo").

Material examined: 10♂♂, 21♀♀, 1 juv.

New localities: West Stara Planina range: Chiprovtsi, county Debledelska Murtvina, on the edge of *Fagus*-forest, under stones, 1100-1300 m, 28.VII.1998, leg. B. Petrov – 1♀ (4.8 mm)(with eggs); the surroundings of hut Kom (the old one), *Picea abies*-forest, 1600-1700 m, 19.VI.1998, leg. B. Petrov – 1♀ (4.8 mm)(with few eggs); Distr. Vratsa, in the region of hut Purshevitsa, 1000-1300 m, 11.-12.VII.1993, leg. B. Petrov – 3♂♂, 2♀♀; above Vurshets: near Botunya River, Vegetation: *Fagus* sp., *Alnus* sp., *Quercus* sp., *Pinus nigra* Arn., *Rubus* sp., under stones, 27.VI.2000, leg. P.M. – 2♂♂, 4♀♀; loc. Vodopada, near Orlovitsa River, Vegetation: *Alnus* sp., *Crataegus* sp., *Rubus* sp., *Urtica dioica* L., 400-500 m, 28.VI.2000, leg. P.M. – 2♂♂, 2♀♀ (with eggs); Railway station Lakatnik, spring "Zhitolyub", 08.VII.1948, leg. P. Drenski, MNHS – 5♀♀, 1 juv. (2.4 mm); Distr. Godech, v. Breze, 750 m, 20.VI.1993, leg. B. Petrov – 1♂, 1♀; Distr. Svoge, v. Zanoge, 1100-1300 m, 02.V.1984, leg. P. Beron, (MNHS: inv. No 350) – 1♂, 4♀♀; Sushtinska Sredna Gora Mt.: above Klisura, loc. Koritata, 900-1100 m, FPT, 05.VI.1996, leg. S. Lazarov – 1♂, 1♀ (without eggs).

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[1] All records from caves in the considered regions are excluded.

2. *Paranemastoma (Paranemastoma) aurigerum ryla* (Roewer, 1951)

Paranemastoma (Paranemastoma) aurigerum ryla: Staręga, 1976: 324 (Vitosha Mt.: "Dragalevci", "Berghütte "Fonfon", "Zlatni mostove").

Paranemastoma aurigerum joannae Staręga, 1976: Mitov, 1987: 60 (Vitosha Mt.: "loc. Yarema, loc. Romanski, Platoto, hut Edelvays, loc. Kiselishte").

Paranemastoma aurigerum ryla: Mitov, 1995b: 70 (Vitosha Mt.: "Bai Krustyu"); Mitov, 1997a: 255 (Vitosha Mt.: "Goli Vruh").

Initially, part of the material was misidentified (on the basis of taxonomical characters first introduced by Staręga (1976)) as *P. aurigerum joannae* Staręga, 1976 (see Mitov, 1987). Considering, that in the region of Vitosha Mt. the other subspecies (*P. a. ryla*) also occurs (Staręga, 1976), we assumed that these two taxa have vertically disjunct areals. Later, more abundant materials of *P. a. aurigerum* (Roewer, 1951), *P. a. joannae* and *P. a. ryla* were collected (incl. from *locus typicus*). Part of this material was SEM-micrographed (the integument sculpture and the male copulatory organ were more closely examined). As a result of these analyses it was found that these subspecies exhibit significant variation in the sculpture and shape of glans penis, even among individuals from a very small area. Other species from the genus *Paranemastoma* are also known to exhibit similar variation (see Kolosvary, 1943; Martens, 1978). Some anomalies in the armament of the cuticle were also found in this genus (Mitov, 1995d). All this evidence indicate that the main taxonomic character introduced by Staręga (1976) for the distinction between both subspecies – i. e. the absence of a spine on Area IV – is not reliable at all. Moreover, in the describtion of *P. a. ryla* (sub *Nemastoma ryla*), Roewer (1951, p. 109, fig. 13; p. 120) clearly states that Areae II-IV are bearing spurs. It is also noteworthy that in some specimens of *P. a. joannae* and *P. a. ryla* Area I (similary to *P. a. aurigerum*) is also armed, a fact not mentioned by Staręga (1976) in the description. As a summary of these notes, it may be stated that it is very possible for *P. a. joannae* to turn out to be synonymous with *P. a. ryla* after examination of an adequate number of material.

3. *Nemastoma lugubre* (O.F. Müller, 1776)

Nemastoma lugubre: Staręga, 1976: 312 (West Stara Planina range: "Paß Petrohan").

4. *Nemastoma bidentatum sparsum* Gruber et Martens, 1968

Nemastoma bidentatum sparsum: Staręga, 1976: 314 (West Stara Planina range: "Komštica"; Sushtinska Sredna Gora Mt.: "Gara Koprivštica", "Koprivštica", "Klisura").

5. *Pyza bosnica* (Roewer, 1919)

Pyza bosnica: Staręga, 1976: 317-318 (West Stara Planina range: "Berghütte "Ledenika", "Paß Petrohan", "Bistrec", "Berg Pyrševica"; Vitosha Mt.: "Zlatni mostove", "Berghütte "Fonfon", "Berghütte "Edelvajs"; Sushtinska Sredna Gora Mt.: "Koprivštica"); Mitov, 1995b: 70 (Vitosha Mt.: "above Dragalevtsi", "Shoumako", "above v. Chuypetlovo").

Material examined: 21♂♂, 21♀♀, 2 juv.

New localities: West Stara Planina range: in the region of Chiprovtsi, below peak Midzhur, 1900 m, 26.X.1969, leg. P. Beron, (MNHS: inv. No 81) – 1♀ (4.0 mm); Lyulin Mt.: R2, 920 m, FPT-2: 08.V.-31.V.1998, leg. I.S. – 3♂♂, 1♀ (with eggs), 1 juv. (3.1 mm); 31.V.-13.VIII.1998, leg. I.S. – 2♂♂, 1♀ (3.5 mm) (without eggs); 04.IV.-09.VIII.1999, leg. I.S. – 6♂♂ (2.8-3.4 mm), 1♀ (with eggs); above Dragichevsko Ezero, 1130 m, forest/meadow boundary, FPT, leg. M. Sotirova: 05.XI.2000-

07.IV.2001 – 1♂ (3.5 mm); 04.IX.-04.X.2001 - 1 juv. (1.8 mm); Vitosha Mt.: loc. Tihiya Kut (R4), 1000 m, FPT-2, 05.IV.-16.IX.1999, leg. I.S. – 4♂♂ (3.1 mm), 4♀♀ (with and without eggs); Sushtinska Sredna Gora Mt.: in the region of v. Chavdar, *Populus tremula*-forest, FPT, 03.VII.1996, leg. S. Lazarov – 1♂, 1♀ (with many eggs); Distr. Koprivshtitsa, below peak Bogdan, *Fagus*-forest, 1380 m, FPT, 05.VI.1996, leg. S. Lazarov – 5♀♀ (4.3 mm)(with many eggs); above hut Chivira, meadows, FPT, 05.VI.1996, leg. S. Lazarov – 4♂♂ (3.3-3.6 mm), 6♀♀ (3.8-4.1 mm)(with many eggs);

Confirmed locality: "Sredna gora", loc. (?), 20.VI.1911, leg. P. Drenski, MNHS – 1♀

6. *Histricostoma drenskii* Kratochvil, 1958

Histricostoma drenskii: Staręga, 1976: 320 (Lozenska Mt.: "Schlucht Urvič")

Material examined: 3♂♂, 1 ad.

New localities: Vitosha Mt.: forest, loc. (?), 1985, leg S. Subeva - 1 adult (2.1 mm); Lozenska Mt.: German monastery (R1), 850 m, FPT-2, 10.VII.-04.VIII.1998, leg. I.S. – 1♂; above v. Pasarel, 800 m, 03.X.1993, leg. B. Petrov – 2♂♂.

7. *Carinostoma ornatum* (Hadži, 1940)

Carinostoma ornatum: Staręga, 1976b: 343 (West Stara Planina range: "Belogradčik", "Berghütte "Ledenika", "Lakatnik"; Zavalska Mt.: "Filipovci"; Lozenska Mt.: "Germanski manastir, Schlucht Urvič"; Sofia: "Gorubljane"; Vitosha Mt.: "Berghütte "Aleko", "Bojana", "Dragalevci"; Sushtinska Sredna Gora Mt.: "Gara Koprivštica"; Mitov, 1995b: 70 (Vitosha Mt.: "above Dragalevtsi", "Shoumako"); Mitov, 1997a: 255 (Vitosha Mt.: "above Dragalevtsi").

Material examined: 68♂♂, 81♀♀, 2 juv.

New localities: West Stara Planina range: the pass above hut Kom, under stones near the road, 1650 m, 19.VI.1998, leg. B. Petrov – 1♀ (2.15 mm)(with eggs)(without silvery spots); Vurshets, city park, under stones, 395 m, 29.VI.2000, leg. P.M. – 3♂♂, 1♀ (without eggs); above Vurshets: near Botunya River, Vegetation: *Fagus* sp., *Alnus* sp., *Quercus* sp., *Pinus nigra* Arn., *Rubus* sp., under stones, 27.VI.2000, leg. P.M. – 1♂; Sofia: Severen Park: on the banks of Kakach River, forest edge: under bark, 09.IV.1999, leg. P.M. – 1♂ (without spots); under stones and tree remnants, 06.IX.2001, leg. P.M. - 1♂, 1♀; Zapaden Park: U2, 525 m, FPT-2: 09.V.-02.VI.1998, leg. I.S. – 1♀ (with eggs); 03.IX.-16.X.1998 – 3♂♂, 1♀; Yuzhen Park: on the banks of Perlovska River (on the side of r.d. "Ivan Vazov" and r.d. "Emil Markov"), under stones and tree remnants, 20.X.2001, leg. P.M. – 5♂♂, 3♀♀; Knyaz Borisovata Gradina: the area of the Open-air Theatre, under stones, forest (*Quercus*, *Tilia*, *Acer*), 04.XI.1999, leg. P.M. – 1♂, 2♀♀ (without spots); in the area of sports-hall "Sofia", 11.VI.2001, leg. P.M. – 2♂♂, 5♀♀ (without eggs); in the area of Astronomical Observatory, 12.VI.2001, leg. P.M. - 2 juv. (1.25 mm); near the crossing of blvd. "Dr. Tsankov" and blvd. "P. Yavorov", under stones, 11.IX.2001, leg. P.M. – 3 mm; in the area of the Television tower, under tree remnants and stones, 11.IX.2001, leg. P.M. – 2♂♂, 4♀♀ (with eggs); in the area between blvd. "Dr. Tsankov" and the Astronomical Observatory, under tree remnants, 14.IX.2001, leg. P.M. – 3♀♀ (with eggs); Loven Park: under stones, 26.II.1994, leg. P. Stoev – 2♀♀ (without eggs); U4, 570 m, FPT-2: 13.V.-12.X.1998, leg. I.S. – 24♂♂, 22♀♀; 07.IV.-03.X.1999, leg. I.S. – 13♂♂ (1.5 mm), 26♀♀ (with eggs); in the area of "Pioneer" railway station, forest (*Tilia*, *Acer*, *Quercus*, *Ulmus*), under tree remnants and stones, 23.V.2001, leg. P.M. – 1♂ (1.5 mm), 5♀♀ (2.15 mm)(with and without eggs); Sofia

Kettle: near v. Chibaovtsi (R3), 800 m, FPT-2, 08.IX.-19.X.1998, leg. I.S. – 4 ♂♂, 2♀♀; Lozenska Mt.: v. German (S1), 650 m, 12.V.-14.X.1998, leg. I.S. – 2♂♂, 1♀ (with eggs);

Confirmed locality: Lozenska Mt.: "Urvic near Sofia", 20.IV.1980, leg. P. Beron, (MNHS: inv. No 143) – 2♂♂, 1♀ (with eggs).

8. *Mitostoma chrysomelas* (Hermann, 1804)

Mitostoma chrysomelas: Staręga, 1976: 337 (West Stara Planina range: "Berghütte "Ledenika", "Paß Petrohan"); Mitov, 1987: 60 (Vitosha Mt.: "loc. Yarema", "loc. Romanski", "monastery "St. Nikola"); Mitov, 1997a: 255 (Vitosha Mt.: "Bay Krustyo").

Material examined: 2 juv.

New localities: West Stara Planina range: Chiprovtsi, county Debledelska Murtvina, on the edge of *Fagus*-forest, under stones, 1100-1300 m, 28.VII.1998, leg. B. Petrov - 1 juv. (3.2 mm); in the region of Chiprovtsi, below peak Midzhur, 1900 m, 26.X.1969, leg. P. Beron, (MNHS: inv. No 81) - 1 juv. (1.3 mm).

Family Dicranolasmatidae Simon, 1879

9. *Dicranolasma scabrum* (Herbst, 1799)

Dicranolasma scabrum: Staręga, 1976: 305 (West Stara Planina range: "Berghütte "Ledenika"), Mitov, 1987: 60 (Vitosha Mt.: "above v. Bistritsa")

Material examined: 1♂, 1♀.

New localities: West Stara Planina range: Distr. Svoge, Bov, 09.05.1982, leg. P. Beron, (MNHS: inv. No 221) – 1♀ (5.3 mm)(with eggs).

Confirmed locality: Vitosha Mt.: above v. Bistritsa, 1200 m, 23.XI.1992, leg. N. Kodzhabashev – 1♂.

Family Trogulidae Sundevall, 1833

10. *Trogulus tricarinatus* (Linnaeus, 1767)

Trogulus tricarinatus: Staręga, 1976: 299 (West Stara Planina range: "Berghütte "Ledenika", "Čelopek", "Bistrec", "Petrohan-Paß"; Surnena Sredna Gora Mt.: "Starozagorski bani"; Vitosha Mt.: "Bojana", "Zlatni mostove"; Lozenska Mt.: "Urvič-Schlucht", "Germanski manastir").

Material examined: 31♂♂, 106♀♀, 3 juv.

New localities: West Stara Planina range: Chiprovtsi, county Debledelska Murtvina, at the edge of a *Fagus*-forest, under stones, 1100-1300 m, 28.VII.1998, leg. B. Petrov – 1♀ (5.5 mm)(with eggs); Distr. Godech, in the region of v. Breze, 750 m, 20.VI.1993, leg. B. Petrov – 1♀; Sofia: r.d. "Nadezhda", the park between r.d. "Lev Tolstoy" and r.d. "Triugulnika" (near the tram-station "Triugulnika", under concrete blocks, 08.X.2001, leg. P.M. – 1♀ (5.9 mm) (without eggs); Severen Park: U3, 575 m, FPT-2: 02.VI.-02.VII.1998, leg. I.S. – 1♀ (with eggs); 06.IV.-14.VI.1999, leg. I.S. – 2♀♀ (5.6-6.0 mm) (with eggs); Zapaden Park: U2, 525 m, FPT-2: 02.VI.-16.X.1998, leg. I.S. – 2♀♀ (without eggs); 07.V.-14.VI.1999, leg. I.S. – 2♀♀ (5.8-6.0 mm) (with eggs); Yuzhen Park: right bank of Perlovska River (the side of r.d. "Ivan Vazov"), under tree remnants, 20.X.2001, leg. P.M. – 1♀ (5.9 mm) (without eggs); Knyaz Borisovata Gradina: U1, 550 m, FPT-2: 03.VII.-12.X.1998, leg I.S. – 5♀♀ (5.2-5.9 mm) (without and with eggs); 07.IV.-01.X.1999, leg. I.S. –

8♀♀ (5.1-5.4 mm)(with eggs); Loven Park: U4, 570 m, FPT-2: 05.VI.-12.X.1998, leg. I.S. – 1♂, 20♀♀ (with eggs), 1 juv. (3.85 mm); 07.IV.-03.X.1999, leg. I.S. – 10♀♀ (5.4-6.1 mm)(with eggs); Sofia Kettle: near v. Chibaovtsi, 800 m, FPT-2, 08.IX.-19.X.1998, leg. I.S. – 2♀♀ (with eggs); Lyulin Mt.: S2, 900 m, FPT-2, 04.IV.-14.IX.1999, leg. I.S. – 5♀♀ (5.3-5.8 mm)(without and with eggs); R2, 920 m, FPT-2: 08.V.-17.X.1998, leg. I.S. – 4♀♀ (with eggs); 04.IV.-13.X.1999, leg. I.S. – 1♂ (4.3 mm), 6♀♀ (5.3-5.75 mm) (without and with eggs); Vitosha Mt.: v. Vladaya (S4), 950 m, FPT-2, 10.IX.-15.X.1998, leg. I.S. – 1♀; 07.VIII.-16.IX.1999, leg. I.S. – 2♀♀ (with eggs); Lozenska Mt.: v. German (S1), 650 m, FPT-2: 04.VI.-14.X.1998, leg. I.S. – 2♀♀ (5.7-5.9 mm)(with eggs); 12.V.-05.VI.1999, leg. I.S. – 1♀ (5.7 mm)(with eggs);

Confirmed localities: Lozenska Mt.: German monastery (R1), 850 m, FPT-2: 07.V.-20.X.1998, leg. I.S. – 16♂♂, 16♀♀ (without and with eggs), 2 juv. (2.73 mm); 02.IV.-10.IX.1999, leg. I.S. – 13♂♂ (4.5-5.2 mm), 12♀♀ (5.0-5.5 mm) (without and with eggs);

Sredna Gora Mt.: "Sredna gora", loc. (?), 20.VI.1911, leg. P. Drenski, MNHS – 1♀ (6.5 mm).

11. *Trogulus nepaeformis* (Scopoli, 1763)

Trogulus nepaeformis: Staręga, 1976: (West Stara Planina range: "Umgebung der Höhle Ledenika").

** 12. *Trogulus closanicus* Avram, 1971

Trogulus nepaeformis: Mitov, 1987: 60 (Vitosha Mt.: "Vladaya", "loc. Cherniya kos").

This species is new to the Bulgarian fauna. *Trogulus closanicus* is known from Romania, Austria, Slovenia, Germany, France and Switzerland (Avram, 1971; Weiss, 1978, 1984, 1996; Chemini, 1984; Weiss *et al.*, 1998; Komposch, 1995, 1997, 1999, 2000; Komposch *et al.*, 1997; Komposch & Gruber, 1999) and is considered as a relatively young species with expanding distribution. It is also described as an ecologically tolerant species, showing significant genetical heterogeneity (see Weiss, 1978).

The initial misidentification of the material from Vitosha Mt. (sub *Trogulus nepaeformis*, see Mitov, 1987) resulted from the opinion of Martens (1978) who considered *Trogulus closanicus* as a synonym of *Trogulus nepaeformis*.

Later, as more abundant comparative material came together, it became possible to confirm the more popular opinion (see Weiss, 1978; Chemini, 1984; Weiss *et al.*, 1998; Komposch, 2000; Klimeš, pers. comm.) concerning the validity of *Trogulus closanicus* and consequently to revise the status of the previously available *Trogulus*-material. The population from Lyulin Mt. has the following parameters: L♂♂ = 7.56±0.03 mm (7.2-8.2 mm, n=61♂♂, C.V.=3.22), d♂♂ = 0.51±0.01 mm (0.4-0.57 mm, n=25♂♂, C.V.=9.56); L♀♀ = 8.74±0.07 mm (8.2-9.2 mm, n=18♀♀, C.V.=3.22), d♀♀ = 0.59±0.01 mm (0.55-0.63 mm, n=8♀♀, C.V.=5.95);

Material examined: 83♂♂, 23♀♀, 1 juv.

Localities: Lyulin Mt.: S2, 900 m, FPT-2: 08.V.-17.X.1998, leg. I.S. - 20♂♂, 5♀♀ (with eggs); 04.IV.-13.V.1999, leg. I.S. - 10♂♂; 13.V.-03.VI.1999, leg. I.S. - 5♂♂, 1 subad. (7.2 mm); 03.VI.-13.X.1999, leg. I.S. - 24♂♂, 13♀♀ (with eggs); R2, 920 m, FPT-2: 08.V.-17.X.1998, leg. I.S. - 2♂♂, 1♀ (without eggs); 13.V.-13.X.1999, leg. I.S. - 15♂♂, 2♀♀ (with eggs); Vitosha Mt.: above Dragalevtsi, in the area of the chair-lift station: fresh to moist forest-meadow, Ass. *Deschampsia caespitosa* + *Lerchenfeldia flexuosa* + *Urtica dioica* - *Rubus idaeus*, 900 m, FPT, 24.V.-25.VI.1988, leg. P.M. - 2♂♂ (7.5-7.7 mm, d=0.5 mm); on the banks of Dragalevska River, Ass. *Carpinus betulus* + *Fagus sylvatica* - *Rubus idaeus* - *Carex* sp., 900 m, FPT, 25.VI.-23.VII.1988, leg. P.M. - 1♂ (7.8 mm, d=0.52 mm); forest, Ass.

Carpinus betulus + *Fagus sylvatica* - *Poa nemoralis* + *Galium odoratum*, 900 m, FPT, 04.IV.-09.V.1988, leg. P.M. - 1♀ (9.0 mm, d=0.575 mm); above Simeonovo, between loc. Zhelezni Vrata and loc. Sovata, 1100 m, fresh forest-meadow, Ass. *Alopecurus pratensis* + *Agrostis capillaris*, FPT, 05.VII.-19.IX.1988, leg. P.M. - 4♂♂ (7.4-7.8 mm, d=0.45-0.575 mm), 1♀ (9.0 mm, d=0.72 mm).

Family Phalangiidae Simon, 1879

13. *Phalangium opilio* Linnaeus, 1758

Phalangium opilio: Šilhavý, 1965: 381 (Lyulin Mt.: "Ljumon"[2], Vitosha Mt.: "Vitoša planing", "Bistrica"; Lozenska Mt.: "Monastir Džerman", "Lozen"; Sredna Gora Mt.: "Srtuna gora"[3]); Staręga, 1976: 371 (West Stara Planina range: "Berg Malyk Kom", "Byrzija", "Komštica", "Paß Petrohan", "Iskrec", "Berg Javorec", "Druževo", "Schlucht Vratcata", "Berghütte "Ledenika", "Čerepiš", "Lakatnik", "Gara Lakatnik", "Cerovo"; Sofia: "Gorubljane"; Vitosha Mt.: "Černi kos", "Berghütte "Aleko", "Bojana", "Bojanski vodopad", "Berg Černata skala", "Berghütte "Fonfon", "Knjaževo", "Kopitoto", "Berghütte "Rodina"; Surnena Sredna Gora Mt.: "Starozagorski bani"); Mitov, 1988: 485 (Vitosha Mt.: "above Zheleznitsa"); Mitov, 1995b: 69-70 (Vitosha Mt.: "above Dragalevtsi", "Bai Krustyu", "Selimitsa hut", "Goli Vruh"); Mitov, 1996: 487-488 (Vitosha Mt.: "über Dragalevzi"); Mitov, 1997a: 255 (Vitosha Mt.: "above Dragalevtsi", "Bay Krustyo", "Goli Vruh").

Material examined: 62♂♂, 65♀♀, 31 juv.

New localities: West Stara Planina range: Vurshets, city park, under stones, 395 m, 29.VI.2000, leg. P.M. - 1♂; above Vurshets: near Botunya River, Vegetation: *Fagus* sp., *Alnus* sp., *Quercus* sp., *Pinus nigra* Arn., *Rubus* sp., under stones, 27.VI.2000, leg. P.M. - 1♂, 1 juv. (6.1 mm); loc. Vodopada, near Orlovitsa River, Vegetation: *Alnus* sp., *Crataegus* sp., *Rubus* sp., *Urtica dioica* L., 400-500 m, 28.VI.2000, leg. P.M. - 2♂♂, 1♀; Distr. Dragoman, Northern slopes of the karstic ridge Chepun, stony terrain with shrubs, 850 m, FPT, 27.VII.-28.IX.1997, leg. D. S. Dimitrov - 1♂, 1♀; Distr. Vratsa: v. Zgorigrad - hut Purshevitsa, 500-1300 m, forest, 10.VII.1993, leg. B. Petrov, P. Stoev - 4 juv. (3.5 mm)(4.0 mm); in the region of hut Purshevitsa, 1000-1300 m, 11.-12.VII.1993, leg. B. Petrov - 6 juv. (3.0 mm); above Etropole, 24.VII.-04.VIII. 1999, leg. G. Krustev - 1♀ (8.5 mm) (with many eggs); Sofia: Severen Park: on leaf-litter, shrubs and tree-trunks, 29.VI.1997, leg. P.M. - 8 juv. (2.7 mm, 3.0 mm, 3.8 mm, 3.9 mm); on shrubs and grassy vegetation in the forest, 02.VII.1998, leg. P.M. - 2♂♂; U3, 575 m, FPT-2, 02.VII.-03.IX.1998, leg. I.S. - 4♀♀ (with many eggs), 1 juv. (4.7 mm); 14.VI.1999, leg. P.M. - 1 juv. (1.9 mm); on a tree-trunk, 06.VII.1999, leg. P.M. - 1♀ (4.6 mm)(without eggs), 1 juv. (3.0 mm); on shrubs, at height 1-1.5 m, 06.IX.1999, leg. P.M. - 1♀; at the Northern periphery of the park, on a *Betula*-trunk at height 0.5 m, 05.VIII.2001, leg. P.M. - 1♀ (without eggs); *Picea abies*-forest, under stones, 28.VIII.2001, leg. P.M. - 1♂ (4.0 mm), 1♀ (6.5 mm)(without eggs); Zapaden Park: U2, 525 m, FPT-2, 02.VII.-11.VIII.1998, leg. I.S. - 1 juv. (3.5 mm); Loven Park: U4, 570 m, FPT-2, 13.V.-05.VI.1998, leg. I.S. - 1 juv. (2.0 mm); Studentski grad, 25.VII.1997, leg. ? - 3♂♂, 1♀; Sofia Kettle: between r.d. "Vrazhdebna" and v. Dolni Bogrov, LTU, wheat-field, 05.VII.-21.VII.1999, leg. R. Kostova - 16♂♂, 34♀♀ (with eggs), 4 juv. (4.3 mm); Vitosha Mt.: "Dragalewzi b. Sofia", 25.VIII.1917,

[2] Šilhavý (1956) reported *Phalangium opilio* from "Ljumon", but such a place does not exist in Bulgaria. Probably this record concerns Lyulin (=Ljulin) Mt.

[3] The same holds also for the record "Srtuna gora" – this is probably a reference to Sredna Gora Mt.

leg. Dr. Buresch, MNHS - 1♂; loc. Tihiya Kut (R4), 1000 m, FPT-2: 08.VIII.-10.IX.1998, leg. I.S. - 1♀ (with many eggs), 01.VII.-09.X.1999, leg. I.S. - 1♂, 2♀♀ (5.9-7.4 mm) (with many eggs), 16.IX.1999, H, leg. P.M. - 1♀; "Zlatnite mostove", 21.X.1943, leg. (?), MNHS - 1♂; Lozenska Mt.: v. German (S1), 650 m, FPT-2, 08.VII.-06.VIII.1998, leg. I.S. - 3♂♂; Sushtinska Sredna Gora Mt.: Koprivshtitsa, 02.VII.1968, leg. K. Kumanski, MNHS - 2 juv. (1.6-2.6 mm); Distr. Koprivshtitsa, pick Bratiya, 1519 m, FPT, 12.V.1996, leg. S. Lazarov - 3♂♂, 1♀ (7.0 mm) (with many eggs); in the region of Panagyurishte, loc. Fetentsi, 900 m, FPT, 27.V.1993, leg. S. Lazarov - 26♂♂ (3.2-4.1 mm), 12♀♀ (4.0-5.5 mm) (with eggs).

Confirmed localities: Lozenska Mt.: "German monast.", 20.VIII.1915, leg. Dr. Buresch, MNHS - 1♀ (with eggs); German monastery (R1), 850 m, 01.VIII.-10.IX.1999, leg. I.S. - 1♀ (5.2 mm) (with eggs); West Stara Planina range: above Lakatnik, pick Yavorets, 1348 m, 12.VII.1948, leg. P. Tranteev & I. A. Ivanov, MNHS - 1 juv. (2.7 mm).

14. *Opilio parietinus* (De Geer, 1778)

Opilio parietinus: Šilhavý, 1965: 379 (West Stara Planina range: "Čurek"; Sofia: "Sofia", Lozenska Mt. "Monastir Džerman"); Staręga, 1976: 399 ("Sofia"; Vitosha Mt.: "Bojana", "Dragalevci").

Remark: According to Staręga (1976), *Opilio parietinus* is a synanthropic species in Bulgaria. This species has been found also on different buildings (climbing up to heights of 20 m) in the city of Sofia (Staręga, 1976).

Material examined: 6♂♂, 7♀♀, 2 juv.

Confirmed localities: Sofia: Severen Park: on a building-wall in the Northern periphery of the park, at 1.0-3.0 m height: 02.X.1998, leg. P.M. - 1♂; 25.X.1998, leg. P.M. - 1♀; 01.X.2000, leg. P.M. - 1♂ (4.4 mm); 14.X.2001, leg. P.M. - 2♂♂ (4.6-5.7 mm), 4♀♀ (6.5-7.0 mm) (with eggs); on building-walls in the Northern periphery of the park at 4 m height, 17.X.1998, leg. P.M. - 2♂♂ (3.8-4.9 mm), 1♀ (4.5 mm)(without eggs); park "Oborishte", on a building-wall at 0.5 m height, 03.VII.2000, leg. P.M. - 1 juv.; park "Doktorska Gradina", at the periphery of the park, next to the National Library, under stones, 12.VI. 2002, leg. P.M. – 1 juv. (2.45 mm); Knyaz Borisovata Gradina: Western periphery of the park, on a building-wall at 1.50 m height, 24.IX.2001, leg. P.M. - 1♀ (4.4 mm) (without eggs).

15. *Opilio saxatilis* C.L. Koch, 1839

Opilio saxatilis: Šilhavý, 1965: 380 (Sofia: "Sofia"); Staręga, 1976: 402-403 (West Stara Planina range: "Berkovica", "Komštica", "Pyrševica", "Berghütte "Ledenika", "Vraca", "Schlucht Vratcata", "Lakatnik", "Kytina", "Kremikovski manastir"; Lyulin Mt.: "Ljulin"; Vitosha Mt.: "Bojana", "Bojanski vodopad", "Železnica", "Dragalevci", "Knjaževo"; Lozenska Mt.: "Schlucht Urvič"; Sushtinska Sredna Gora Mt.: "Gara Koprivštica"; Surnena Sredna Gora Mt.: "Starozagorski bani").

Material examined: 29♂♂, 17♀♀, 38 juv.

New localities: West Stara Planina range: Vurshets, city park, under stones, 395 m, 29.VI.2000, leg. P.M. - 2♂♂, 1♀ (with many eggs); above Vurshets: loc. Vodopada, near Orlovitsa River, Vegetation: *Alnus* sp., *Crataegus* sp., *Rubus* sp., *Urtica dioica* L., 400-500 m, 28.VI.2000, leg. P.M. - 1♂; Distr. Dragoman, southern slopes of the karstic ridge Chepun, among short *Syringa vulgaris* L. shrubs, 1000 m, FPT, 27.VII.-28.IX.1997, leg. D. S. Dimitrov - 1 juv. (3.25 mm); Sofia Kettle: between r.d. "Vrazhdebna" and v. Dolni Bogrov, LTU, 05.VII.-21.VII.1999, wheat-field, leg. R. Kostova - 3♀♀ (5.0 mm)(with eggs); v. Dolni Bogrov, 13.XI.1987, carrot-field, leg. P.M. - 1♂ (2.5

mm), 1♀ (3.5 mm); Lozenska Mt.: v. German (S1), 650 m, FPT-2, 06.VIII.-07.IX.1998, leg. I.S. - 1♀ (subad.) (4.0 mm);

Confirmed localities:

Note: *Opilio saxatilis* was recorded from Sofia by Šilhavý (1965), but without an exact locality within the city.

Sofia: the park between r.d. "Lev Tolstoy" and r.d. "Triugulnika" (near the tram-station "Triugulnika"), under stones, concrete blocks and tree remnants, 08.X.2001, leg. P.M. - 11♂♂ (3.0-5.0 mm), 1 juv. (2.8 mm); Severen Park: under stones, *Picea abies* forest-edge, 575 m: 14.VIII.2001, leg. P.M. - 2 juv. (1.3-2.7 mm); 28.VIII.2001, leg. P.M. - 1♂ (3.5 mm), 2 juv. (1.8-3.0 mm); 14.X.2001, leg. P.M. - 1♂ (3.3 mm); Zapaden Park: park "Chr. Smirnenski", 575 m, under stones and tree remnants, and on tree trunks, 13.IX.2001, leg. P.M. - 3♂♂ (3.6-4.1 mm), 3♀♀ (3.5-3.7 mm)(without eggs), 1 juv. (2.7 mm); Knyaz Borisovata Gradina: at the periphery of the park, in the area of "Ariana" pond, under bark and in grass , 19.X.1998, leg. P.M. - 1♂ (2.6 mm); U1, 550 m, FPT-2, 03.VIII.-04.IX.1998, leg. I.S. - 2♂♂ (3.5-4.0 mm); at the area of "Narodna armia" stadium, at the base of oak-trees and under stones, 12.VI.2001, leg. P.M. - 1♂ (3.7 mm), 2♀♀ (3.6-4.0 mm)(without eggs), 2 juv. (2.2-3.5 mm); in the area of the Astronomical observatory, 12.VI.2001, leg. P.M. - 2 juv. (1.75-2.75 mm); near the crossing of "Dr. Tsankov" blvd. and "P. Yavorov" blvd., under stones, 11.IX.2001, leg. P.M. - 2♂♂ (3.5 mm), 1♀ (4.9 mm) (without eggs), 1 juv. (3.0 mm); in the area of the TV-tower, under tree remnants and stones, 11.IX.2001, leg. P.M. - 3♀♀ (6.1 mm) (without eggs), 1 juv. (3.2 mm); in the area between blvd. "Dr. Tsankov" and the Astronomical observatory, under tree remnants and stones, 14.IX.2001, leg. P.M. - 1♂ (2.7 mm), 17 juv. (1.8-4.0 mm); on a building-wall (at 1.5 m height) at the tennis-court, near "V. Levski" stadium, 05.X.2001, leg. P.M. - 1♂ (3.9 mm), 1♀ (4.8 mm)(without eggs); Loven Park: in the area of the railway-station "Pioneer", under stones and in grass, forest-edge (*Tilia*, *Acer*, *Quercus*, *Ulmus*), near the railway, crossing "Simeonovsko Shousse" blvd., 23.V.2001, leg. P.M. - 5 juv. (1.3-3.7 mm); the park between the National Palace of Culture and "Bulgaria" blvd., under stones, 10.VI. - 20.VI. 2002, leg. P.M. – 1♂ (3.5 mm), 1♀ (3.4 mm)(without eggs), 3 juv. (2.6-3.25 mm).

16. *Opilio dinaricus* Šilhavý, 1938

Opilio dinaricus: Mitov, 1987: 61 (Vitosha Mt.: "loc. Shumako, above v. Bistritsa, above v. Chuypetlovo, loc. Kisselishte, monastery "St. Nikola"); Mitov, 1997a: 255 (Vitosha Mt.: "above Dragalevtsi").

Material examnied: 6♂♂, 2♀♀, 5 juv.

New localities: West Stara Planina range: in the region of Vratsa, hut Purshevitsa, 1000-1300 m, 11.-12.VII.1993, leg. B. Petrov - 1♂ (4.0 mm); Vurshets, city park, under stones, 395 m, 29.VI.2000, leg. P.M. - 1♂; above Vurshets: near Botunya River, Vegetation: *Fagus* sp., *Alnus* sp., *Quercus* sp., *Pinus nigra* Arn., *Rubus* sp., under stones, 27.VI.2000, leg. P.M. - 2♂♂ (3.0-3.5 mm); loc. Vodopada, near Orlovitsa River, Vegetation: *Alnus* sp., *Crataegus* sp., *Rubus* sp., *Urtica dioica* L., 400-500 m, 28.VI.2000, leg. P.M. - 1 juv. (3.75 mm); Sofia: Zapaden Park: U2, 575 m, FPT-2, 02.VII.-11.VIII.1998, leg. I. S. - 1♂, 1♀ (with eggs); Loven Park: U4, 570 m, FPT-2, 03.VII.-10.VIII.1998, leg. I. S. - 1♀ (with eggs); Lyulin Mt.: S2, 900 m, FPT-2, 06.VII.-09.VIII.1999, leg. I. S. - 1♂ (3.4 mm); R2, 920 m, FPT-2, 09.VIII.-14.IX.1999, leg. I. S. - 1 juv.; Lozenska Mt.: v. German (R1), 650 m, FPT-2, 07.V.-30.V.1998, leg. I. S. - 1 juv. (2.0 mm); v. Lozen, ~700-800 m, leg. ?, 15.VI.1993 - 2 juv. (3.7 - 4.8 mm).

17. *Opilio ruzickai* Šilhavý, 1938

Opilio ruzickai: Šilhavý, 1965: 380 (Vitosha Mt.: "Vitoša planina"); Beron, 1975: 57 (Vitosha Mt.: "Petrohan"); Staręga, 1976: 406 (West Stara Planina range: "Berghütte "Ledenika", "Cerovo", "Druževo", "Zaselje", "Želen-Tynkoserci", "Kalotina"; Vitosha Mt.: "Bojana", "Bojanski vodopad", "Knjaževo", "Zlatni mostove", "Černi kos"; Lozenska Mt.: "Schlucht Urvič"; Sofia: "Gorubljane"); Mitov, 1995b: 69-70 (Vitosha Mt.: "above Dragalevtsi", "Shoumako", "Selimitsa hut"); Mitov, 1996: 486-487 (Vitosha Mt.: "über Dragalevzi").

Material examined: 59♂♂, 20♀♀, 9 juv.

New localities: Sofia: Severen Park: in leaf-litter, grass, shrubs (*Ulmus* sp., *Corylus* sp.; at 0.5-2.0 m height) and on tree-trunks (*Fraxinus* sp.; at 0.5-2.0 m height): 29.VI.1997, leg. P.M. - 3 juv. (1.75-2.3 mm); 06.VIII.1997, leg. P.M. - 2♂♂; 06.IX.1997, leg. P.M. - 3♂♂, 1♀; 12.X.1997, leg. P.M. - 3♂♂, 1♀; 12.X.1997, leg. P.M. - 3♂♂, 1♀ (6.1 mm)(with many eggs); 02.VII.1998, leg. P.M. - 4 juv. (3.1-4.2 mm); 04.X.1998, leg. P.M. - 3♂♂, 1♀ (5.0 mm) (with eggs); 29.VIII.1999, leg. P.M. - 12♂♂, 2♀♀ (7.0 mm)(with and without eggs); 06.IX.1999, leg. P.M. - 4♂♂, 3♀♀; 11.IX.2000, leg. P.M. - 2♂♂, 1♀ (6.5 mm) (with eggs); U3, 575 m, FPT-2: 03.VIII.-03.IX.1998, leg. I. S. - 1♂, 09.VII.-04.VIII.1999, leg. I. S. - 1 juv. (3.2 mm); in the Northern periphery of the park, on leaves of *Rubus* and *Ulmus*-shrubs: 05.VIII.2001, leg. P.M. - 3♂♂, 2♀♀ (without eggs); 14.VIII.2001, leg. P.M. - 2♂♂; on a building-wall in the Northern periphery of the park: 02.X.1998, leg. P.M. - 2♂♂; 16.I.1999, leg. P.M. - 1♂; 08.IX.2000, leg. P.M. - 1♀ (7.3 mm) (with many eggs); 11.IX.2000, leg. P.M. - 2♂♂, 1♀ (7.2 mm), 2♀♀ (5.1 mm)(without eggs); 26.-28.VIII.2001, leg. P.M. - 1♂, 1♀ (7.2 mm) (with many eggs); Zapaden Park: on shrub, 19.XI.1997, leg. P.M. - 1♂; Knyaz Borisovata Gradina: on a Northern wall of the Ecclesiastical Seminary, 13.VIII.1990, leg. P.M. - 1♂; Lyulin Mt.: Bankya, 15-16.IX.1990, leg. B. Mitov - 1♂; S2, 900 m, FPT-2, 09.VIII.-14.IX.1999, leg. I. S. - 1♀ (7.0 mm); Vitosha Mt.: loc. Tihiya Kut (R4), 1000 m, FPT-2, 06.VI.-11.VII.1998, leg. I. S. - 1 juv.; 16.IX.1999, H, leg. P.M. - 2♂♂, 1♀; Lozenska Mt.: "German monast.", 20.VIII.1915, leg. Dr. Buresch, MNHS - 1♂ (4.2 mm); Sushtinska Sredna Gora Mt.: in the region of Panagyurishte, loc. Fetentsi, 900 m, 19.IX.1993, FPT, leg. S. Lazarov - 9♂♂ (3.8 mm)(4.2 mm), 1♀ (5.8 mm)(with eggs).

18. *Rafalskia olympica* (Kulczyński, 1903)

Rafalskia olympica: Staręga, 1976: 396 (Vitosha Mt.: "Berghütte "Aleko", "Berghütte "Tintjava")

Material examined: 1♀.

New localities: Sushtinska Sredna Gora Mt.: above Klisura, forest, FPT, 05.VI.1996, leg. S. Lazarov - 1♀ (5.5 mm) (without eggs).

19. *Rilaena triangularis* (Herbst, 1799)

Rilaena triangularis: Staręga, 1976: 382 (West Stara Planina range: "Paß Petrohan", "Berghütte "Ledenika").

Material examined: 2♀♀.

New localities: West Stara Planina range: above Vurshets, 395-500 m, 27.VI.-02.VII.2000, leg. P.M. - 2♀♀.

20. *Rilaena balcanica* Šilhavý, 1965

Rilaena balcanica: Staręga, 1976: 380 (Zavalska Mt.: "Filipovci"; Vitosha Mt.: "Bojana"; Plana Mt.: "Kokaljane"); Mitov, 1992: 75 (Vitosha Mt.: "above Dragalevtsi"); Mitov, 1988: 484 (Vitosha Mt.: "Cherniya Kos"); Mitov, 1995b: 69 (Vitosha Mt.: "Chernya Kos"); Mitov, 1996: 484 (Vitosha Mt.: "über Dragalevzi"); Mitov, 1997a: 255 (Vitosha Mt.: "above Dragalevtsi").

Material examined: 23♂♂, 33♀♀, 33 juv.

New localities: West Stara Planina range: Distr. Godech, v. Gintsi, in front of cave Dinevata dupka, EPT, 10.V.-27.IX.1992, leg. B. Dimitrova - 1♂ (2.8 mm); Distr. Dragoman, Northern slopes of the karstic ridge Chepun, forest (*Carpinus orientalis* Miller, *Fagus sylvatica* ssp. *moesiaca* (K. Maly) Hjelmq., *Acer* sp.), 1100 m, FPT, 18.V.-07.VII.1997, leg. D. S. Dimitrov - 13♂♂, 12♀♀ (with many eggs); in the region of Lakatnik railway-station, under stones, 06.IV.1991, leg. Z. Mitova - 1 juv. (4.0 mm); Lyulin Mt.: S2, 900 m, FPT-2: 08.V.-13.VIII.1998, leg. I.S. - 1♂, 4♀♀ (4.5 mm) (with eggs); 11.IX.-17.X.1998, leg. I.S. - 1 juv. (2.0 mm); 04.IV.-13.V.1999, leg. I.S. - 1♂ (3.6 mm), 1 juv. (3.6 mm); 09.VIII.-13.X.1999, leg. I.S. - 8 juv. (1.8-3.0 mm); R2, 920 m, FPT-2: 08.V.-13.VIII.1998, leg. I.S. - 2♂♂, 2♀♀ (with many eggs); 11.IX.-17.X.1998, leg. I.S. - 1 juv. (2.75 mm); 13.V.-03.VI.1999, leg. I.S. - 1♂, 1♀; 14.IX.-13.X.1999, leg. I.S. - 3 juv. (2.2-2.6 mm); Vitosha Mt.: v. Vladaya (S4), 950 m, FPT-2, 06.VI.-11.VII.1998, leg. I.S. - 1♂; loc. Tihiya Kut (R4), 1000 m, FPT-2: 21.V.-06.VI.1998, leg. I.S. - 1♀ (with eggs); 09.V.-10.VI.1999, leg. I.S. - 1♀ (with eggs); 01.VII.-07.VIII.1999, leg. I.S. - 1 juv. (2.0 mm); Lozenska Mt.: v. German (S1), 650 m, FPT-2: 04.VI.-08.VII.1998, leg. I.S. - 1♂, 1♀ (4.6 mm); 12.V.-05.VI.1999, leg. I.S. - 1♀ (5.5 mm) (with many eggs); 31.VII.-06.X.1999, leg. I.S. - 2 juv. (1.6-1.85 mm); German monastery (R1), 950 m, FPT-2: 07.V.-10.VII.1998 - 1♂, 6♀♀ (with many eggs); 04.VIII.-20.X.1998, leg. I.S. - 4 juv. (1.7-2.1 mm); 02.IV.-05.V.1999, leg. I.S. - 2 juv. (3.6 mm); 13.VI.-05.VII.1999, leg. I.S. - 1♀ (4.4 mm) (with many eggs); 01.VIII.-10.IX.1999, leg. I.S. - 6 juv. (1.65-2.1 mm); Pancharevski Prolom, under tree remnants, 600 m, 17.X.1993, leg. B. Petrov - 3 juv. (2.0 mm); in the region of v. Pasarel, loc. Hambar Dere, 1000-1400 m, 15.V.1993, leg. D. S. Dimitrov - 1♂; Sushtinska Sredna Gora Mt.: in the region of v. Chavdar, *Populus tremula*-forest, FPT, 03.VII.1996, leg. S. Lazarov - 3♀♀ (5.2 mm)(with eggs);

** 21. *Rilaena serbica* Karaman, 1992

This species is new to the Bulgarian fauna. It was described in 1992 by I. Karaman from the Zlatibor Mt., a subspecies of it (*R. s. kopaonica*) was described simultaneously from the Kopaonik Mt. (both in Serbia). *Rilaena serbica* was later found on Golija Mt., Bjelasica Mt., Zlot Mt., Durmitor Mt. and at many other localities on the mountains of Serbia, Macedonia and Montenegro (Karaman, 1995, pers. comm.).

Karaman (1995) notes that *R.* cf. *serbica* from Durmitor Mt. (Montenegro) differs slightly from the Kopaonik and Zlatibor populations with respect to body coloration, shape of dorsal saddle, the male chelicerae and penis. The Bulgarian *R. serbica* also differs[4] from these populations in the abovementioned structures by having a combination of their character states. The individuals from the Bulgarian population have both distinctive characters, as well as characters shared with

[4] For comparative purposes 3♂♂, 5♀♀ *Rilaena serbica serbica* Karaman, 1992 were examined and 2♂♂, 2♀♀ (Paratypes) *R. serbica kopaonica* Karaman, 1992 (see Material and methods).

R. serbica serbica (shape and colouration of the pedipalps and saddle, shape of tuber oculorum, etc.), *R. s. kopaonica* (dorsal shape of tuber oculorum, shape of glans penis, etc.), and *R.* cf. *serbica* from Durmitor Mt. (shape of male chelicerae). According to Karaman (pers. comm.), the Bulgarian population combines the characteristics (based on the structure of penis only) of *R. s. kopaonica* and of *Rilaena* sp. from Kučaj Mt. (East Serbia). These findings indicate that it is fairly possible for *R. s. kopaonica* to be a subjective synonym of the highly variable *R. serbica*.

Material examined: 25♂♂, 19♀♀, 18 juv.

New localities: West Stara Planina range: Distr. Dragoman, Northern slopes of the karstic ridge Chepun, Vegetation: *Quercus pubescens* Willd., *Carpinus orientalis* Miller, *Fagus sylvatica* ssp. *moesiaca* (K. Maly) Hjelmq., *Rosa canina* L., *Festuca valesiaca* Schleich. ex Gaud., *Genista subcapitata* Pancic, *Satureja montana* L., *Edraianthus serbicus* (Kern.) Petrovic, *Achillea ageratifolia* (Sibth. et Sm.) Boiss.; 800-1100 m, FPT, leg. D. S. Dimitrov - on open stony terrain with shrubs, 850 m: 18.V.-07.VI.1997 - 2♀♀; 27.VII.-28.IX.1997 - 9♂♂, 2♀♀ (with many developed eggs in the uterus); under shrubs, 1100 m, 18.V.-07.VI.1997 - 3 juv. (3.5 mm); in mixed deciduous forest (*Fagus* sp., *Carpinus* sp., *Acer* sp.), 1000 m: 18.V.- 07.VI.1997 - 13♂♂, 14♀♀ (with many developed eggs in the uterus), 15 juv. (4.4-5.5 mm; $\bar{x}=4.9\pm0.27$, n=4)(1 juv. (5.2 mm), vermined with Gregarinia); 27.VII.-28.IX.1997 - 3♂♂, 1♀.

** 22. *Rilaena* cf. *serbica* Karaman, 1992

Rilaena triangularis: Mitov, 1995b: 70 (Vitosha Mt.: "Goli Vruh"); Mitov, 1997a: 255 (Vitosha Mt.: "Bay Krustyo", "Goli Vruh").

In this taxon we refer to all parthenogenetic (thelytokous) forms which are very similar to *Rilaena serbica*, but are characterised by the presence of very atypical for the entire genus strongly shortened ampullae of the *receptaculum seminis* (16-180 μm long; their length is minimum 220 μm in *R. serbica*) – a situation most probably a result of the absent copulation. A similar phenomenon of receptacle-reduction is also known among other groups of parthenogenetic invertebrates [see Enghoff, 1976; Korge, 1975, Omodeo, 1953 (after Enghoff, 1976)], but here we describe this phenomenon for the first time in Opiliones and hypothesize its relation to the parthenogenetical development of the respective species.

Initially, due to the absence of male specimens and because of the observed similarity with the only known from representative of the genus in Bulgaria, the parthenogenetic material from Vitosha was determined as *Rilaena triangularis* (Herbst, 1799) (see Mitov, 1995b, 1997a). Later, as comparative material from *R. serbica* became available, and after the discovery of its bisexual forms in Bulgaria, it became possible to distinguish morphologically (but still not formally taxonomical) the previously determined *R. triangularis* material from Vitosha Mt.

Material examined: 295♀♀, 399 juv.

New localities: West Stara Planina range: Distr. Vratsa, in the region of pick Sokolets, 800 m, in forest, 05.VI.1994, leg. B. Petrov - 1♀; Distr. Svoge, v. Zanoge, 1100-1300 m, 02.V.1984, leg. P. Beron, (MNHS: inv. No 350) - 1 juv. (3.2 mm); Sofia: Severen Park: on a shrub, at 0.5 m height, 13.VI.1997, leg. P.M. - 1♀; U3, 575 m, FPT-2: 02.IV.-03.VIII.1998, leg. I.S. - 2♀♀; 06.IV.-07.V.1999 - 1 juv. (3.0 mm); 07.V.-14.VI.1999, leg. I.S. - 1♀; in a spruce-forest, under stones and tree remnants, in the leaf-litter, 28.III.1999, leg. P.M. - 2 juv. (1.7 mm, 2.4 mm); under stones and tree-remnants, 04.IV.1999, leg. P.M. - 1 juv. (2.9 mm); forest (*Betula* sp., *Populus* sp.), under stones and tree-remnants, 09.IV.1999, leg. P.M. - 2 juv. (2.5 mm, 2.5 mm); *Picea abies*-forest-edge, under tree remnants, 14.X.2001, leg. P.M. - 1 juv. (1.7 mm); Zapaden Park: "Chr. Smirnenski" park area, 575 m, under stones and tree remnants, on three-trunks, dry, 13.IX.2001, leg. P.M. - 2 juv. (1.32-1.42 mm); Knyaz Borisovata Gradina: on a shrub, 3-5 m from "Dr. Tzankov" blvd., 20.V.1998, leg. P.M. - 1♀ (with eggs); under tree remnants, 23.V.1998, leg. P.M. - 5♀♀; U1, 550 m, FPT-2: 05.VI.-03.VII.1998, leg. I.S. - 1♀ (6.8 mm); 07.IV.-13.V.1999, leg. I.S. - 1 juv. (4.2 mm); 13.V.-02.VII.1999, leg. I.S. - 2♀♀; in the TV-tower area, under tree remnants, 11.IX.2001, leg. P.M. - 1 juv. (1.7 mm); Loven Park: U4, 570 m, FPT-2, 07.IV.-11.V.1999, leg. I.S. - 1 juv. (4.1 mm); in the area of the railway-station "Pioneer", forest (*Tilia* sp., *Acer* sp., *Quercus* sp., *Ulmus* sp.), under tree remnants, moist and shady, 23.V.2001, leg. P.M. - 2♀♀ (with eggs) (later (31.V.) one of them layed 248 eggs (l=0.60-0.65 mm) in laboratory conditions); Lyulin Mt.: S2, 900 m, FPT-2: 31.V.-13.VIII.1998, leg. I.S. - 1♀ (with many eggs); 04.IV.-13.V.1999, leg. I.S. - 3 juv. (2.75-3.15 mm); R2, 920 m, FPT-2, 04.IV.-13.V.1999, leg. I.S. - 1 juv. (3.4 mm); above Dragichevsko Ezero, 1130 m, at forest/meadow border, 05.XI.2000-07.IV.2001, FPT, leg. M. Sotirova - 1 juv. (2.5 mm); in the region of peak Dupevitsa, 1130 m, meadow, 01.VI.-01.VII.2001, FPT, leg. M. Sotirova - 1♀; in the region of loc. Dobrinova Skala, 1130 m, meadow, FPT, leg. M. Sotirova: 04.X.-05.XI.2001 - 8 juv. (1.40-1.5 mm); 01.VIII.-04.IX.2001 - 1 juv. (1.65 mm); Vitosha Mt.: loc. Tihiya Kut (R4), 1000 m, FPT-2: 21.V.-11.VII.1998, leg. I.S. - 16♀♀ (6.75 mm), 2♀♀ (4.25 mm)(without eggs)(male-like, probably gynandromorphic); 05.IV.-09.V.1999, leg. I.S. - 2 juv. (2.15-2.9 mm); 01.VII.-07.VIII.1999, leg. I.S. - 2♀♀; loc. Cherniya Kos, 900 m, FPT, 08.X.1987-03.XI.1988, leg. P.M. - 4♀♀, 3 juv.; 31.V.1988, leg. P.M. - 2♀♀; above Boyana: 800-900 m, FPT, VI.1994, forest, leg. B. Petrov - 4♀♀; 900 m, FPT, V.1994, leg. B. Petrov - 2 juv.; hut Iglika-loc. Dendrariuma, 1100 m, 03.VII.1988, leg. P.M. - 1♀; above Dragalevtsi: in the area of the lift-station, 900 m, FPT, 03.IX.-20.X.1988, leg. P.M. - 1 juv.; between loc. Pascha bunar and loc. Kaleto 1100 m, FPT, 05.VI.1987-18.IX.1988, leg. P.M. - 26♀♀, 2 juv.; above Simeonovo, 1100 m, FPT, 30.V.1988-04.III.1989, leg. P.M. - 27♀♀, 10 juv.; loc. Bay Krustyo, 1300-1350 m: FPT, 07.IV.1987-18.IX.1988, leg. P.M. - 20♀♀, 108 juv.; 02.V.1987-08.VII.1988, leg. P.M. - 1♀, 2 juv.; peak Goli Vruh: 1800-1820 m, 10.V.1987-24.X.1988, leg. P.M. - 90♀♀, 85 juv.; 10.VII.-24.X.1988, leg. P.M. - 3♀♀, 1 juv.; peat-bog "Dolnoto Blato", 1800 m, FPT, 31.VIII.1987-24.IX.1988, leg. P.M. - 7♀♀, 11 juv.; above peak Goli Vruh, at the periphery of peat-bog "Gornoto Blato", 1950 m, FPT, 12.VIII.1987-11.VI.1988, leg. P.M. - 1♀, 3 juv.; above v. Bistritsa, 1200 m: FPT-1, 29.VI.- 31.X.1985, leg. S.S. - 10 juv.; 24.X.1988, leg. P.M. - 1 juv.; above v. Zheleznitsa, 1100-1300 m, FPT, 09.IV.-17.VII.1988, leg. P.M. - 3♀♀, 3 juv.; loc Yarema, 1200-1600 m: FPT-1, 10.VI.1984-30.X.1985, leg. S.S. - 1♀, 4 juv.; loc. Mecha Polyana, 1820 m: FPT, 11.IX.1987-20.IX.1988, leg. P.M. - 10♀♀, 80 juv.; 28.V.1988, leg. P.M. - 1 juv.; above hut Aleko, 2000 m, FPT-1, 31.X.1984-28.X.1985, leg. S.S. - 2 juv.; in the region of the "St. Nikola" monastery, 1100-1200 m: FPT-1, 31.VII.1985, leg. S.S. - 1♀; FPT, 10.V.-08.X.1988, leg. P.M. - 8♀♀, 8 juv.; 10.V.1988, leg. P.M. - 2 juv.; in the region of hut Selimitsa, 1250-1300 m, FPT, 10.I.-24.VII.1988, leg. P.M. - 1♀, 5 juv.; loc. Zlatni Mostove-hut Kumata, 1500-1600 m, 03.VII.1988, leg. P.M. - 1♀; in the region of hut Kumata, 1735 m, FPT, 03.VII.-27.IX.1988, leg. P.M. - 1♀; above v. Bosnek, loc. Luvski Rid, 1500 m, FPT, 01.V.1992, leg. G. Tsonev - 14 juv.; above v. Chuypetlovo, 1200-1407 m: FPT-1, 30.V.-31.VII.1985, leg. S.S. - 2♀♀, 1 juv.; FPT, 20.VI.1987-16.X.1988 - 15♀♀; 26.IV.-05.V.1989 - 3 juv.; above v. Chuypetlovo, 1800 m, FPT, 12.IX.1992, leg. G. Tsonev - 1♀; under peak Mecha Dupka, 1790 m, FPT, 25.IX.1988-28.X.1989, leg. P.M. - 1 juv.; loc. Tihiya Kut, 1000 m, FPT-2: 21.V.-11.VII.1998, leg. I.S. - 18♀♀ (4.25-6.75 mm); 05.IV.-09.V.1999, leg. I.S. - 2 juv. (2.15-2.9 mm); 01.VII.-07.VIII.1999, leg. I.S. - 2♀♀; Sushtinska Sredna Gora Mt.: in the region of v. Chavdar, *Populus tremula*-forest, FPT, 03.VII.1996, leg. S. Lazarov - 1 juv. (3.4 mm); Distr. Koprivshtitsa, pick Mala Bratiya, beech-forest/meadow border, 1370 m, FPT: 08.VII.1996, leg. S. Lazarov - 1♀; 08.VIII.1996, leg. S. Lazarov - 3♀♀ (with eggs); Distr. Koprivshtitsa, below peak Bogdan, northern slope, 1380 m: beech-forest, 05.VI.1996, leg. S. Lazarov - 2 juv. (2.0-2.8 mm); beech-forest/meadow border, FPT, 09.VIII.1996, leg. S. Lazarov - 1♀ (with eggs); above Klisura, loc. Koritata, swampy meadow, 900-1100 m, FPT, 05.VI.1996, leg. S. Lazarov - 2 juv. (2.0 mm).

23. *Lophopilio palpinalis* (Herbst, 1799)

Lophopilio palpinalis: Staręga, 1976: 391-392 (West Stara Planina range: "Berghütte "Ledenika", "Paß Petrohan"; Vitosha Mt.: "Bistriški vodopad", "Bojanski vodopad", "Berghütte "Fonfon", "Zlatni mostove"; Lozenska Mt.: "Germanski manastir"; Sushtinska Sredna Gora: "Koprivštica"); Mitov, 1996: 485-486 (Vitosha Mt.: "über Dragalevzi").

Material examined: 3♂♂, 2♀♀, 6 juv.

New localities: West Stara Planina range: v. Gorni Lom, county Zastavata, *Fagus*-leaf litter, 1000 m, 05.IX.1999, leg. B. Petrov - 2 juv. (2.8-3.2 mm); Chiprovtsi, county Debledelska Murtvina, on the edge of a *Fagus*-forest, under stones, 1100-1300 m, 28.VII. 1998, leg. B. Petrov - 3 juv. (1.9 mm); Distr. Vratsa, in the region of hut Purshevitsa, 1000-1300 m, 11.-12.VII.1993, leg. B. Petrov - 1 juv. (2.0 mm); Lyulin Mt.: above Dragichevsko Ezero, 1130 m, forest/meadow border, 05.XI.2000-07.IV.2001, FPT, leg. M. Sotirova - 2♂♂ (2.8-3.0 mm); between Vladayska River and loc. Bonsovi Polyani, 1010 m, *Fagus-Carpinus* forest, FPT, leg. M. Sotirova: 04.IX.-04.X.2001 - 1♀; 04.X.-05.XI.2001 - 1♂ (2.8 mm); Vitosha Mt.: loc. Tihiya Kut (R4), 1000 m, FPT-2, 10.IX.-15.X.1998, leg. I.S. - 1♀.

24. *Zachaeus crista* (Brullé, 1832)

Zacheus crista: Šilhavý, 1965: 392 (Vitosha Mt.: "Bistrica", "Vladzio"[5], Lozenska Mt.: "Monastir Džerman"); Staręga, 1976: (West Stara Planina range: "Čelopek"; Sofia Kettle: "Belediehan", "Busmanci"; Surnena Sredna Gora Mt.: "Mračenik", "Starozagorski bani"); Mitov, 1996: 487 (Vitosha Mt.: "über Dragalevzi"); Mitov, 1997a: 255 (Vitosha Mt.: "above Dragalevtsi", "Bay Krustyo").

Material examined: 142♂♂, 154♀♀, 68 juv.

New localities: West Stara Planina range: Distr. Dragoman, Northern slopes of the karstic ridge Chepun, forest (*Carpinus orientalis* Miller, *Fagus sylvatica* ssp. *moesiaca* (K. Maly) Hjelmq., *Acer* sp.), 1100 m, FPT, 18.V.-07.VII.1997, leg. D. S. Dimitrov - 2♂♂ (7.3-7.5 mm), 2♀♀ (9.0-10.0 mm)(with eggs); Distr. Vratsa, in the region of hut Purshevitsa, 1000-1300 m, 11.-12.VII.1993, leg. B. Petrov - 3♂♂ (6.5 mm); above Vurshets: near Botunya River, Vegetation: *Fagus* sp., *Alnus* sp., *Quercus* sp., *Pinus nigra* Arn., *Rubus* sp., under stones, 27.VI.2000, leg. P.M. - 1♀, 1 juv.; loc. Vodopada, near Orlovitsa River, Vegetation: *Alnus* sp., *Crataegus* sp., *Rubus* sp., *Urtica dioica* L., 400-500 m, 28.VI.2000, leg. P.M. - 1♂ (6.5 mm); Iskurski prolom, along Ochindolska River, above v. Eliseyna, in forest, 700 m, 21.V.1994, leg. B. Petrov - 3 juv. (2.5 mm); Railway station Lakatnik; 06.VII.1948, leg. I. Buresh, MNHS - 1♂ (7.5 mm); above Lakatnik, peak Yavorets, 1348 m, 12.VII.1948, leg. P. Tranteev & I. A. Ivanov, MNHS - 1♂, 1 juv. (4.7 mm); "d. Eleschniza b. Sofia", 22.V.1927, leg. P. Drenski, MNHS - 3 juv.; in the region of Etropole, 01.V.1994, leg. T. Lyubomi-

[5] Šilhavý (1956) mentions, for *Z. crista*, the locality "Vladzio bei Sofia, Vitoša planina, 1300 m". In this case we suggest that this record refers to Vladaya.

rov - 1 juv. (2.5 mm); Sofia: Zapaden Park: U2, 525 m, FPT-2: 02.VI.-11.VIII.1998, leg. I.S. - 32♂♂, 40♀♀ (without/with eggs), 11 juv. (2.2-6.0 mm); 07.V.-04.VIII.1999, leg. I.S. - 15♂♂ (6.1-8.2 mm), 14♀♀ (8.2-10.2 mm) (with many eggs), 12 juv. (2.2-5.2 mm); Knyaz Borisovata Gradina: U1, 550 m, FPT-2: 07.V.-03.VIII.1998, leg. I.S. - 12♂♂ (6.2 mm), 4♀♀, 9 juv. (3.2-6.0 mm), 13.V.-03.VIII.1999, leg. I.S. - 15♂♂ (5.7-6.0 mm), 7♀♀ (7.3 mm) (without/with eggs); under tree remnants, 23.V.1998, leg. P.M. - 1 juv. (4.6 mm); mixed deciduous forest, 600 m, 19.VI.1998, leg. Ch. Ivanova & R. Gorelska - 1♂; at the periphery of forest east of the Ecclesiastic Seminary, under stones and tree remnants, 560-570 m, 23.V.2001, leg. P.M. - 6 juv. (3.2-5.3 mm); Loven Park: U4, 570 m, FPT-2: 13.V.-10.VIII.1998, leg. I.S. - 8♂♂, 12♀♀ (without/with eggs), 1 juv. (5.2 mm); 11.V.-03.VIII.1999, leg. I.S. - 5♂♂ (6.0 mm), 5♀♀ (without/with eggs), 4 juv. (2.5-6.0 mm); behind railway station "Pioneer", in a meadow in the forest (*Tilia* sp., *Acer* sp., *Quercus* sp., *Ulmus* sp.), under tree remnants, 23.V.2001, leg. P.M. - 10 juv. (2.75-4.2 mm); Sofia Kettle: between r.d. "Vrazhdebna" and v. Dolni Bogrov, LTU, wheat-field, FPT, 05.VII.-21.VII.1999, leg. R. Kostova - 4♂♂, 9♀♀ (with eggs); Lyulin Mt.: S2, 900 m, FPT-2: 08.V.-31.V.1998, leg. I.S. - 2♂♂, 1♀, 2 juv. (3.0-3.7 mm); 06.VII.-09.VIII.1999, leg. I.S. - 7♂♂ (7.5-7.7 mm), 6♀♀ (10-10.9 mm) (with many eggs); R2, 920 m, FPT-2, 31.V.-13.VIII.1998, leg. I.S. - 1♂, 1 juv. (6.0 mm); 06.VII.-09.VIII.1999, leg. I.S. - 2♂♂ (5.7 mm), 5♀♀ (8.8 mm) (with eggs); Lozenska Mt.: v. German (S1), 650 m, FPT-2: 04.VI.-06.VIII.1998, leg. I.S. - 8♂♂, 10♀♀ (without eggs), 1 juv. (7.5 mm); 05.VI.-07.IX.1999, leg. I.S. - 11♂♂ (6.5 mm), 20♀♀ (9.7-10 mm) (with eggs), 1 juv. (3.9 mm); v. Lozen, 07.VII.1981, leg. ? - 2♂♂, 2♀♀ (10 mm) (with many eggs); Sushtinska Sredna Gora Mt.: in the region of v. Chavdar, *Populus tremula*-forest, FPT, 03.VII.1996, leg. S. Lazarov - 2♂♂, 2♀♀ (with eggs).

Confirmed localities: Sofia Kettle: near v. Chibaovtsi (R3), 800 m, FPT-2, 29.VI.-06.VIII.1999, leg. I.S. - 1♂; Vitosha Mt.: v. Vladaya, 950 m, FPT-2, 10.VI.-07.VIII.1999, leg. I.S. - 6♂♂ (6.0-8.0 mm), 10♀♀ (6.2-8.3 mm) (without/with eggs); loc. Tihia Kut, 1000 m, FPT-2, 01.VII.-07.VIII.1999, leg. I.S. -1♀; Lozenska Mt.: German monastery (R1), 850 m, FPT-2, 13.VI.-05.VII.1999, leg. I.S. - 3♀♀ (without/with eggs).

25. *Zachaeus anatolicus* (Kulczyński, 1903)

Zacheus anatolicus: Mitov, 1987: 60 (Vitosha Mt.: "above v. Chuypetlevo")

Material examined: 41♂♂, 39♀♀, 4 juv.

New localities: Sofia Kettle, r.d. "Vrazhdebna" and v. Dolni Bogrov, LTU, wheat-field: 15.IV.1999, leg. R. Kostova - 4 juv. (1.5-1.8 mm); FPT, 05.VII.-21.VII.1999, leg. R. Kostova - 39♂♂, 36♀♀ (with eggs); Lyulin Mt.: NW of Vladaya railway-station, grassland (abandoned agricultural plot) with *Prunus spinosa* L., 890 m, FPT, 28.VI.2002, leg. M. Sotirova – 1♂ (8.0 mm), 3♀♀ (7.0 mm) (without eggs); Sushtinska Sredna Gora Mt.: in the region of Klisura, loc. Koritata, 900-1100 m, FPT, 07.VII.1996, leg. S. Lazarov - 1♂.

26. *Egaenus convexus* (C.L. Koch, 1835)

Egaenus convexus: Staręga, 1976: 411 (West Stara Planina range: "Vraca", "Berghütte "Ledenika", "Brusen", "Botevgrad").

Material examined: 3♀♀, 3 juv.

New localities: West Stara Planina range: above Vurshets, 400-500 m, *Pinus nigra*-forest, under tree remnants, 29.VI.2000, leg. P.M. - 1♀ (10.5 mm); Distr. Dragoman, Northern slopes of the karstic ridge Chepun, forest (*Carpinus orientalis* Miller*, Fagus sylvatica* ssp. *moesiaca* (K. Maly) Hjelmq.*, Acer* sp.), 1100 m, FPT, 18.V.-07.VII.1997, leg. D. S. Dimitrov - 2♀♀ (11.0-11.5 mm) (with eggs), 1 juv. (7.5 mm); Sofia Kettle: in the region of hut Belidie Han, *Fagus*-forest, in leaf-litter, 11.V.1996, leg. A. Antov - 2 juv. (4.0-6.8 mm).

27. *Lacinius horridus* (Panzer, 1794)

Lacinius horridus bulgaricus Šilhavý, 1965: 378 (syn. after Staręga, 1976) (Vitosha Mt.: "Vitoša planina", "Slatni mostove"; Lozenska Mt.: "Monastir Džerman", "Džermanski manastir");

Lacinius horridus: Staręga, 1976: 362 (West Stara Planina range: "Berg Malyk Kom", "Kalotina", "Komštica", "Lakatnik", "Paß Petrohan", "Ginci", "Byrzija", "Čerepiš", "Berghütte "Ledenika", "Schlucht Vratcata"; Zavalska Mt.: "Filipovci"; Vitosha Mt.: "Bistriški vodopad", "Bojana", "Bojanski vodopad", "Zlatni mostove", "Železnica"; Lozenska Mt.: "Germanski manastir", "Schlucht Urvič"; Sushtinska Sredna Gora Mt.: "Gara Koprivštica", "Koprivštica"; Surnena Sredna Gora Mt.: "Kazanka", "Starozagorski bani", "Staro Zaimovo"); Mitov, 1992: 75 (Vitosha Mt.: "Bai Krustyo", "above Zheleznitsa"); Mitov, 1995b: 70 (Vitosha Mt.: "Goli Vruh"); Mitov, 1996: 485 (Vitosha Mt.: "über Dragalevzi"); Mitov, 1997a: 256 (Vitosha Mt.: "above Dragalevtsi", "Bay Krustyo", "Goli Vruh").

Material examined: 8♂♂, 38♀♀, 59 juv.

New localities: West Stara Planina range: Chiprovtsi, county Debledelska Murtvina, at the edge of a *Fagus*-forest, under stones, 1100-1300 m, 28.VII.1998, leg. B. Petrov - 2 juv. (2.7-3.3 mm); the pass above hut Kom, under stones near the road, 1650 m, 19.VI.1998, leg. B. Petrov - 2 juv. (1.7 -2.0 mm); Distr. Godech, v. Breze, 750 m, 20.VI.1993, leg. B. Petrov - 2 juv.; Distr. Dragoman, Northern slopes of the karstic ridge Chepun, on a stony terrain with shrubs, 850 m, FPT, 27.VII.-28.IX.1997, leg. D. S. Dimitrov - 1♂, 1♀; Distr. Vratsa, in the region of hut Purshevitsa, 1000-1300 m, 11.-12.VII.1993, leg. B. Petrov - 5 juv. (2.8 mm); above Vurshets, 400-500 m, 27.VI.2000, leg. P.M. - 1 juv. (4.0 mm); above Lakatnik, peak Yavorets, 1348 m, 12.VII.1948, leg. P. Tranteev & I. A. Ivanov, MNHS - 1 juv. (3.8 mm); Sofia: Knyaz Borisovata Gradina: U1, 550 m, FPT-2: 03.VII.-12.X.1998, leg. I.S. - 2♀♀ (5.0-8.0 mm) (without eggs), 1♀ (7.0 mm) (with eggs), 3 juv. (2.8 mm); 12.VI.-03.IX.1999, leg. I.S. - 4 juv. (3.0-4.2 mm); at the periphery of a forest east of the Ecclesiastical Seminary, 560-570 m, under tree-remnants, 23.V.2001, leg. P.M. - 2 juv. (2.6 mm, 2.8 mm); in the area of the Astronomical Observatory, 12.VI.2001, leg. P.M. - 1 juv. (3.0 mm); in the TV-tower area, under tree-remnants, 11.IX.2001, leg. P.M. - 1 juv. (5.2 mm); in the area between "Dragan Tsankov" blvd. and the Astronomical Observatory, under tree-remnants, 14.IX.2001, leg. P.M. - 1 juv. (5.8 mm); Loven Park: in the area of the railway-station "Pioneer", forest (*Tilia* sp.*, Acer* sp.*, Quercus* sp.*, Ulmus* sp.), on the tree-trunks up to 1.5 m height, moist and shady, 23.V.2001, leg. P.M. - 2 juv. (3.0 mm); Lyulin Mt.: above Dragichevsko Ezero, FPT, leg. M. Sotirova: 1010 m, *Betula-Pinus* forest, 04.X.-06.XI.2001 - 1♀ (7.5 mm)(without eggs); 1130 m, forest/meadow border, 05.XI.2000-07.IV.2001 - 1♂ (5.7 mm); in the region of peak Dupevitsa, 1130 m, meadow, 01.X.-05.XI.2000, FPT, leg. M. Sotirova - 2♀♀ (5.5-7.5 mm)(without/with eggs), 1 juv. (4.0 mm); in the region of loc. Dobrinova Skala, 1130 m, meadow, 01.VIII.-04.IX.2001, FPT, leg. M. Sotirova - 1♂ (4.5 mm), 1♀ (7.3 mm)(with many eggs); Vitosha Mt.: v. Vladaya (S4), 950 m, FPT-2, 01.VII.-07.VIII.1998, leg. I.S. - 1 juv. (5.3 mm); loc. Tihiya Kut (R4), 1000 m, FPT-2, 08.VIII.-10.IX.1998, leg. I.S. - 1 juv. (4.2 mm); 16.IX.1999, H, leg. P.M. - 2 juv.; Sushtinska Sredna Gora Mt.: in the region of v. Chavdar, *Populus tremula*-forest, FPT, 03.VII.1996, leg. S. Lazarov - 1 juv. (3.0 mm); Distr. Koprivshtitsa: peak Mala Bratiya, beech-forest/meadow border, 1370 m, FPT, 08.VII.1996, leg. S. Lazarov - 1 juv.; pick Bratiya, 1519 m, FPT, 12.V.1996, leg. S. Lazarov - 2♂♂ (5.1 mm), 5♀♀ (7.8 mm) (with many eggs); in the region of Panagyurishte, loc. Fetentsi, 900 m, FPT, 27.V.1993, leg. S. Lazarov - 2juv. (2.8 mm); 19.IX.1993 - 3♂♂, 22♀♀ (4.0 mm, 6.2 mm, 7.6 mm), 23 juv. (3.0-4.8 mm); Surnena Sredna Gora Mt.: in the region of Kazanluk, TVK Kavakliyka, 1050 m, loc. Batakluka, deciduous forest, FPT, 21.VII.1982, leg. S. Lazarov - 1 juv. (5.5 mm).

Confirmed localities: Lozenska Mt.: “Germanski monastir”, 1-15.VIII.1914, leg. A. Urumow, MNHS - 1 juv. (4.6 mm); R1, 850 m, FPT-2: 04.VIII.-07.IX.1998, leg I.S. - 1♀ (without eggs); 01.VIII.-10.IX.1999, leg. I.S. - 1♀ (4.5 mm), 1♀ (without eggs);

28. *Lacinius ephippiatus* (C.L. Koch, 1835)

Lacinius ephippiatus: Staręga, 1976: 365 (West Stara Planina range: “Berghütte “Ledenika”; Vitosha Mt.: “Bojanski vodopad”).

Material examined: 2♂♂, 8♀♀, 1 juv.

New localities: West Stara Planina range: Distr. Chiprovtsi, below peak Midzhur, 1900 m, 26.X.1969, leg. P. Beron, (MNHS: inv. No 81) - 1♀ (4.3 mm); Lyulin Mt.: S2, 900 m, FPT-2, 06.VII.-09.VIII.1999, leg. I.S. - 2♀♀ (5.3-6.2 mm) (with eggs); R2, 920 m, FPT-2: 31.V.-13.VIII.1998, leg. I.S. - 1♀ (with eggs), 1 juv. (3.25 mm); 06.VII.-09.VIII.1999, leg. I.S. - 2♂♂ (4.5 mm), 4♀♀ (5.2-6.0 mm)(with eggs).

29. *Lacinius dentiger* (C. L. Koch, 1848)

Lacinius dentiger: Šilhavý, 1965: 378 (Lozenska Mt.: “Monastir Džermen”); Staręga, 1976: 367 (West Stara Planina range: “Berghütte “Ledenika”, “Schlucht Vratcata”, “Paß Petrohan”, “Druzevo”, “Lakatnik”; Zavalska Mt.: “Filipovci”; Vitosha Mt.: “Bojana”, “Bojanski vodopad”, “Zlatni mostove”); Mitov, 1988: 486 (Vitosha Mt.: “above Dragalevtsi”); Mitov, 1995b: 69-70 (Vitosha Mt.: “above Dragalevtsi”, “Shoumako”, “Selimitsa hut”, “Bai Krustyu”); Mitov, 1995c: 2-4 (Vitosha Mt.: “Gelände zwischen Pascha bunar und Kaleto”); Mitov, 1996: 487 (Vitosha Mt.: “über Dragalevzi”); Mitov, 1997a: 256 (Vitosha Mt.: “above Dragalevtsi”, “Bay Krustyo”).

Material examined: 1♂, 4♀♀, 6 juv.

New localities: West Stara Planina range: Chiprovtsi, county Debledelska Murtvina, at the edge of a *Fagus*-forest, under stones, 1100-1300 m, 28.VII.1998, leg. B. Petrov - 1 juv. (3.2 mm);

Sofia: “Vrana” residence: on a wall at 0.3-0.4 m height, 06.-08.V.2000, leg. P.M. - 2 juv. (1.8 mm)(3.0 mm); Loven Park: the area of the railway-station “Pioneer”, forest (*Tilia* sp., *Acer* sp., *Quercus* sp., *Ulmus* sp.), on tree-trunks, moist and shady, 23.V.2001, leg. P.M. - 1 juv. (2.75 mm).

Lyulin Mt.: in the region of peak Dupevitsa, 1130 m, meadow, 01.X.-05.XI.2000, FPT, leg. M. Sotirova - 4♀♀ (5.5-7.0 mm) (with eggs).

Vitosha Mt.: loc. Tihiya Kut (R4), 1000 m, 16.IX.1999, H, leg. P.M. - 1♂.

Confirmed localities: Lozenska Mt.: German monastery (R1), 850 m, FPT-2, 04.VIII.-07.IX.1998, leg. I.S. - 2 juv. (4.4-5.5 mm);

30. *Odiellus lendli (*Sørensen, 1894)

Odiellus bieniaszi: Staręga, 1976: 358-359 (West Stara Planina range: "Lakatnik", "Berghütte "Ledenika", Sushtinska Sredna Gora Mt.: "Gara Koprivštica"; Lozenska Mt.: "Schlucht Urvič"; Vitosha Mt.: "Bojana", "Železnica") (syn. after Martens, 1978).

Material examined: 9♂♂, 18♀♀, 21 juv.

New localities: West Stara Planina range: Distr. Dragoman, Northern slopes of the karstic ridge Chepun, on stony terrain with shrubs, 850 m, FPT, 27.VII.-28.IX.1997, leg. D. S. Dimitrov - 1♂, 1♀; above Etropole, 24.VII.-04.VIII.1999, leg. G. Krustev - 1 juv. (3.8 mm); Sofia Kettle: between r.d. "Vrazhdebna" and v. Dolni Bogrov, LTU, wheat-field, 05.VII.-21.VII.1999, leg. R. Kostova - 1 juv. (3.5 mm); Sofia: Severen Park: at the base of three-trunks, 29.VI.1997, leg. P.M. - 2 juv. (2.5 mm, 2.5 mm); under tree-remnants and in leaf-litter, *Picea abies*-forest/*Quercus rubra*-forest border, 02.X.1998, leg. P.M. - 2♂♂, 1♀ (with eggs); 14.X.2001, leg. P.M. - 1♂ (4.8 mm), 2♀♀ (6.2 mm) (with eggs); on a building-wall at the northern periphery of the park, up to 0.30-0.50 m height, 25.X.1998, leg. P.M. - 2♂♂; on a tree-trunk, 06.VII.1999, leg. P.M. - 13 juv. (2.7-3.2 mm); *Picea abies*-forest, under tree-remnants: 14.VIII.2001, leg. P.M. - 1 juv. (3.7 mm); 28.VIII.2001, leg. P.M. - 5♀♀ (5.0 mm) (without eggs), 2 juv. (3.9 mm); Zapaden Park: U2, 525 m, FPT-2, 11.VIII.-03.IX.1998, leg. I.S. - 1 juv. (4.1 mm); Lyulin Mt.: above railway station Vladaya, meadow between wheat and maize-fields, 890 m, FPT, leg. M. Sotirova: 02.IX.-01.X.2000 - 1♂ (4.3 mm), 3♀♀ (5.6-6.0 mm)(with eggs); 01.IX.-05.X.2001 - 2♂♂ (4.3-4.5 mm), 5♀♀ (5.5-6.0 mm)(with eggs); above Dragichevsko Ezero, 1130 m, forest/meadow border, 05.XI.2000-07.IV.2001, FPT, leg. M. Sotirova - 1♀ (6.0 mm) (without eggs).

31. *Mitopus morio* (Fabricius, 1779)

Mitopus morio: Beron, 1975: 57 (Vitosha Mt.: "Chalet Aleko"); Staręga, 1976: 354 (West Stara Planina range: "Berg Kom", "Berg Malyk Kom", "Paß Petrohan", "Druževo"; Vitosha Mt.: "Berghütte "Aleko", "Bistriški vodopad", "Bojana", "Bojanski vodopad", "Berg Černi vryh", "Berghütte "Edelvajs", "Berghütte "Fonfon", "Zlatni mostove"); Mitov, 1995b: 69-70 (Vitosha Mt.: "Bai Krustyu"); Mitov, 1997a: 256 (Vitosha Mt.: "Bay Krustyo", "Goli Vruh").

Material examined: 3♀♀, 6 juv.

New localities: West Stara Planina range: Chiprovtsi, county Debledelska Murtvina, at the edge of a *Fagus*-forest, under stones, 1100-1300 m, 28.VII.1998, leg. B. Petrov - 2 juv. (5.3-5.6 mm); the surroundings of hut Kom (the old one), *Picea abies*-forest, 1600-1700 m, 19.VI.1998, leg. B. Petrov - 2 juv. (2.0-4.2 mm); in the region of Vratsa, hut Purshevitsa, 1000-1300 m, 11.-12.VII.1993, leg. P. Beron, MNHS - 1 juv. (5.5 mm); District of Berkovitsa, v. Burziya, *Fagetum*, 19.VII.1968, leg. P. Beron, (MNHS: inv. No. 193) - 1♀; Lyulin Mt.: W of loc. Cherniya Kos, in the region of loc. Bonsovi Polyani, *Carpinus betulus*-forest with grass layer, 1010 m, FPT, 31.V.2002, leg. M. Sotirova – 1 juv. (3.6 mm); Sushtinska Sredna Gora Mt.: in the region of v. Chavdar, *Populus tremula*-forest, FPT, 03.VII.1996, leg. S. Lazarov - 1♀ (6.2 mm)(without eggs); Surnena Sredna Gora Mt.: in the region of Kazanluk, TVK Kavakliyka, 1050 m , loc. Batakluka, deciduous forest, FPT, 21.VII.1982, leg. S. Lazarov - 1♀ (7.0 mm) (with eggs).

32. *Leiobunum rumelicum* Šilhavý, 1965

Leiobunum rumelicum: Staręga, 1976: 347-348 (West Stara Planina range: "Byrzija", "Paß Petrohan", "Druževo", "Berghütte "Ledenika"; Vitosha Mt.: "Berghütte "Aleko", "Bojana", "Bojanski vodopad", "Berghütte "Edelvajs", "Kopitoto", "Vladaja", "Zlatni mostove"; Lozenska Mt.: "Germanski manastir"; Sushtinska Sredna Gora Mt.: "Koprivštica"); Mitov, 1995c: 2-4 (Vitosha Mt.: "Gelände zwischen Pascha bunar und Kaleto"); Mitov, 1997a: 256 (Vitosha Mt.: "Bay Krustyo", "Goli Vruh"); Mitov, 1997c: 2 (Vitosha Mt.: "über Dragalevtzi").

Material examined: 2♂♂, 1♀, 17 juv.

New localities: West Stara Planina range: Distr. Godech, v. Gintsi, in front of cave Dinevata dupka, ETP, 10.V.-27.IX.1992, leg. B. Dimitrova - 1 juv. (2.7 mm); in the region of Vratsa, hut Purshevitsa, 1000-1300 m, 11-12.VII.1993, leg. B. Petrov - 1♂, 1♀; above Vurshets: near Botunya River, Vegetation: *Fagus* sp., *Alnus* sp., *Quercus* sp., *Pinus nigra* Arn., *Rubus* sp., under stones, 27.VI.2000, leg. P.M. - 1♂, 5 juv. (3.0 mm); loc. Vodopada, near Orlovitsa River, Vegetation: *Alnus* sp., *Crataegus* sp., *Rubus* sp., *Urtica dioica* L., 400-500 m, 28.VI.2000, leg. P.M. - 11 juv. (2.5 mm).

DISSCUSSION

Local fauna

Species assemblages in the urban habitats: U1-U4.

Severen Park (U3), 575 m a. s. l., area: 100 ha (970 dka)

This site is characteristic with a very low abundance of the four harvestmen-species caught using pitfall traps. (Table 2). Additional hand-collecting revealed the presence of another four species, also occurring at low abundances. These are *Carinostoma ornatum*, *Opilio parietinus*, *O. saxatilis* and *Odiellus lendli*, which may be found mainly at the periphery of the park.

This park was created about 40 years ago on agricultural terrain (e. g. vegetable gardens, forest nursery) (see Kovachev, 2001; Radoslavova, 2001). Furthermore, the recent deforestation and the active urban development occuring around this park during the last 30 years, as well as the presense of vast dry grasslands northwards, has led to a relatively strong isolation of the park in comparison to the other parts in this study, and possibly to limit the exchange in species with the relatively more preserved habitats from the lower mountain zone.

Due to the closeness of "Severen Park" to the heavily built up housing estate, a tendency towards a stronger manifesting anthropogenization of the opilionid fauna may be observed – the presence of *Opilio parietinus* on buildings within the territory of the park is an indication of a probable faunal exchange with the heavily urbanised fauna, since the mentioned species is a typical representative of building walls within the central parts of the city of Sofia (Mitov, in prep.). The rest of the species also show preferences to warm climate and under natural conditions are typical forest (*Opilio ruzickai*), open habitat (*Phalangium opilio*, *Odiellus lendli*) or habitat generalist (*Trogulus tricarinatus*, *Carinostoma ornatum*) species. It is most likely that *Odiellus lendli* has invaded the park from the surrounding open grassy habitats; the same may hold true for *Phalanguim opilio*. The latter species prefers open and sunny habitats with a well developed grassy layer, but in the park it also occurs in the grassy ecotones within the forested zones (under stones, on tree trunks and on shrubs). Regardless of the fact that the termophilous and night active species *Zachaeus crista* does not avoid anthropogenically influenced habitats (see Martens, 1978), "Severen Park" is the only park where this species was not presently found. This phenomenon may be explained with the special microclimatic conditions in this park (e. g. lower temperatures and rainfall (and humidity), frequent and long-lasting temperature inversions, low nightly temperatures during the summer) (see Bluskova *et al.*, 1983). According to Martens (1978) *Opilio saxatilis* occurs in anthropogenically influenced habitats as well, but contrary to *Zachaeus crista*, *O. saxatilis* is ecologically more tolerant (see Avram & Dumitrescu, 1969 (after Weiss, 1975)) and withstands much lower temperatures and humidity. The presence of the parthenogenetic (and probably primary mountaineous species) *Rilaena* cf. *serbica* in the park is of great interest. The shape of its rudimentary *receptacula seminis* is very similar to the populations found on Lyulin and Vitosha Mts. This fact, together with the reports of Stoyanov (1937) about forest corridors that have existed in the territory between these mountains and parts of the present city (e. g. Sukhodol and Konyovitsa), may be an indication that this taxon is a pre-urbanization relict for the city and especially for "Severen Park". However, it is also possible that some of the harvestmen are transported into the areas by humans.

Zapaden Park: "Christo Smirnenski" park area (U2), 525 m a. s. l., area: 48 ha

The park area "Chr. Smirnenski" of Zapaden Park was created between 1934 and 1940 as a tree nursery. In 1961 this part of the park was transformed into a typical park and later, after 1967, the forest-like part was established (Kovachev, 2001). This park is opened only towards its W-SW end and is bordered in this direction by open grassy habitats. This has most probably determined the opilionid taxocoenoses inhabiting the park at present. Here, nine harvestmen species were found, three of them - *Opilio saxatilis*, *O. ruzickai* and *Rilaena* cf. *serbica* – were only found by hand-collecting (see Table 2). The most numerous species is *Zachaeus crista* – here, in comparison to the other parks, it reaches the highest densities. It is known that in areas with a more continental climate *Z. crista* is more strongly adherent to moist and shady habitats (Weiss & Sarbu, 1977). The rest of the species are also thermophilous; some of them are forest-dwellers (*Opilio dinaricus*, *O. ruzickai*, *Rilaena* cf. *serbica*), some are open habitat inhabitants (*Phalangium opilio*, *Odiellus lendli*) and habitat generalists are also represented (*Trogulus tricarinatus*, *Carinostoma ornatum*, *Opilio saxatilis*). Due to the higher temperatures in this part of the city (see Bluskova *et al.*, 1983), finding the opilionid species *Opilio parietinus* and *Lacinius horridus* is highly possible.

Knyaz Borisovata Gradina: Park area (U1) - 550 m a. s. l., area: 88.0 ha

According to data provided by Kovachev (2001, pers. comm.), the terrain on which the park "Knyaz Borisovata Gradina" is situated, was initially constituted by private gardens, vineyards and other agricultural lands. In 1885 the park was established on these, first as a tree-nursery outside the city, and later (between 1892 and 1934) as a typical park (Kovachev, 2001). Presently, "Knyaz Borisovata Gradina" is completely surrounded by urban infrastructure – housing estates and some of the most traffic-loaded highways within the city of Sofia. The northern (and oldest) part of the park is situated almost at the very center of the city, where the air temperatures nearly reach their maximum within the boundaries of the city (see Bluskova *et al.*, 1983), and where it is heavily used for recreational purposes. In contrast, the vegetation of the Southern part of "Knyaz Borisovata Gradina" is much less cultivated and managed and appears much more forest-like (more shady and with more leaf-litter). These conditions reflect the composition of the opilionid fauna as well.

Pitfall traping collected five species here (Table. 2). Additionally, hand-collecting yielded three more species - *Carinostoma ornatum*, *Opilio parietinus* and *O. ruzickai*. The latter occurs only at the periphery of the park (between boulevards "Dragan Tsankov" and "Peyo Yavorov"), on building-walls. The occurrence of *Opilio parietinus*, which may be found mainly on building-walls is an indicator of anthropogenic pressure. This collecting site is also characterised by the extremely low numbers of Opiliones caught using pitfall traps (Table 2). The only exception is, again, *Zachaeus crista* – the collected specimens of this species rank second, right after those caught at U2. This species seem to be much more competitive, compared to other species, and is very successful in colonizing young and fast developing secondary forest habitats.

Although at very low densities, the termophilous *Opilio saxatilis* and *Lacinius horridus* also occur in the park. At densities just below these of *Z. crista*, here may be found *Trogulus tricarinatus*, which inhabits the leaf-litter where it possibly finds suitable shelter and food (Gastropoda) (about the gastropod fauna of the park and the city as a whole, see Dedov & Penev, 2000).

In the more shady and forest-like parts of the park, the parthenogenetic forms *Rilaena* cf. *serbica* may also be found. Most probably, the natural forest-vegetation corridor (consisting mainly of *Quercus*, *Ulmus*, *Fraxinus*, *Acer*, *Populus*, *Corylus*, *Crataegus*, and *Rubus*), that existed until the beginning of the 20th century between the territory of the city and the surrounding mountains (i.e. Vitosha Mts. and Sredna Gora Mts.) (see Stoyanov 1937; Kitanov 1985) permitted this peculiar harvestmen species to become more widespread throughout the southern vicinity of the city (consisting recently of "Loven Park", which contact the Southern part of "Knyaz Borisovata Gradina"). Later, with the destruction of the abovementioned forest massives, these animals perhaps remained isolated within the forested patches left in the city. Nevertheless, the alternative scenario – i .e. that species interchange between these territories have occurred much later, when the park was widely opened southwards (until the second half of the 20th century) to the relatively low-developed region between the city and the surrounding villages (as Dragalevtsi, Simeonovo, and Durvenitsa), is also plausible.

It could be expected that the species *Opilio dinaricus* and *Odiellus lendli* may also be found here in the future.

Knyaz Borisovata Gradina: Forest part (="Loven Park") (U4), 570 m a. s. l., area: 169,570 ha (municipality Izgrev) + 57,764 ha (municipality Lozenets)

Chronologically, this park was created after "Knyaz Borisovata Gradina" and during the first 20 years of the 20th century it served as a tree-nursery, that had to meet later the increased demand for trees along the roads of the intensively growing city after WWII (Kovachev, pers. comm.). "Loven Park" is the closest park to the Vitosha Mt., and is also opened toward the mountain. The Dragalevska River runs through the park and the habitat is more humid and shady, the vegetation is more uncultivated and dense, and the leaf-litter is thicker. Due to its function and distance from the city center, this park is much less anthropogenically influenced. All this may be the reason for the high species richness of the park and for the higher number of forest-specific harvestmen-species that inhabit it.

The pitfall traps yielded a catch of 6 opilionid species (Table 2). Additionally, a further 3 species (i. e. *Lacinius dentiger, L. horridus*, and *Opilio saxatilis*) were hand-collected.

The most numerous species is *Carinostoma ornatum*, followed by *Zachaeus crista* and *Trogulus tricarinatus*. *Carinostoma ornatum* is less vagile and, as a representative of the family Nemastomatidae, requires a higher humidity. Much less abundant here is the photophylic species *Phalangium opilio*, which has probably colonized the park from the surrounding open habitats. Here also occurs the ombrophylic and mesothermophilic *Opilio dinaricus,* a species typical of the dense forest habitats at the lower foothills of the mountains. The same is frue for the species *Lacinius dentiger*.

Rilaena cf. *serbica* is also very sparse in this park. This species has probably colonized this park through "Knyaz Borisovata Gardina" or through the abovementioned forest-corridor that connected the territory of the city with Vitosha Mt.

In the warmer and dry parts of this park, the occurrence of *Opilio parietinus* and *Odiellus lendli* may be expected.

Species assemblages in the non-urban habitats (S1, S2, S4, R1, R2, R3, R4)

Sofia Kettle: near Drenovo Village (R3), 800 m a. s. l.

Despite weak anthropogenic pressures, this habitat is highly isolated, very dry, and in addition provides an insuffcent trophic base for supporting a species-rich opilionid fauna. Here, at very low densities, occur only three species typical of warm forest habitats and the plain – *Trogulus tricarinatus*, *Carinostoma ornatum*, and *Zachaeus crista.*

Lyulin Mt.: a forest-patch between "Gorna Banya" residental district and locality Bonsovi Polyani (S2), 900 m a. s. l.

This is a thinner oak-hornbeam forest (8,0 ha) with a relatively well developed grass layer. Its opilionid fauna is represented by 7 species, among which the number of harvestmen with preferences to shady, moist, and cool places is clearly reduced (e. g. *Lacinius ephippiatus*), and, moreover, *Pyza bosnica* is totally absent. On the contrary, here *Trogulus closanicus* dominates. The next most abundant species are *Zachaeus crista* and *Rilaena balcanica*, which are indicators for warm foothill habitats. Here, the parthenogenetic forms of *Rilaena serbica* are scarce, which is probably a result of competition with the other opilionid species in the warmer foothill habitats.

Lyulin Mt.: forest N of locality Bonsovi Polyani (R2), 920 m a. s. l.

This habitat is a similar to the previous oak-hornbeam forest, which is characterized by a more dense tree-vegetation, thicker leaf-litter, and is larger (15,2 ha). This, together with the larger number of microhabitats, probably determines the larger species-richness (8) in comparison to S2. The heavier shade and the river that runs through this forest lead to an decrease (both proportion and abundance) of the warmth-loving species (*Zachaeus crista*, *Opilio dinaricus*) at the expense of the species that prefer shady and moist (*Rilaena balcanica*, *Lacinius ephippiatus*), or cool habitats (*Pyza bosnica*). *Trogulus closanicus* is again the dominating species (but much less abundant in comparison to S2), followed by *Pyza bosnica* and *Trogulus tricarinatus*. Here the parthenogenetic forms of *Rilaena serbica* are very scarce, and the explanation may be the same as already stated above.

Vitosha Mt.: above Vladaya Village (S4), 950 m a. s. l.

In this foot hill forest habitat, only 4 opilionid species were found. Among them, only the thermophilous *Zachaeus crista* dominates (Table 2). Despite the fact that *Trogulus tricarinatus* and

Lacinius horridus are ecologically more tolerant species, at this site they are very scarce. This may be due to a relatively limited trophic basis. In such dry forest habitats the gastropod fauna is poor, and it is well known (Pabst, 1953), that *T. tricarinatus* is strongly associated with it. Besides, the main destructors in decidous forests are members of Lumbricidae and Enchytraeidae, but *Lacinius horridus* feeds on Acari (see Šilhavý, 1956), which together with Collembola are the main decomposers not in the decidous, but in the coniferous forests (Dyilis, 1978; I. Tsonev, pers. comm.).

The reasons for the absence of *Rilaena* cf. *serbica* in this habitat is perhaps a complex one, but the most important are probably 1) lower moisture (indicator of this is also the low density of *Rilaena balcanica*, which prefer moist and shady forest habitats) and 2) competitive exclusion by the dominant of *Zachaeus crista*.

Vitosha Mt.: loc. Tikhiya Kat (R4), 1000 m a. s. l.

In this habitat, natural vegetation predominates, both the tree-density and the diversity of microhabitats are higher, and with the increase in altitude the temperatures naturally decrease. Taking all this into account, it seems easy to predict the observed species richness, which is twice as high as in S4. Ombrophilous and psychrophilous harvestmen species such as *Pyza bosnica*, *Rilaena balcanica*, and *Lophopilio palpinalis* appear, whereas the photophilous (*Phalangium opilio*) and thermophilous species (*Zachaeus crista, Lacinius horridus, Opilio ruzickai*) decrease in abundance. Here, also, hylobiont species such as *Lacinius dentiger* occurs, which prefers moderately warm and moist forest habitats in the oak-hornbeam zone of Vitosha Mt.

It is important to note that in this habitat the cold-resistant parthenogenetic forms of *Rilaena* cf. *serbica* are the most abundant opilionids. As already mentioned, this is a species of mountaineous origin and occurs only in these investigated habitats, which are mountaneous (S2, R2, R4) or in those (U1, U3, U4) that are known to have been connected to mountains in the past (see Stoyanov, 1937; Kitanov, 1985).

Lozenska Mt.: German Village (S1), 650 m a. s. l.

S1 is a small (1,9 ha) secondary forest that is relatively isolated from the other forest habitats through dry open grasslands. Due to this, the species assemblage (6 species) is composed of thermophilous and ecologically tolerant species and do not differ from those occurring in the region of the Sofia Kettle and the city parks (Table 2). The only exception is *Rilaena balcanica*, which prefers habitats in the oak-hornbeam zone of the mountains and may be considered as an indicator species of the shady and moist forests of the mountain foothills. In this forest, these conditions are met and here *Rilaena balcanica* probably finds necessary shelter and food. Among the species that may be found in S1, only *Phalangium opilio* and *Opilio saxatilis* prefer open lands and tend to migrate seasonally from the surrounding grasslands into the forest, where they may find shadow, shelter and food. In this opilionid assemblage, *Zachaeus crista* dominate, thus showing again clear preferences for young forest habitats at the mountain foothills.

Lozenska Mt.: German monastery (R1), 850 m a. s. l.

This is an oak-hornbeam forest, much larger than S1 (18 ha), and offers thus a more diverse spectrum of microhabitats to the Opiliones. These characteristics, combined with the more dense tree stand and the more stable moisture conditions, is reflected in the species composition of the harvestmen assemblage at R1. The traps yielded 8 species, and the hand-collecting added a further species to the list (Table 2). Among them, indicators for shady and moist forest-habitats at the foothills are mainly *Histricostoma drenskii* and *Rilaena balcanica*, as well as *Opilio dinaricus,* and the more ecologically tolerant *Opilio ruzickai* and *Lacinius dentiger*. Photophilous species, as for example *Phalangium opilio*, are scarce. Here the most abundant harvestmen species is *Trogulus tricarinatus*, which, at the foothills, prefers mainly forest habitats, where it finds shelter, moisture, and food (snails) among the leaf-litter. *Rilaena balcanica* and *Zachaeus crista* are ranked respectively second and third in abundance. The above-mentioned fauna that include species which prefer higher temperatures, species that show preferences toward cool microclimate and higher moisture, as well as species that are more tolerant with respect to ecological conditions, directly reflect the combination of climatic peculiarities of the Sofia Kettle and of Lozenska Mt. (see Bluskova *et al*., 1983; Nikolov & Yordanova, 1997).

Local fauna in the context of the regional species pool

When examining the ordination diagram of the sites (regions and sampled localities) (Fig. 1A), it is evident the clearly differentiated cluster containing the mountain massifs enclosing the Sofia Kettle from north and south (including the regions SG, SPW, and V). This region-group posseses a high species richness, mainly due to the contribution of more locally restricted species (*N. bidentatum sparsum*, *M. chrysomelas*, *D. scabrum*, *P. radewi*, *R. olympica*, *M. morio*, *L. rumelicum*) (Fig. 1B). Additionally, there occur species that are distributed throughout other regions (e. g. Lyulin Mt., “L” on Fig. 1A) – *Tr. closanicus*, *L. epphipiatus*, *P. bosnica*, *L. palpinalis*, and *H. drenskii*, for example. A much inferior position in the fauna of this mountain-group possess species that inhabit the lower altitudes and the lowlands (*Z. anatolicus*, *E. convexus*) (Fig. 1B).

In the second, much less differentiated cluster, fall the region of the Lyulin Mt. (L), together with the localities S4, R4 (both geographically within Vitosha Mt.), R1 (geographically within Sredna Gora Mt.), and the two localities R2 and S2 (both geographically within Lyulin Mt.). One of the striking peculiarities within this cluster is the placement of locality R4 closer to L than to V (to which it belongs geographically). This situation may be attributed to the natural heterogeneity of the latter region, which is currently a National Park and thus quite well conserved. Another interesting feature, observed in Fig. 1, is the even much farther placement of S4 relative to its geographical origin. This “behavior” is most probably related to the faunal heterogeneity of the region, which is closely related to the anthropogenic pressure since it is still strongly tangible at S4 (for a more detailed description of S4 see Penev *et al.* this volume). The close relationship of R1 (quite well separated on the plot from its geographical region – Sredna Gora Mt.) with this and its affinities to the next site/region cluster, is probably due to the effects of the abovementioned trends – i.e. this could be a result of the natural heterogeneity of the larger region, to which this site pertains, or due to the anthropogenically induced faunal transformation that is also quite well notable there. The same may be valid for the two localities within the Lyulin Mt. – R2 and S2 – which possess an opilionid fauna that is generally non-representative of the mountain, but nevertheless, on the ordination diagram the less influenced locality (R2) is still placed closer to its region. The position of the only region in this cluster – Lyulin Mt. itself – indicates the existence

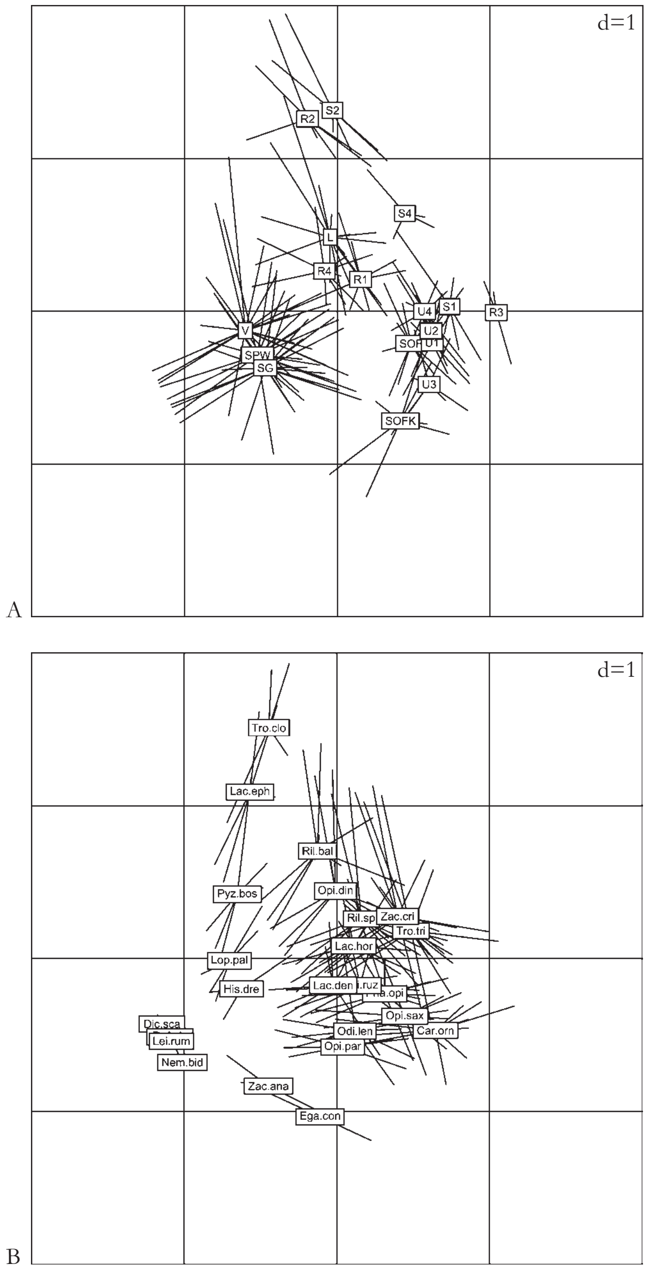

Figure 1. Reciprocal scaling of sample diversity (A) and opilionid species tolerance (B) after a correspondence analysis (CA). The relative values of sample (locality, region) diversity and species tolerance may be inferred from the spread of "stars" centered at the corresponding label.

of a transitional zone on a gradient from the Sofia Kettle to the surrounding high mountains. This gradient is most probably a result of the mixed influence of both the orography of the investigated area, and the anthropogenically induced transformation and subsequent degradation of the forest vegetation in the region. As support for this statement, the relative positioning of S2 and R2 may be used. At these localities, as already mentioned – quite isolated from their geographical region, a (to a different degree) typical mezophylous forest opilionid fauna (*Tr. closanicus*, *O. dinaricus*, *L. ephippiatus*, *R. balcanica*, and *P. bosnica* among others) (Fig. 1B) survived mainly due to the more conserved forest vegetation and soil in this part of Lyulin Mt.

The third cluster obvious from the diagram is centered around the regions of the city of Sofia and the Sofia Kettle (SOF, SOFK). The sites forming this cluster are inhabited by open-habitat, highly ecologically tolerant harvestmen species that are relatively eurytopic – *O. parietinus*, *O. saxatilis*, *C. ornatum*, *O. ruzickai*, *Ph. opilio*, *Tr. tricarinatus*, and *Z. crista* (Fig. 1B). Due to these characteristics, these species are also relatively resistant to anthropogenic influences and some of them are the only representatives of Opiliones that are found in the very urban center of the city of Sofia (Mitov, in prep.). The strong clumping of the park-localities (U1, U2, U4) around SOF on the ordination diagram indicates that the fauna of the city is very homogeneous as a result of the strongly impoverished opilionid fauna. The extreme example for such faunal impoverishment represents the highly isolated and dry locality R3 (geographically at the transition between the Sofia Kettle and the foothills of Western Stara Planina Mts.) which is inhabited by only three, relatively eurytopic harvestmen species. Further, the fauna of the Sofia Kettle may be considered as a relatively well delimited unit within the transition-zone between the fauna of the city and that of the surrounding high mountains, being in close geographical and faunistic relationships with the local fauna of U3 (Severen Park).

Finally, it is noteworthy that the overall structure of the ordination diagram of regions and localities (Fig. 1A) almost exactly approaches the picture obtained by the ordination of the faunistic structure that possess all the characteristics of a "nested subset" (about nested subsets see details in Atmar & Patterson, 1993). Moreover, a preliminary analysis (Stoyanov, unpublished data) in this respect has shown that the resulting pattern is extremely highly-ordered – thus providing more evidence that the observed species-diversity pattern most probably originates from heavy fragmentation processes that have occurred within faunistically structured landscape.

Origin and characteristics of the opilionid fauna of the Sofia Kettle and the City of Sofia

In the past, the territory of the Sofia Kettle was covered with dense deciduous forests (*Quercus, Ulmus, Acer, Carpinus, Populus, Corylus* and other), which extended to the foothills of the surrounding mountains, and survived until the 18th century (Stoyanov, 1937). Considering this, and bearing in mind our knowledge on the biology, ecology and recent distribution of harvestmen in Bulgaria, it may be suggested that the historical fauna of the Sofia Kettle was not much different from the fauna of the foothills of the surrounding mountains, and has included mainly species inhabiting forest habitats, forest meadows and moist riverside vegetation communities.

The destruction of forests in the Kettle as a result of human activities, and the gradual transformation of the forested landscape into a steppe-like habitat (Stoyanov, 1937), accompanied with further transformation of parts of this newly-created habitat into ruderal lands with the ongoing development of the city (Avramova, 1956), has led most probably to a strongly impoverished and altered opilionid fauna. The species that prefer moist and shady habitats (e. g. representatives of *Paranemastoma, Pyza, Histricostoma, Mitostoma*, *Rilaena balcanica*) as well as the slightly more ecologically tolerant species that are associated with a broader spectrum of forest habitats (e. g. forest meadows) (e. g. *Trogulus closanicus, Dicranolasma scabrum*) have disappeared. The thermophilous species and species resistant to dry conditions, with better dispersal abilities, have survived and have come to dominate the newly created habitats. It is most likely, that in the forest-remnants and in the riverside vegetation, some small-bodied and ecologically tolerant trogulid and nemastomatid species (as e. g. *Carinostoma ornatum*, *Trogulus tricarinatus*) able to occupy very confined habitats with condensed moisture, as well as larger and more agile forest-dwelling species from the family Phalangiidae (*Opilio ruzickai*, *O. dinaricus*, *Lacinius dentiger*, *Rilaena cf. serbica*), have retained some of their populations or have established new ones after secondary migrations.

During the 1940's, the forest habitats in the Sofia Kettle were already very rare (Stoyanov, 1937). The period of creation of the tree-nurseries, gardens and parks in Sofia (about 40-116 years ago (see Kovachev, 2001)) coincides with the disappearance of the last forest-remnants in the Sofia Kettle. The latter is already entirely transformed into a patchwork of diverse antropogenic habitats and the harvestmen-species that inhabit it are almost identical to these that colonize the newly established tree-nurseries and park areas within the city of Sofia. This may be a reason for the high similarity of the fauna of the city of Sofia and that of the Sofia Kettle (Fig. 1A).

When declared a capital in 1879, Sofia covered an area of only 250 ha, and was inhabited by 11500-18000 citizens (Kovachev, 2001). The territories north of Vladayska River and east of Perlovska River were agricultural (Kovachev, 2001). With the increased population migration towards the city and as a result of intensive building, the city has grown "like an ink-spot" (Kovachev, pers. comm.). Many former villages fused into the growing city, becoming part of it and part of the former agricultural lands were covered with new buildings, gardens, parks and nurseries. So the harvestmen, originally inhabiting open grasslands and degraded forest habitats outside the boundary of the city (for examples of such habitats see the pictures in Takhov, 1987), faced new habitat-types with a much lower trophical basis, higher temperatures, and lower humidity. These harsh habitat conditions have caused, most probably, higher mortality rates throughout the affected opilionid populations and the affected animals have tried to minimize such effects by migration into the newly-created parks and nurseries, while the synanthropic forms have found appropriate food and shelter in the gardens, on building-walls, and in the interior of houses and cellars.

The favourable habitats in the city were colonized by the harvestmen most probably directly, from the surrounding open environments, through the riverside habitats, and also through the forest remnants that have connected the territory of the city with the surrounding mountains (mainly Lyulin, Vitosha, and Stara Planina). Direct evidence supporting this hypothesis is the faunal similarity between the mentioned regions (Fig. 1A). Part of the species are probably transferred into the city and its park areas through planting (e. g. saplings (see Vekov, 1983)) and/or building (stones, timber, soil) materials.

To draw a general conclusion, the opilionid fauna of the city of Sofia has most likely been formed under the outlined abovementioned conditions of anthropogenic pressure, in combination with the gradually increasing air temperature within the borders of the city, and accompanied by a severe loss of primary plant communities representing the vanishing natural habitats. The fauna may thus be considered as a result of adaptation of the impoverished fauna of the Kettle to secondary forest and park areas (currently the city parks cover 901,608 ha, or 21.03% of the green area within the city of Sofia (see Kovachev, 2001)).

CONCLUSIONS

To summarise, we draw the following conclusions concerning the opilionid fauna of the city of Sofia and its surroundings:

1) The fauna of the city of Sofia includes only 12 of the 32 species that inhabit the territory of the Sofia Kettle and the surrounding mountains. It is clearly differentiated, and is most similar to the fauna of the Sofia Kettle.
2) The fauna of the city is characterized by: the presence of: a) ecologically tolerant species that resist higher temperatures and lower humidity (e. g. *Phalangium opilio, Opilio saxatilis, Lacinius horridus*); b) species that may inhabit diverse habitats (open/forest, ruderal, buildings) and may switch to different habitats with an increase in altitude (e. g. *Trogulus tricarinatus, Carinostoma ornatum, Odiellus lendli, Rilaena* cf. *serbica, Zachaeus crista*); c) species that possess high agility, and respectively high dispersal abilities (e. g. *Phalangium opilio, Opilio parietinus, O. ruzickai, O. dinaricus, Zachaeus crista, Lacinius dentiger*); d) thermophilous species that may adapt more easily to anthropogenic habitats (e. g. *Opilio parietinus*, *O. ruzickai, Lacinius dentiger*, *Phalangium opilio*, and *Opilio saxatilis,* which occur on building-walls (Staręga, 1976; Klimeš, 1987; Komposch, 1993, 1997), as well as *Lacinius horridus* and *Zachaeus crista*, which are often found in anthropogenically influenced habitats (Martens, 1978). Here was also mention *Odiellus lendli*, which (in Bulgaria) occurs also in fields and rarely on building-walls in the city-parks. As is known (Klausnitzer, 1990), some species with southern origins show signs of anthropogenization toward the northern parts or the margins of their distributions. Higher temperatures within the cities[6] is important here.
3) The effect of urbanization manifest mainly in the absence of species that prefer shady, moist and cool habitats (examples are *Paranemastoma*, *Nemastoma*, *P. bosnica, Histricostoma drenskii, Mitostoma chrysomelas, Rilaena balcanica, Lacinius ephippiatus,* and *Lophopilio palpinalis*). The low humidity, typical for urban habitats and the remote mountain regions, prevented their dispersal and/or survival within the boundary of the city.
4) The urban opilionid fauna has been formed as a result of the adaptation of the highly impoverished fauna of the Sofia Kettle to the secondary vegetation in the parks that replaced the forests under conditions of anthropogenic pressure (forest fragmentation and deforestation), accompanied by a gradual increase in temperatures in the city and the appearance of new habitats.

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[6] Bluskova *et al*. (1983) have shown that the mean annual temperature in the centre of Sofia is about 0.7-0.8°C higher in comparison to the city surroundings. Moreover, the mean nightly temperature is also 1.5°C higher because of slower air-cooling processes in the city.

ACKNOWLEDGMENTS

We would like to express our gratitude to Dr. Stoitse Andreev, Andrey Antov, Dr. Petar Beron, Bozhana Dimitrova, Dimitar S. Dimitrov, Nikolay Kodzhabashev, Georgi Krustev, Rumyana Kostova, Dr. Stoyan Lazarov, Dr. Toshko Lyubomirov, Boris Mitov, Zorka Mitova, Boyan Petrov, Maria Sotirova, Dr. Pavel Stoev, Stefanka Subeva, and Georgi Tsonev for their contribution to the materials of Opiliones, on which this study is based.

Thanks are also due to Ivo Karaman (Yugoslavia, Novi Sad) (for the literature provided and specimens of *Rilaena serbica*, as well as for important information about its distribution; he also made valuable comments on the status of the Bulgarian material of this species), Christian Komposch (Austria, Graz) (for the literature provided and materials of *Trogulus closanicus*), Dr. Leoš Klimeš (Czech Republic, Trebon) (for the literature provided), Dr. Pavel Stoev (MNHS) (for the literature provided), Ing. Dr. Atanas Kovachev (University of Forestry, Sofia) (for the literature provided and comments on the historical development of the parks in Sofia), Dr. Dimitar Dimitrov (University of Sofia, Sofia) and Prof., Dr. Ivan Bondev (University of Sofia, Sofia) (for determination of botanical material and help with the phytocoenological characterization of the vegetation). This work was partly supported by the National Scientific Research Fund (grant No. B-808/1998).

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Spiders from the Sofia Region. A Faunistic and Zoogeographical Analysis

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Abstract

112 spider species were collected from the region of Sofia: Atypidae - 1; Nemesiidae - 1; Dysderidae - 7; Mimetidae - 1; Theridiidae - 5; Linyphiidae - 17; Tetragnathidae - 3; Araneidae - 3; Lycosidae - 22; Pisauridae - 1; Agelenidae - 3; Dictynidae - 1; Amaurobiidae - 5; Anyphaenidae - 1; Liocranidae - 2; Clubionidae - 6; Zodariidae - 1; Gnaphosidae - 15; Zoridae - 1; Sparassidae - 1; Philodromidae - 5; Thomisidae - 9; Salticidae - 3. 67 species are new to the study region and 2 (*Dysdera adriatica, Amaurobius deelemanae*) are new to the Bulgarian fauna. The spiders are classified into 15 zoogeographical categories combined into 4 chorological complexes. The composition of the fauna shows that the spider fauna of the Sofia region has a Palearctic and European character. Endemics and Southeasteuropean species emphasize the local character of this fauna, but their low persentage suggests an important process of colonization.

Key words

Spiders, Araneae, faunistic, zoogeography, urban fauna, Sofia, Bulgaria.

INTRODUCTION

No detailed study of spiders in the Sofia region has been published to date. The only information can be found in the papers of Drensky (1913, 1936, 1937, 1938, 1940, 1943), and Deltshev (1967), where 227 species are reported.

The present study is a result of collecting and processing of original material and observations during the period from 1998 to 1999 in the framework of the GLOBENET project (see Penev *at al.*, this volume).

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 355-363

STUDY AREA AND METHODS

The survey of spiders inhabiting the region of Sofia comprises study sites distributed along four gradients: South East, West, North and South (see map in Penev *et al*., this volume). The exploration includes only stationary methods – pitfall traps. The study lines served by pitfall traps include 11 points (South East - 3; West - 3; North - 2; South - 3) (Table 1). Twelve pitfall traps (mouth diameter 6 cm) with 4 % formalin were placed in a line, about 7 meters apart from each other, at each study site. The traps were emptied once a month and operated during June, July, August, September and October in 1998 and in May, June, July, August, September and October in 1999.

List of the localities where the spiders have been collected in the Sofia region:
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*.

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*.

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*.

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.

RESULTS AND DISCUSSION

Species composition

112 species of 23 families were collected: Atypidae - 1; Nemesiidae - 1; Dysderidae - 7; Mimetidae - 1; Theridiidae - 5; Linyphiidae - 17; Tetragnathidae - 3; Araneidae - 3; Lycosidae - 22; Pisauridae - 1; Agelenidae - 3; Dictynidae - 1; Amaurobiidae - 5; Anyphaenidae - 1; Liocranidae - 2; Clubionidae - 6; Zodariidae - 1; Gnaphosidae - 15; Zoridae - 1; Sparassidae - 1; Philodromidae - 5; Thomisidae - 9; Salticidae - 3 (Table 1). 67 species are new to the region, and 2 are new to the spider fauna of Bulgaria.

Table 1. Species composition and distribution of spiders in the Sofia region. **Zoogeographic categories:** COS - Cosmopolitan, HOL - Holarctic, PAL - Palearctic, WPA - W-Palearctic, EUS - Europeo-Sibirian, EMC - Europeo-Mediterrano-Centralasiatic, ECA - Europeo-Centralasiatic, MCA - Mediterrano-Centralasiatic, ETU - Europeo-Turanian, EET - E- Europeo-Turanian, EUR - European, EEU - East European, SEE - South East European, SE - European, BALK - Balkan Endemic, BULG - Bulgarian Endemic.

TAXA	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4	Zoog
ATYPIDAE												
Atypus piceus (Sulzer, 1776)							1					ETU
NEMESIIDAE												
Brachythele denieri (Simon, 1916)					2		1	1				BALK
DYSDERIDAE												
Dysdera adriatica KulczyDski, 1897				1								BALK
Dysdera longirostris Doblika, 1853	18	64	3	24		6	19	21	10			EEU
Harpactea rubicunda (C. L. Koch, 1838)		2			6							EUR
Harpactea saeva (Herman, 1879)					9	4		2				EEU
Harpactea srednagora Dimitrov & Lazarov, 1999												BULG
MIMETIDAE												
Ero furcata (Villers, 1789)	3			1								PAL
THERIDIIDAE												
Enoplognatha ovata (Clerck, 1757)						1			1			HOL
Episinus truncatus Latreille, 1809	1											PAL
Robertus lividus (Blackwall, 1836)				2								HOL
Steatoda meridionalis (KulczyDski, 1894)							11					EET
Steatoda phalerata (Panzer, 1801)							2					PAL
LINYPHIIDAE												
Bathyphantes nigrinus (Westring, 1851)			4									PAL
Centromerus sylvaticus (Blackwall, 1841)	1		1	3							6	HOL
Diplocephalus picinus (Blackwall, 1841)	8											PAL
Diplostyla concolor (Wider, 1834)	11	11	3	9		4					3	HOL
Gonatium paradoxum (L. Koch, 1869)									1		1	PAL
Gongylidium rufipes (Linnaeus, 1758)			8									PAL
Lepthyphantes istrianus KulczyDski, 1914									2		3	EEU
Linyphia hortensis Sundevall, 1830						5	8					PAL
Linyphia triangularis (Clerck, 1757)	3											PAL
Microneta viaria (Blackwall, 1841)		1		2	1		1			1	1	HOL
Neriene clathrata (Sundevall, 1830)				5							1	HOL
Tenuiphantes drenskyi (van Helsdingen, 1977)					1							BULG
Tenuiphantes flavipes (Blackwall, 1854)		20	2	8	12	4			1	2		PAL
Tenuiphantes floriana (van Helsdingen, 1977)					2			1		1		SEE
Walckenaeria acuminata Blackwall, 1833				4	3							PAL
Walckenaeria alticeps (Denis, 1952)						1						EUR

Table 1. Continued.

TAXA	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4	Zoog
Walckenaeria mitrata (Menge, 1868)				1								PAL
TETRAGNATHIDAE												
Metellina segmentata (Clerck, 1757)		3									6	HOL
Pachygnatha degeeri Sundevall, 1830		1	9		1							PAL
Tetragnatha montana Simon, 1874			1									PAL
ARANEIDAE												
Araniella cucurbitina (Clerck, 1757)									3	2		PAL
Araniella displicata (Hentz, 1847)					3		1					HOL
Argiope bruennichi (Scopoli, 1772)												PAL
LYCOSIDAE												
Alopecosa accentuata (Latreille, 1817)							1					PAL
Alopecosa aculeata (Clerck, 1757)		3										HOL
Alopecosa pulverulenta (Clerck, 1757)		3										PAL
Alopecosa trabalis (Clerck, 1757)		1			7		1	2	1	1	1	ECA
Arctosa cinerea (Fabricius, 1777)						1						PAL
Hogna radiata (Latreille, 1817)												MCA
Pardosa agrestis (Westring, 1861)							3					PAL
Pardosa agricola (Thorell, 1856)					2				4			ETU
Pardosa alacris (C. L. Koch, 1833)		6	4		68	14	767	15	16	14	906	EUR
Pardosa amentata (Clerck, 1757)			6								1	EUR
Pardosa hortensis (Thorell, 1872)	1	2	4		14							PAL
Pardosa lugubris (Walckenaer, 1802)		14	92	10	1			7				PAL
Pardosa palustris (Linnaeus, 1758)					1						3	HOL
Pardosa prativaga (L. Koch, 1870)									2		1	EUS
Pardosa proxima (C. L. Koch, 1847)		1										PAL
Pardosa tatarica (Thorell, 1875)							1					PAL
Pardosa vittata (Keyserling, 1863)						1						EUR
Pirata hygrophilus Thorell, 1872				3							10	PAL
Pirata latitans (Blackwall, 1841)			5									EUR
Trochosa ruricola (De Geer, 1778)			2		1							PAL
Trochosa terricola Thorell, 1856	1	7		1	4		36	3	4	9	4	HOL
Xerolycosa nemoralis (Westring, 1861)											1	PAL
PISAURIDAE												
Pisaura mirabilis (Clerck, 1757)		3	17		2							PAL
AGELENIDAE												
Histopona torpida (C. L. Koch, 1837)				3		12	11	20	26		6	EUR
Tegenaria campestris C. L. Koch, 1834	3				1			4				EUR
Tegenaria domestica (Clerck, 1757)			3	5								COS

Table 1. Continued.

TAXA	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4	Zoog
DICTYNIDAE												
Cicurina cicur (Fabricius, 1793)						4						ECA
AMAUROBIIDAE												
Amaurobius deelemanae Thaler & Knoflach, 1995					24			20				BALK
Coelotes falciger KulczyDski, 1897						29		9	28		13	EEU
Coelotes jurinitschi (Drensky, 1915)	2					73	1	74	64		2	BALK
Coelotes karlinskii (KulczyDski, 1906)											3	SEE
Urocoras longispinus (KulczyDski, 1897)	161			20	2			5		41		EEU
ANYPHAENIDAE												
Anyphaena accentuata (Walckenaer, 1802)	4		4									ECA
LIOCRANIDAE												
Agroeca brunnea (Blackwall, 1833)											1	EUS
Apostenus fuscus Westring, 1851									4		2	EUR
CLUBIONIDAE												
Clubiona brevipes Blackwall, 1841		3										ECA
Clubiona caerulescens L. Koch, 1867									5			PAL
Clubiona comta C. L. Koch, 1839	10			5								WPA
Clubiona lutescens Westring, 1851			4									HOL
Clubiona marmorata L. Koch, 1866		1										EUR
Clubiona pallidula (Clerck, 1757)			3									HOL
ZODARIIDAE												
Zodarion geticum Weiss, 1987							1					SEE
GNAPHOSIDAE												
Drassodes lapidosus (Walckenaer, 1802)					1							PAL
Drassyllus praeficus (L. Koch, 1866)							1					ECA
Drassyllus pusillus (C. L. Koch, 1833)			6									PAL
Drassyllus villicus (Thorell, 1875)							26				6	EUR
Gnaphosa lucifuga (Walckenaer, 1802)					1							PAL
Gnaphosa modestior KulczyDski, 1897		3					9					EEU
Haplodrassus signifer (C. L. Koch, 1839)				1	7		1					HOL
Haplodrassus silvestris (Blackwall, 1833)		62	5	11	10	5			35		23	PAL
Scotophaeus scutulatus (L. Koch, 1866)					1							WPA
Trachyzelotes pedestris (C. L. Koch, 1837)		10	13		2				1			EUR
Zelotes apricorum (L. Koch, 1876)											12	ETU
Zelotes erebeus (Thorell, 1871)					1						5	EUR
Zelotes hermani (Chyzer, 1897)					2							EUR
Zelotes latreillei (Simon, 1878)							1					EUR
Zelotes petrensis (C. L. Koch, 1839)					1							ECA

Table 1. Continued.

TAXA	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4	Zoog
ZORIDAE												
Zora spinimana (Sundevall, 1833)	2	138	13	71	15		17					PAL
SPARASSIDAE												
Micrommata virescens (Clerck, 1757)										1		PAL
PHILODROMIDAE												
Philodromus aureolus (Clerck, 1757)	1											PAL
Philodromus collinus C. L. Koch, 1835											1	EUR
Philodromus dispar Walckenaer, 1826					3			4				HOL
Philodromus praedatus O. P.-Cambridge, 1871										1		EUS
Thanatus arenarius L. Koch, 1872								2				ECA
THOMISIDAE												
Ozyptila atomaria (Panzer, 1801)										1		PAL
Ozyptila praticola (C. L. Koch, 1837)	39		24	13								HOL
Ozyptila sanctuaria (O. P.-Cambridge, 1871)				1								EUR
Xysticus acerbus Thorell, 1872											1	ECA
Xysticus cristatus (Clerck, 1757)					1							PAL
Xysticus erraticus (Blackwall, 1834)										1		EUR
Xysticus kochi Thorell, 1872				2	6							EMC
Xysticus lanio C. L. Koch, 1835		10				10					6	PAL
Xysticus luctator L. Koch, 1870		29									34	PAL
SALTICIDAE												
Aelurillus v-insignitus (Clerck, 1757)										1		PAL
Ballus chalybeius (Walckenaer, 1802)										1		WPA
Marpissa muscosa (Clerck, 1757)								2				PAL

Interesting new faunistic records are:

Dysdera adriatica – This species is new to the Bulgarian spider fauna and is well presented in the territory of the Balkan Peninsula (Deltshev & Blagoev, 2001).

Amaurobius deelemanae - This species is new to the Bulgarian spider fauna and is known only from Greece until now (Deltshev & Blagoev, 2001).

Harpactea srednogora - described and known only from Sushtinska Sredna Gora mountain. The new localities in the region of Sofia show that the species may be widespread in Bulgaria.

Tenuiphantes drenskyi - hitherto known only from single localities in the Vitosha and Rila mountains.

Tenuiphantes floriana - hitherto known only from single localities in Bulgaria, Romania and Serbia.

Zodarion geticum - hitherto known only from single locality in Zemen Gorge (Southwestern Bulgaria).

Gnaphosa modestior - hitherto known only from single localities in Sustinska Sredna Gora and Northern Black Sea coast.

Most characteristic are the families: Lycosidae (22) - 19.1 %, Linyphiidae (17) - 15.1 %, Gnaphosidae (15) - 12.3 % and Thomisidae (9) - 8.5 %. The presence of species of families such as Dysderidae, Araneidae, Linyphidae, Theridiidae, Agelenidae, Amaurobiidae, Gnaphosidae, Liocranidae and Heteropodidae in the urban parts of the region is due to the eu- and hemysinantropic representatives (Sacher, 1983). The number of Linyphiidae spiders increase in urban areas and decrease in suburban areas. The genus *Pardosa* is the most numerous, represented by 12 species.

Zoogeographical characteristics

According to their current distribution, the established 112 species can be classified in 15 zoogeographical categories and grouped into four chorological complexes (Table 1, Fig. 1). The data concerning the general distribution of spiders are taken from Platnick (2002) and Taglianti *et al.* (1999).

Best represented is the complex of species widely distributed in the Holarctic Region (HOL + PAL + WPA + EUS + EMC + ECA + MCA + ETU + EET) and comprises 76 species (42 %) inhabiting both lowlands and mountains. Palearctic species *s.l.* are dominant (41.50 %), followed by Holarctic species (17.2%), Europeo-Sibirian (7.8 %) and Europeo-Centralasiatic (7.8 %). Most abundant species are: *Diplocephalus picinus, Xerolycosa nemoralis, Pisaura mirabilis* and *Alopecosa accentuata.* These species are best represented in the urban territory.

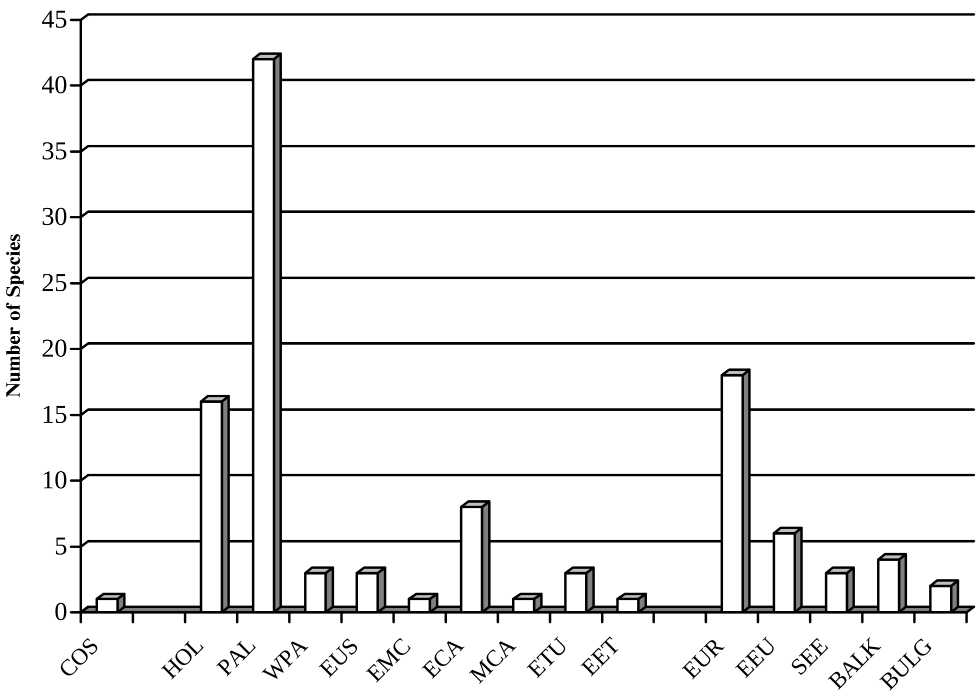

Fig. 1. Distribution of the spiders of the Sofia region by zoogeographical categories. For abbreviation of categories see Table 1.

The European complex (EUR + EEU + SEE, 24.1%) comprises 27 species widespread in the territory of Europe. European species *s.l.* are dominant (66.6 %); followed by East-European species (22.2 %); Well presented in the region are: *Dysdera longirostris, Harpactea rubicunda, Pirata latitans, Tegenaria campestris,* and *Zelotes erebeus*. The percentage of European elements increases in the sites outside the city.

The group of endemics (BALK + BULG, 5.3 %) comprises six species. Well represented are *Coelotes jurinitsci, Amaurobius deelemane* and *Brachythele deniei,* while *Dysdera adriatica, Harpactea srednogora* and *Tenuiphantes drenskyi* are found only as singletons. The endemics are presented only in non-urban territories.

Cosmopolitan elements are presented only from the species *Tegenaria domestica*.

CONCLUSION

The faunistic diversity of the 112 spider species shows that the small region of Sofia is a territory of high species richness. This conclusion is supported also by the existence of six endemic species.

The outline of the araneofauna in the Sofia region is determined by the Palearctic and European species Holarctic species *s.l.* are best presented in the urban territory, while the percentage of European elements increased in sites outside the city. The group of endemics is present only in the non-urban territory. Endemics and South-East-European species emphasise the local character of this fauna, but its low percentage suggests an important process of colonization.

ACKNOWLEDGEMENTS

We are especially indebted to our colleagues Dr L. Penev, I. Dedov and I. Stoyanov for the faunistic materials which they provided. The first author is thankful to Dr. Lyubomir Penev and Dr. Ch. Deltshev who supervised his diploma work on the spiders of Sofia. This work was partly supported by the National Scientific Research Fund (grant No. B-808/1998).

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A Checklist of the Aphids (Homoptera, Aphidodea) from the City of Sofia

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Abstract

A checklist of all recorded aphid species from the city of Sofia consisting of 189 species and 80 genera in 10 families is presented. 37 aphid species have not been recorded elsewhere in Bulgaria.

Key words

Aphidodea, aphids, urban area, checklist, Sofia, Bulgaria.

INTRODUCTION

Aphids from the city of Sofia are well studied. One hundred and eighty-nine species, almost half of the known aphid species for the Bulgarian fauna, are recorded from Sofia.

Investigations on this group date back to the beginning of the twentieth century. For the first time Joakimov (1909) published six species from Sofia. The first reports refer to aphid pests on crops (Dimitrov & Russkoff, 1927; Chorbadjiev, 1928; Russkoff, 1928). Tashev (1959) published a paper on the species composition and biology of aphids on fruit trees and in 1961 (Tashev, 1961a) reviewed dendrophilous aphid species. Information on aphids from Sofia is present in the faunistic studies of Pintera (1959), Szelegiewicz (1962), Grigorov (1966) and Popov (1971). Tashev (1981) reported 39 new species from Sofia. Besides, several more authors, i.e. Paspalev (1929), Tashev (1961b, 1963a, 1963b, 1964a, 1964b, 1974), Tashev *et al.* (1970), Tashev & Berova (1973), Tsankov *et al.* (1980), Grigorov & Grigorov (1996) and Tasheva-Terzieva (1999) contributed to the Sofia aphidofauna.

In this article I list all aphid species present in Sofia to date. In the checklist species are arranged according to the classification in Tashev (1984), and within each genus the species are listed alphabetically. Species names are according to Eastop & Hille Ris Lambers (1976).

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 365-370

CHEKLIST

Ordo **HOMOPTERA**
Subordo **APHIDODEA**
Superfam. **APHIDOIDEA**
Fam. **LACHNIDAE**
Subfam. **Cinarinae**
Eulachnus del Guercio, 1909
agilis (Kaltenbach, 1843)
rileyi (Williams, 1843)
Cinara Curtis, 1835
brauni Börner, 1949
tujafilina (del Guercio, 1909)
Subfam. **Lachninae**
Tuberolachnus Mordvilko, 1909
salignus (Gmelin, 1788)

Fam. **CHAITOPHORIDAE**
Periphyllus van der Hoeven, 1863
acericola (Walker, 1848)
aceris (Linnaeus, 1761)
hirticornis (Walk., 1848)
lyropictus (Kessler, 1886)
minutus Shaposhnikov, 1952
obscurus Mamontova, 1955
villosus (Hartig., 1841)
Chaitophorus Koch, 1854
nassonovi Mordvilko, 1895
niger Mordvilko, 1929
populialbae (B. de Fonscolombe, 1841)
tremulae Koch, 1854
versicolor Koch, 1854

Fam. **CALLAPHIDIDAE**
Subfam. **Phyllaphidinae**
Symydobius Mordvilko, 1894
oblongus (von Heyden, 1873)
Euceaphis Walker, 1870
betulae Koch, 1855
Phyllaphis Koch, 1856
fagi (Linnaeus, 1767)
Betulaphis Glendenning, 1926
quadrituberculata (Kaltenbach, 1843)
Callipterinella van der Goot, 1913
calliptera (Hartig., 1841)
tuberculata (von Heyden, 1837)
Calaphis Walsh, 1863
betulicola (Kaltenbach, 1843)
Drepanosiphum Koch, 1855
acerinum (Walker, 1948)
platanoidis (Schrank., 1801)
Subfam. **Callaphidinae**
Callaphis Walker, 1870
juglandis (Goeze, 1778)
Chromaphis Walker, 1870
juglandicola (Kaltenbach, 1843)
Eucallipterus Schouteden, 1906
tiliae (Linnaeus, 1758)
Myzocallis Passerini, 1860
carpini (Koch, 1855)
Tuberculatus Mordvilko, 1894
annulatus (Hartig., 1841)
eggleri (Börner, 1950)
neglectus Krzywiec, 1965
querceus (Kaltenbach, 1843)
Tinocallis Matsumura, 1919
platani (Kaltenbach, 1843)
Pterocallis Passerini, 1860
alni (Degeer, 1773)
Appendiseta Richards, 1965
robiniae (Gillete, 1907)
Subfam. **Therioaphidinae**
Therioaphis Walker, 1870
rhiemi (Börner, 1949)
tenera (Aizenberg, 1956)

Fam. **APHIDIDAE**
Pterocomma Buckton, 1879
populeum (Kaltenbach, 1843)
salicis (Linnaeus, 1758)
rufipes (Hartig, 1841)
Hyalopterus Koch, 1854
pruni (Geoffroy, 1762)
Rhopalosiphum Koch, 1854
insertum (Walker, 1849)
maidis (Fitch, 1856)

padi (Linnaeus, 1758)
Schizaphis Börner, 1931
graminum (Ronddani, 1847)
Melanaphis van der Goot, 1917
pyraria (Passerini, 1861)
Aphis Linnaeus, 1758
armata Hausmann, 1802
brunellae Schouteden, 1903
chloris Koch, 1854
clematidis Koch, 1854
comosa (Börner, 1950)
craccivora Koch, 1854
cytisorum Hartig., 1841
esulae (Börner, 1940)
euphorbiae Kaltenbach, 1843
euonymi Fabricius, 1775
fabae Scopoli, 1763
farinosa Gmelin, 1788
frangulae Kaltenbach, 1885
grossulariae Kaltenbach, 1843
hederae Kaltenbach, 1843
idaei van der Goot, 1912
lambersi (Börner, 1940)
mammulata Gimingham&H.R.L., 1949
nasturtii Kaltenbach, 1843
nerii Boyer de Fonscolombe, 1841
ruborum (Börner, 1932)
rumicis Linnaeus, 1758
sambuci Linnaeus, 1758
sedi Linnaeus, 1843
spiraephaga Müller, 1961
umbrella (Börner, 1950)
urticata Gmelin, 1790
vandergooti (Börner, 1933)
verbasci Schrk., 1801
vitalbae Ferrari, 1872
Protaphis Börner, 1952
alexandrae (Nevsky, 1928)
Subfam. **Anuraphidinae**
Roepkea Hille Ris Lambers, 1935
phlomicola (Nevsky, 1929)
Anuraphis del Guercio, 1907
catonii Hille Ris Lambers, 1935
farfarae (Koch, 1854)
pyrilaseri Shaposhnikov, 1950
subterranea (Walker, 1852)
Dysaphis Börner, 1931
crataegi (Kaltenbach, 1843)
devecta (Walker, 1949)
lappae (Koch, 1854)
plantaginea (Passerini, 1860)
pyri (Boyer de Fonscolombe, 1841)
radicola (Mordvilko, 1896)
ranunculi (Kaltenbach, 1843)
reaumuri (Mordvilko, 1929)
Brachycaudus van der Goot, 1913
cardui (Linnaeus, 1758)
lychnidis (Linnaeus, 1758)
helichrysi (Kaltenbach, 1843)
schwartzi (Börner, 1931)
Subfam. **Myzinae**
Brachycorinella Aizenberg, 1956
asparagi (Mordvilko, 1928)
Hayhurstia del Guercio, 1917
atriplicis (Linnaeus, 1761)
Hyadaphis Kirkaldy, 1904
tataricae (Aizenberg, 1935)
Coloradoa Wilson, 1910
achilleae H.R.L., 1939
artemisiae (del Guercio, 1913)
Longicaudus van der Goot, 1913
trirhodus (Walker, 1849)
Myzaphis van der Goot, 1913
rosarum (Kaltenbach, 1843)
Chaetosiphon Mordvilko, 1914
tetrarhodum (Walker, 1849)
Liosomaphis Walker, 1868
berberidis (Kaltenbach, 1843)
Cavariella del Guercio, 1911
aegopodii (Scopoli, 1763)
pastinacae (Linnaeus, 1758)
theobaldi (Gillette&Bragg, 1918)
Ovatus van der Goot, 1913
crataegarius (Walker, 1850)
mentarius (van der Goot, 1913)
Phorodon Passerini, 1860

cannabis Passerini, 1860
humuli (Schrank., 1801)
Myzus Passerini, 1860
ascalonicus Doncaster, 1946
cerasi (Fabricius, 1775)
ligustri (Mosley, 1841)
lythri (Schrank, 1801)
ornatus Laing, 1932
persicae (Sulzer, 1776)
varians (Davidson, 1912)
Aulacorthum Mordvilko, 1914
circumflexum (Bunckton, 1876)
Capitophorus van der Goot, 1913
carduinus (Walker, 1850)
hippophaes (Walker, 1852)
horni Börner, 1931
inulae (Passerini, 1860)
similis van der Goot, 1915
pakansus (Hottes & Frison)
Cryptomyzus Oestlund, 1922
ballotae Hille Ris Lambers, 1953
Paramyzus Börner, 1933
heraclei Börner, 1933
Hyperomyzus Börner, 1933
lactucae (Linnaeus, 1758)
Microlophium Mordvilko, 1914
carnosum (Buckton, 1876)
Aulacorthum Mordvilko, 1914
circumflexum (Bunckton, 1876)
solani (Kaltenbach, 1843)
Acyrthosiphon Mordvilko, 1914
caraganae (Cholodkovsky, 1907)
pisum (Harris, 1776)
Metopolophium Mordvilko, 1914
dirhodum (Walker, 1849)
Corylobium Mordvilko, 1914
avellanae (Schrank., 1801)
Macrosiphum Passerini, 1860
centranthi Theobald, 1915
euphorbiae (Thomas, 1878)
gei (Koch, 1855)
rosae (Linnaeus, 1758)
Pleotrichophorus Börner, 1930
glandulosus (Kaltenbach, 1846)
Paczoskia Mordvilko, 1914
major Börner, 1930
Macrosiphoniella del Guercio, 1911
abrotani (Walker, 1852)
absinthii (Linnaeus, 1758)
artemisiae (Boyer de Fonscolombe, 1841)
atra (Ferrary, 1872)
helichrysi Remaudiere, 1952
millefolii (Degeer, 1773)
oblonga (Mordvilko, 1901)
sanbornii (Gillette, 1908)
tanacetaria (Kaltenbach, 1843)
Uroleucon Mordvilko, 1914
achilleae (Koch, 1855)
carthami (Hille Ris Lambers, 1948)
cichorii (Koch, 1885)
jaceae (Linnaeus, 1758)
jaceicola (Hille Ris Lambers, 1939)
sonchi (Linnaeus, 1767)
tanaceti (Linnaeus, 1758)
tussilaginis (Walker, 1850)
Metopeurum Mordvilko, 1914
fuscoviridae Stroyan, 1950
Amphorophora Buckton, 1876
rubi (Kaltenbach, 1843)
Amphorosiphon H. R. Lambers, 1949
pulmonariae (Börner, 1942)
Megoura Buckton, 1876
viciae Buckton, 1876

Fam. **ANOECIIDAE**
Anoecia Koch, 1857
corni (Fabricius, 1775)

Fam. **THELAXIDAE**
Thelaxes Westwood,1840
cerridis Börner, 1942
dryophila (Schrank, 1801)

Fam. **MINDARIDAE**
Mindarus Koch, 1857
abietinus Koch, 1856

Fam. **HORMAPHIDIDAE**
Hamamelistes Shimer, 1867
betulinus (Horvath, 1896)

Fam. **PEMPHIGIDAE**
Subfam. **Eriosomatinae**
Eriosoma Leach, 1818
lanuginosum (Hartig, 1839)
ulmi (Linnaeus, 1758)
Colopha Monell, 1877
compressa (Koch, 1856)
Kaltenbachiella Schouteden, 1906
pallida (Haliday, 1838)
Tetraneura Hartig, 1841
akinire Sasaki, 1904
Subfam. **Pemphiginae**
Patchiella Tullgren, 1925
Reaumuri (Kaltenbach, 1843)
Prociphilus Koch, 1857
bumeliae (Schrk., 1801)
fraxini (Fabricius, 1777)
xylostei (Degeer, 1773)
Thecabius Koch, 1857
affinis (Kaltenbach, 1843)
Pemphigus Hartig, 1839
bursarius (Linnaeus, 1758)
populinigrae (Schrank., 1801)
protospirae Lichtenstein., 1885
spirothecae Passerini, 1856

Superfam **ADELGOIDEA**
Fam. **ADELGIDAE**
Pineus Shimer 1869
strobi (Hartig., 1837)
Dreyfusia Börner, 1908
nordmannianae (Eckstein, 1890)
piceae (Ratzeburg, 1844)
Adelges Vallot, 1836
laricis Vallot, 1836
Gilletteella Börner, 1930
cooleyi (Gillette, 1907)
Sacchiphantes Curtis, 1844
abietis (Linnaeus, 1758)
viridis (Ratzeburg., 1843)

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Spatial Structure of Carabid Beetle Assemblages along an Urban-Rural Gradient

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Abstract

In the present study the spatial structure of carabid beetle assemblages along an urban-rural gradient, centered in the city of Sofia, was investigated. The full-featured data matrix (up to the level of individual samples) resulting from a two-year survey within 11 woodland patches in the area and around the city, containing totals of 132 samples (=traps) and 18,953 specimens belonging to 86 species, was subjected to multivariate eigenanalysis techniques in order to reveal if the internal structure of the sample typology and species assemblages followed the hypothesized urban-rural gradient.

As a result, no simple urban-to-rural gradient was recognizable – although most of the "urban" sampling sites formed a cluster at the urban end of gradient, the remaining stations did not form the expected "suburban" and "rural" zones. The landscape mosaic was instead merely subdivided into complicately intergressing local gradients and partitions, among which a more clearly separated "urban" zone and a vaguely differentiated "non-urban" zone may be discerned. Accordingly, the carabid beetle assemblages did not form a *continuum* along the urban-rural gradient.

It is suggested that the observed patterns are a consequence of the interaction between human-caused landscape transformation (i. e. the urbanization) and the natural zoogeographical zonation of the investigated area.

Key words

Groung-beetle assemblages, Carabidae, urban, Sofia, Bulgaria.

INTRODUCTION

Since the first investigations of urban ecosystems, several important studies have focused on carabid beetles (e. g. Topp, 1972 – dealing with the abilities of certain taxa to colonize urban habitats; Becker, 1977 – on the bioindicative value of ground-beetles in urban ecosystems; Schaefer

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 371-400

& Kock, 1979 – faunistic similarities between urban and non-urban habitats and Klausnitzer *et al.*, 1979 – faunistic studies of an urban habitat). With the gradual accumulation of quantitative data, originating mainly from intensive studies of carabid beetle associations within the city of Leipzig conducted by Bernhard Klausnitzer, first attempts to develop the notion of urban gradients have been made (Klausnitzer, 1982, 1983). At the same time, several authors worked in the area of the city of Warsaw and its environs and published a series of studies (among them two papers on carabid beetles – Czechowski, 1981, 1982) examining the species composition, origin, zoogeographical and ecological structure of the fauna of a large city (for a detailed review and references see Luniak & Pisarski, 1994). Further, urbanisation gradients in Bratislava and Brno were studied by Šustek (1989, 1992), but aside from some effort to classify the observed patterns, the main results remained in the context of bioindicative criteria (e. g. life-form representation and sex ratio fluctuation). Unfortunately, the most basic multivariate techniques, which have been known to be extremely useful for analysis and description of species responses along diverse gradients, and already successfully applied in plant ecology (e. g. Hill, 1974; Gauch *et al.*, 1974; Hill & Gauch, 1980), were not available to the aforementioned research-workers and so the internal structure and organisation of the investigated (very numerous) assemblages remained largely unexplored, and the proposed hypotheses about the effects of urbanization on these were left virtually untested.

Despite efforts to study urban environments in more detail, such investigations remained rather sporadic in comparison to the attention paid to the more natural, less disturbed rural ecosystems. Consequently, the urgent need for comprehensive studies on the ecological impact of urbanisation was recognized, and the great potential of the conceptual model that the urban-rural gradients (defined as general gradients from a highly developed (city) core to a rural or natural area) provide, allowing the explicit incorporation of the human population and structures generated by it into the analyses of ecological processes, was acknowledged (McDonnell & Pickett, 1990; McDonnell *et al.*, 1997). A further development based on this framework represents the GLOBENET initiative, that aims at assessment and comparison of human-induced landscape changes over a larger scale, stressing again the importance of utilizing the globally recurring urban-rural gradients (Niemelä *et al.*, 2000; Niemelä *et al.*, 2002). Inspite of the strong shift towards the employment of the gradient approach, serious analytical work still needs to be done. Important questions that have been frequently discussed in community ecology studies and thus require further attention in the context of the previously mentioned research activities, are for example, how the human-transformed environment is structured, how this environmental structure relates to the community structure of organisms inhabiting this environment, and whether these communities are organized systems or merely a random collection of co-occurring species. Further, such examinations of the faunal changes along urban-rural gradients may be also very important for implementing of nature conservation practices within the urban end of the gradient (Niemelä, 1999).

Employing the main techniques of gradient analysis, the present study focuses on the following important problems: 1) do the carabid beetle assemblages change continuously along the studied urban-rural gradient or are there discernible discrete units in their spatial structure and 2) do the sampling stations demonstrate the hypothesized urban-suburban-rural typology along the gradient.

MATERIAL AND METHODS

Study area and sampling design

The study area covered a landscape mosaic centered at the historical centre of the city of Sofia and extended about 29 km to the surroundings (see Penev *et al.*, this volume). Within this study area we selected *Quercus spp.*-dominated woodland patches, based on their distance from the city center. Four of these patches were embedded in the urban area of the city (within a 7 km radius), 3 were situated at medium distances from it (within a 14 km radius), and the remaining 4 were much farther away (within a 29 km radius). The relative position of these sampling sites along the hypothesized urban-rural gradient were denoted by the corresponding codes: "U" - urban, "S" - suburban, and "R" - rural. At each site we collected carabid beetles using pitfall traps which were active during the vegetation seasons of 1998 (07.V-22.X) and 1999 (01.IV-26.X). Traps were emptied monthly. For further details on sites and sampling design see Niemelä *et al.* (2002), and the much more detailed summary by Penev *et al.* (this volume). All the carabid beetles caught in the pitfall traps were identified to species using standard keys (Freude *et al.* 1976; the Balkan and Bulgarian endemic species were identified using an unpublished manuscript by the late Oleg L. Kryzhanovskij). The systematic nomenclature follows Kryzhanovskij *et al.* (1995).

Data analysis

The two sample-by-species matrices (from 1998 (132 samples (traps) by 71 species) and 1999 (132 by 80) catches) were summed, and the resulting matrix yielded totals of 132 (4 x 12 + 3 x 12 + 4 x 12) samples (=traps) and 18,953 specimens belonging to 86 species (Appendix 1). Although it has been demonstrated to be sensitive to the presence of rare species (e. g. Legendre & Legendre, 1998), we have chosen to use correspondence analysis (CA) for our numerical analyses, mainly because of its unique and

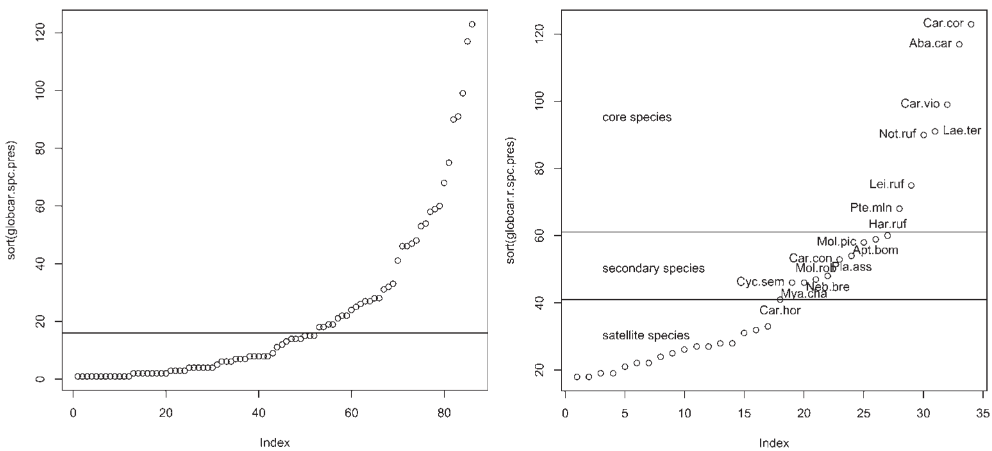


Fig. 1. Rank-occupance plot of carabid beetle species from the full matrix (A) and from the reduced dataset (B). The horizontal lines represent the cut-levels assigned to the breakpoints in the relationship. See the Appendix (second column) for species codes.

extremely valuable property to provide a joint scaling of sites and species (e. g. Greenacre, 1984; Thioulouse & Chessel, 1992). To minimize the unduly effect of rare species on the analyses, we removed them according to the following procedure. Species with less than 16 occurences (out of 132) – altogether 1250 specimens (6.6% of the total catch) belonging to 52 species that were classified as being rare by examining the first breakpoint in the rank-occupation plot (Fig. 1 – A). As a result, the final data-matrix consisted of 132 samples and 17,738 specimens belonging to 34 species. These were further classified using the same criterion (Fig. 1 – B), and categorized as "common", "intermediate", and "rare" species (corresponding roughly to the categories of Hanski (1982) – i. e. "core", "secondary", and "satellite species") but with slightly different cut-levels, resulting from the actual situation). Further attention was paid only to the first two categories. All computations and graphics were performed in the **R** statistical environment (Ihaka & Gentleman, 1996), using the ADE-4 library (Thioulouse *et al.*, 1997).

RESULTS

The multivariate analysis (CA) of the data-matrix demonstrated only one prominent ordination axis (Table 1), thus indicating that the essential part of the variation in the faunistic matrix is summarized by it (Fig. 2A). Projected on this axis, the most apical samples belonged to the "urban" sites (Severen Park – U3, Borisova Gradina – U1, and Zapaden Park – U2, all located well inside the matrix of the city), they form a relatively compact cluster and are opposed to the rest of the sites. Some of the non-urban sites form a second, more heterogeneous group (i. e. the site near German village – S1, Loven Park – U4, the locality Tikhiya kat – R4, and the forest in the vicinity of Drenovo village – R3) that take an intermediate position between the "urban" and the last, even more widely scattered, group of sites that include mostly "rural" forest-patches (at the foothills of Lyulin – S2, R2, Vitosha – S4, and Lozenska Mts. – R1). On the second axis we observed sites "R3", "R1", and "S1" being associated with the remaining of the gradient, already described along the first axis. When taking into account the third axis as well, the three-branched structure of the "sample-cloud" becomes apparent (Fig. 2B) – the "urban" cluster is associated with the samples of "R1" and are opposited to the rest of the samples. An even more interesting structure is revealed by the reciprocal scaling diagram (obtained after the CA) (Fig. 3A, B). Since the scales on both ordination diagrams are identical, this representation allows a direct side-by-side comparison of both samples and species from the data-matrix. From this representation it becomes obvious that the sampled landscape-mosaic consists of several more or less clearly defined partitions (i. e. several short, regionally confined gradient-structures), that are linked by species with large distribution amplitude. The most easily discernible structure consists of the samples

Table 1. Eigenvalues and percentage of variance of the first four axes of the CA of the species abundance matrix.

Axis	Eigenvalue	Cummulative Percentage of Variance
1	0.6801	19.3
2	0.3675	29.8
3	0.3395	39.4
4	0.3237	48.6

taken at the most distant and isolated forest-patch (R3), showing probably some affinities with the adjacent mountain range (Stara Planina Mts.). The most characteristic species that inhabits mainly this site is *Carabus montivagus*. Site "R1" (just above the Germanski monastery, Lozenska Mt.) takes a peculiar position, sharing certain carabid species (and e.g. inhabited by a unique assemblage, containing relatively stenotopic (i. e. with a more limited distribution within the landscape under study) forest species like *Xenion ignitum*, *Aptinus bombarda* (Fig. 5C), *Carabus convexus* (Fig. 5F), *Molops robustus parallelus* (Fig. 6B), and *Cychrus semigranosus* (Fig. 6C)) with both the latter site, and the group of sites located south-east from the city of Sofia (S2, R2, S4). This indicates that Lozenska Mt. may be considered a separate zoogeographic entity. Another well separated site on the ordination diagram is the (also very isolated) forest plantation (S1). This patch is not inhabited by any characteristic species, but merely by a characteristic assemblage of species that show a more or less stronger tendency towards a bimodal (outside its primary, and restricted to a diffrent degree, distribution-range) distribution (e.g. *Pterostichus melanarius* (Fig. 5A), and *Carabus convexus* (Fig. 5F)). The eight remaining sampling sites form three well-defined regional gradients that are joined through transition zones: the first of these gradients contains the gradually overlapping samples at the foothills south-west of Sofia (i. e. the foothills of Lyulin Mt. (R2, S2), and the adjacent regions of Vitosha Mt.(S4)). The second one includes the recently well separated (but known as being connected in the past (see Mitov & Stoyanov, this volume)) sampling sites at the locality "Tikhiya kat" (Vitosha Mt.) and the park "Loven Park", that share, the species *Platynus assimilis* (Fig. 5E) among others. The last of the mentioned structures include three of the four greatest city parks holding the most peculiar carabid beetle assemblages (including *Leistus rufomarginatus* (Fig. 4D), *Nebria brevicollis* (Fig. 6A), and the "satellite species" *Asaphidion flavipes, Bembidion lampros*) and

Table 2. The occurrence frequency of core and secondary species (see text for details on classification).

Species Category	Occurence [%]
Core species	
Carabus coriaceus	93.2
Abax carinatus	88.6
Carabus violaceus	75.0
Laemostenus terricola	68.9
Notiophilus rufipes	68.2
Leistus rufomarginatus	56.8
Pterostichus melanaruis	51.5
Secondary species	
Harpalus rufipes	45.5
Aptinus bombarda	44.7
Molops piceus	43.9
Platynus assimilis	40.9
Carabus convexus	40.2
Nebria brevicollis	36.4
Molops robustus	35.6
Myas chalybaeus	34.8
Cychrus semigranosus	34.8
Carabus hortensis	31.1

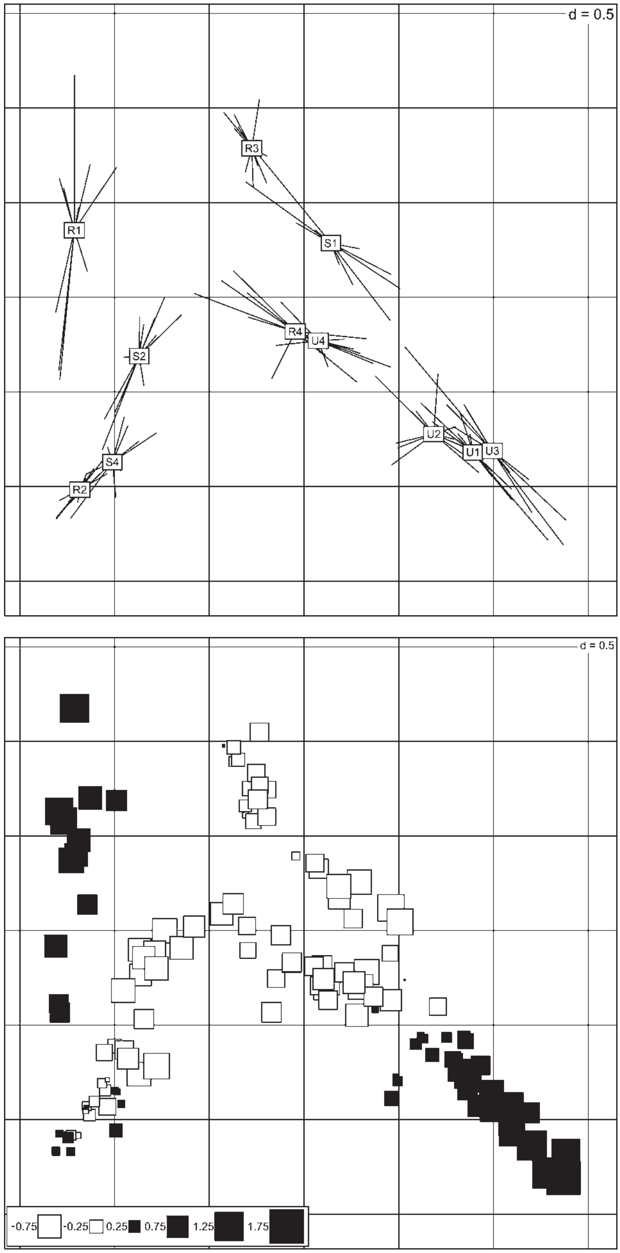
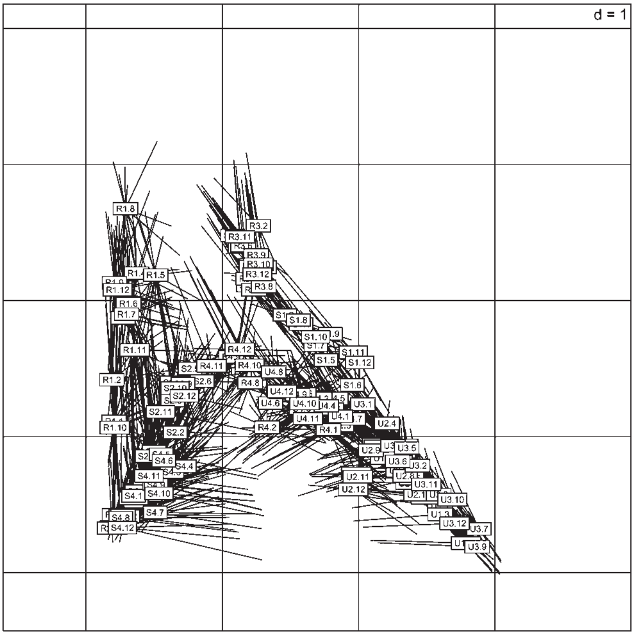


Fig. 2. CA ordination diagram of the samples (traps). A – the samples grouped by site (patch); B – representation of the samples in the first two factorial planes; the 3rd dimension is represented by a symbolic code (black squares–positive values, white squares–negative values along the 3rd ordination axis). See text for site codes.

therefore lie at the "urban" end of the complicated gradient/partition structure revealed by the current analysis. It may be finally noted, that all these local structures are articulated on species with a wide distribution range within the investigated landscape mosaic. These species are (in ascending order): *Harpalus rufipes* (Fig. 5B), *Laemostenus terricola* (Fig. 4F), *Notiophilus rufipes* (Fig. 4E), *Carabus violaceus* (Fig. 4C), *Abax carinatus* (Fig. 4B) and *Carabus coriaceus* (Fig. 4A)). Figure 3B also supports the impression about the wider ecological tolerances of species, that are placed at the joints between the already delimited assemblage-units. On Figures 4–5 we also observe that only one out of the seven core, and two of the ten "secondary species" have their main distribution ranges in the "urban" cluster; the rest of the species contribute either to the specificity of various parts of the landscape mosaic under study, or to the complex global behavior of the internal structure of the analyzed region.

DISCUSSION

The results of this investigation reveal that the structure of the full-rank (i. e. fully-featured up to the trap-level) dataset ordinations do not allow us to identify a simple, circular gradient – at least not concentrically shaped as the *a priori* hypothesized urban-rural gradient running from the core at the city center, trough a well-defined "suburban" zone, and ending in the homogeneous rural area outside the city. It rather demonstrates a mixture between partitions and ordinations evident from the results of the multivariate analyses. On the other hand, the carabid beetle assemblages also show a complicated spatial structure, especially in the "non-urban" part of the "gradient" (Fig. 2-3). An important factor that supports the observed complex spatial structure of the ground beetle assemblages seems to be the interaction between the natural zoogeographical zonation of the investigated landscape and the developement of the human-induced landscape changes. For example, sampling sites that are located close to one another, tend to be more similar in terms of carabid assemblages, unless the increasing isolation transforms their fauna to such an extent that the original community undergoes severe changes and forms a new partition in the spatial structure. In our opinion, such processes have led to the faunal transformation observed in the "urban" sites (U1, U2, U3) that are relatively well separated from the remaining sites, thus forming the urban end of the gradient. This statement is further supported by the high similarity of the fourth "urban" site (U4) with the foothill fauna of the greatest and most proximal mountain to the city (Vitosha Mt. – R4). This may be considered as a phenomenon of relict distribution of similar species-assemblages, in view of the close historical and topical relationships between the corresponding landscape structures, (the latter being no longer present). Therefore, the considerations that the former (less affected by habitat fragmentation) fauna of the Sofia kettle had been more homogeneous, with strong affinities to the typical fauna of the hilly lower mountain zone (as presented by the Vitosha Mt.) (see for more details Mitov & Stoyanov, this volume), seems to gain additional support. In view of these facts, the already mentioned "urban" sites may be considered as heavily transformed fragments of the former homogeneous landscape. Recently they are inhabited mainly by species considered to be eurytopic (Thiele, 1964) – *Leistus rufomarginatus*, *Notiophilus rufipes*, *Nebria brevicollis, Asaphidion flavipes*, as well as by species typically inhabiting open grasslands – e. g. many *Amara* and *Harpalus* species. Concerning the eurytopic species, there exists at least one documented observation that some of these (i. e. *Leistus rufomarginatus* and *Nebria brevicollis*) have acquired nearly dominant status in the "urban" forest-patches at the end of 20th century, while being rare in the early



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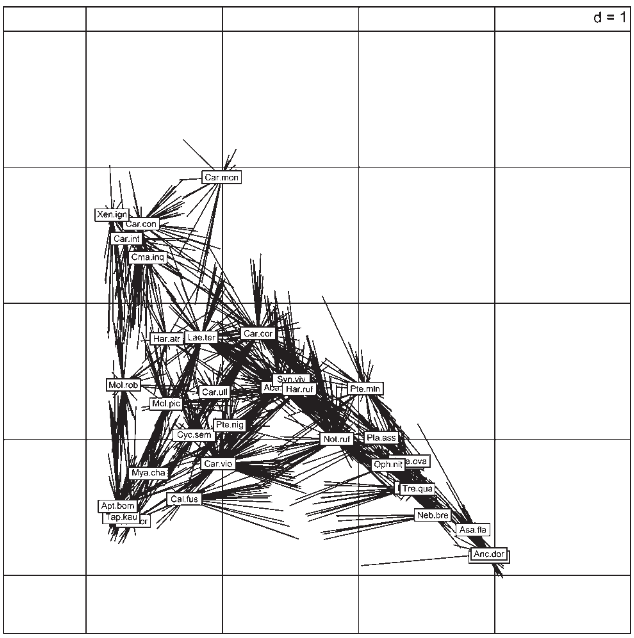


B

Fig. 3. Reciprocal scaling of sample diveristy (A) and carabid beetle species tolerance (B). A – each of the 132 samples is represented by a star; B – stars of the 34 beetle species (may be superimposed to the figure above). Each unit (sample, species) is labeled at its centroid.

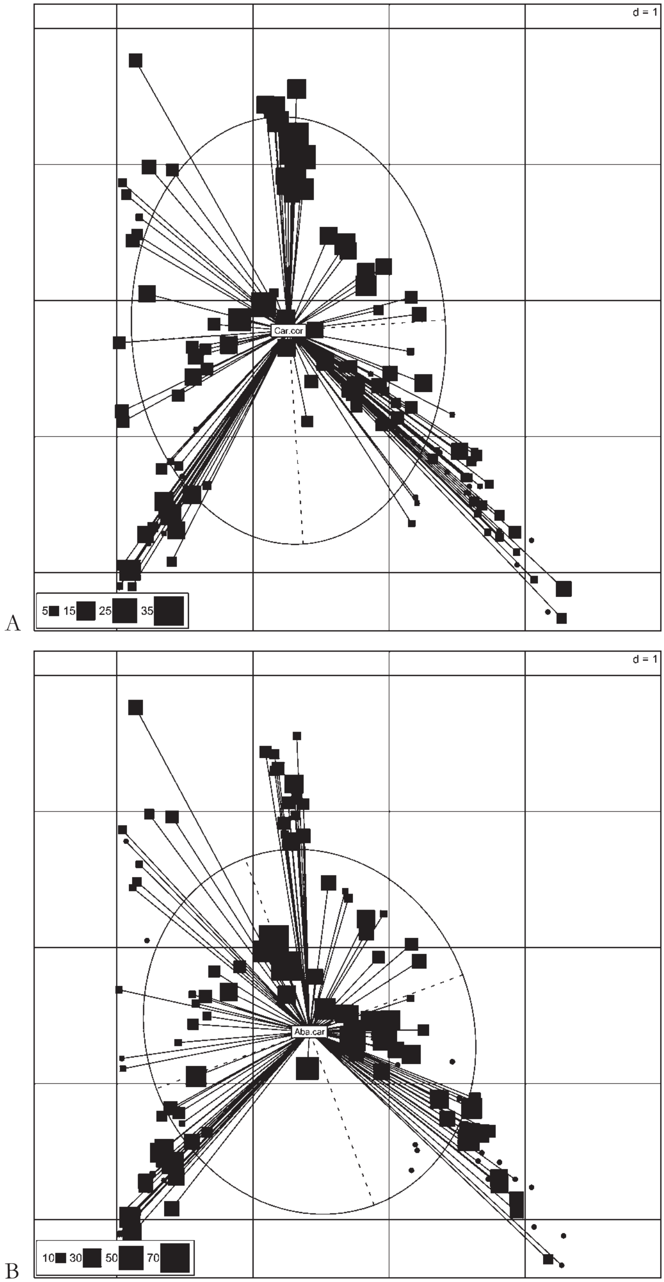
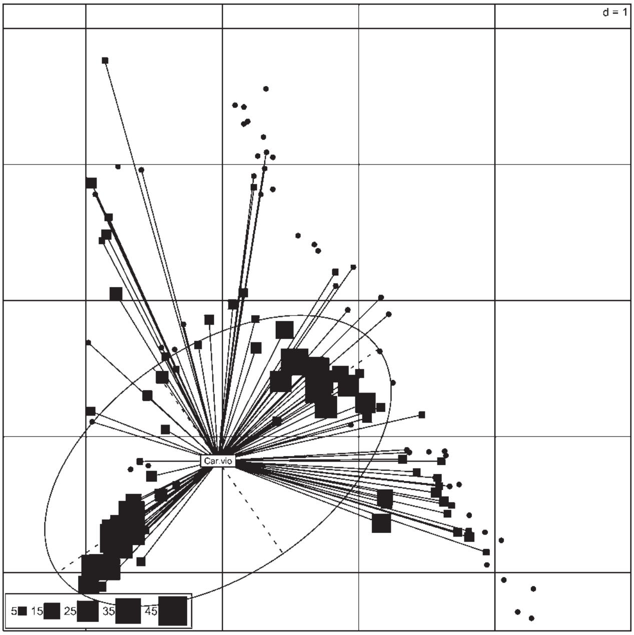


Fig. 4. The distribution of principal carabid beetle species (see Table 2) among the samples on the CA ordination plot. A – *Carabus coriaceus*, B – *Abax carinatus*, C – *Carabus violaceus*, D – *Laemostenus terricola*, E – *Notiophilus rufipes*, F – *Leistus rufomarginatus*.



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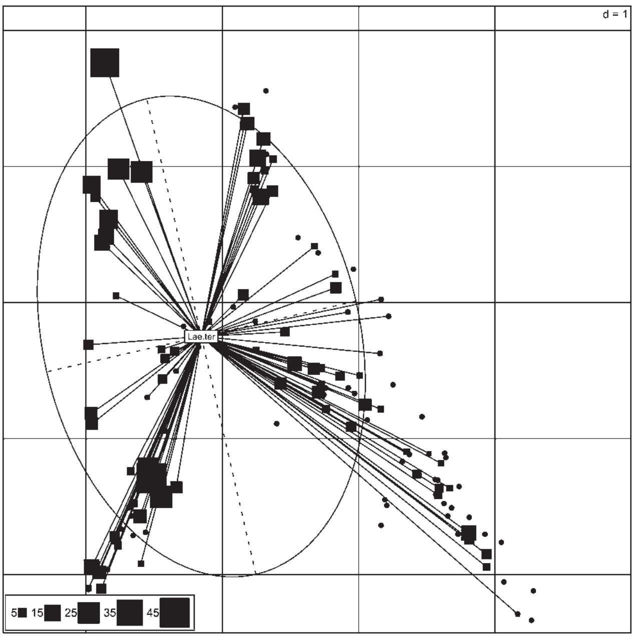

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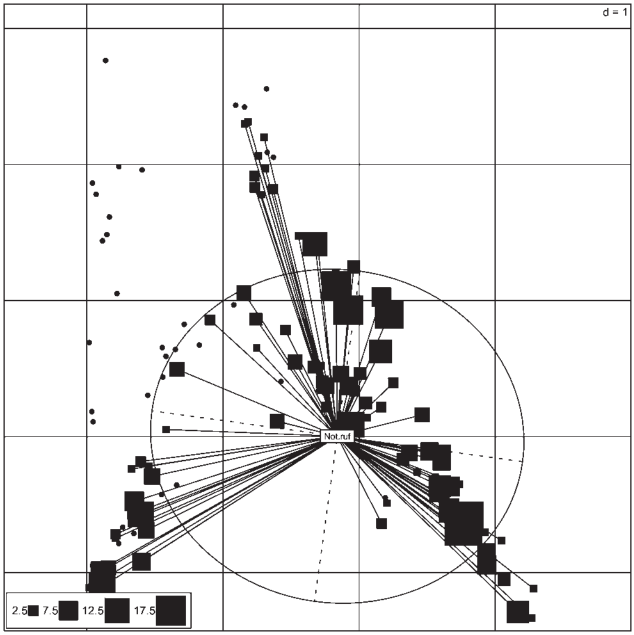

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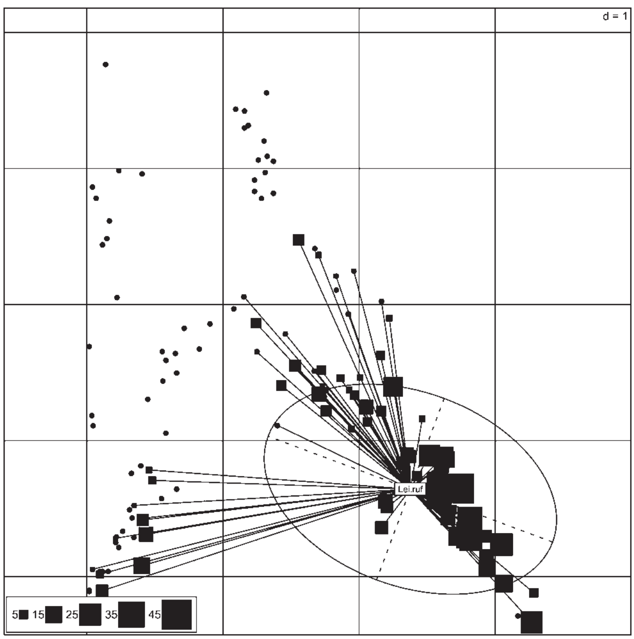

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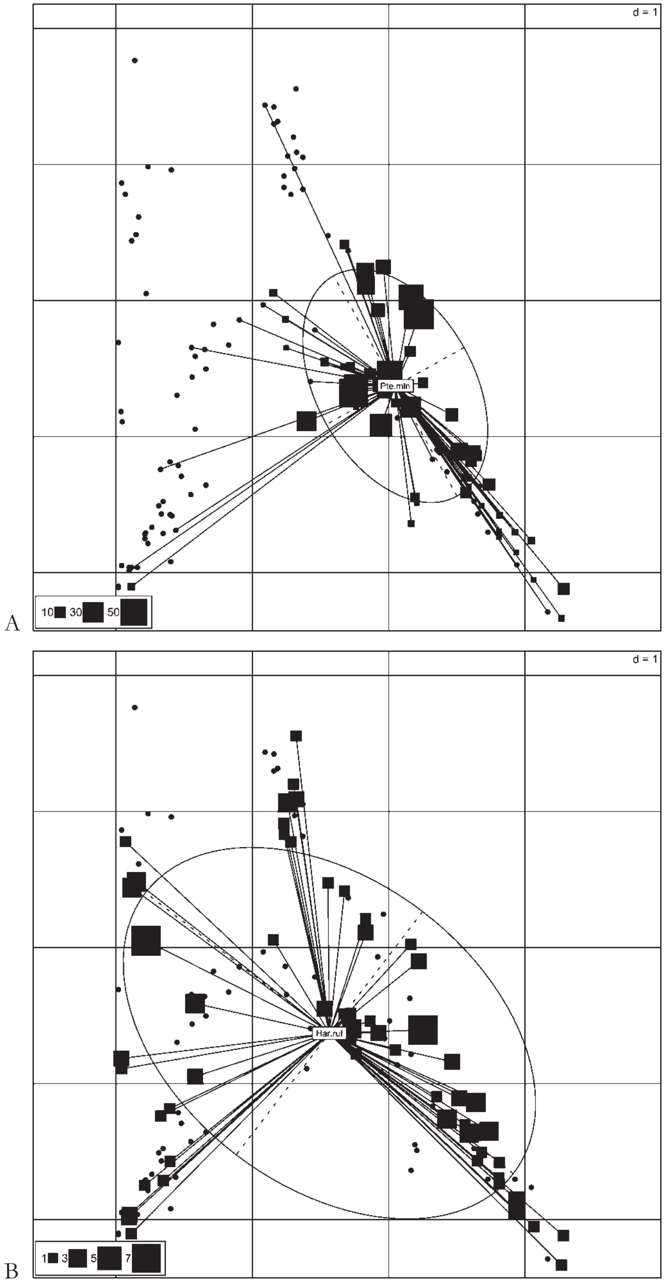
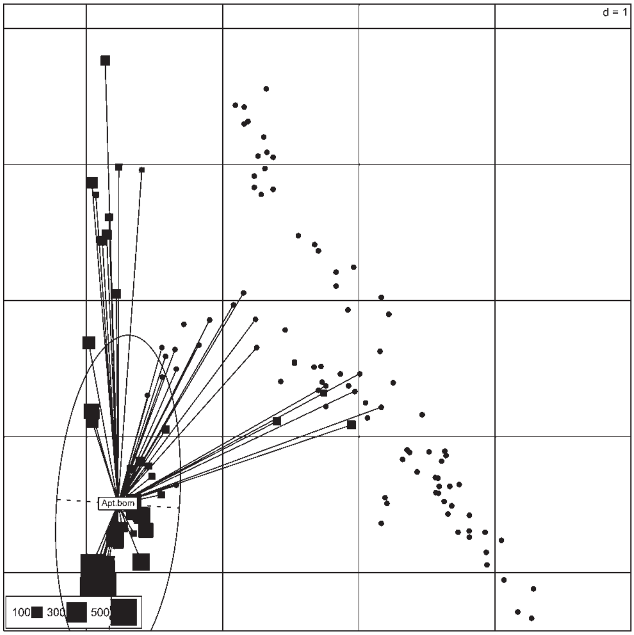


Fig. 5. The distribution of principal carabid beetle species (see Table 2) among the samples on the CA ordination plot. A – *Pterostichus melanarius*, B – *Harpalus rufipes*, C – *Aptinus bombarda*, D – *Molops piceus*, E – *Platynus assimilis*, F – *Carabus convexus*.



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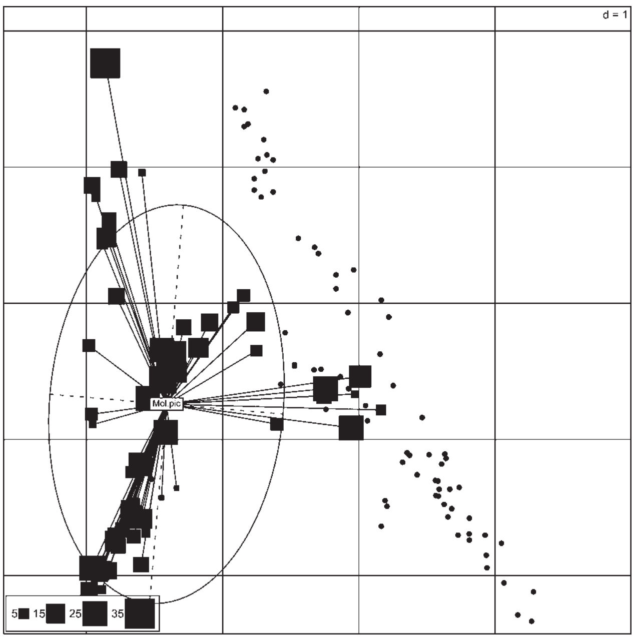

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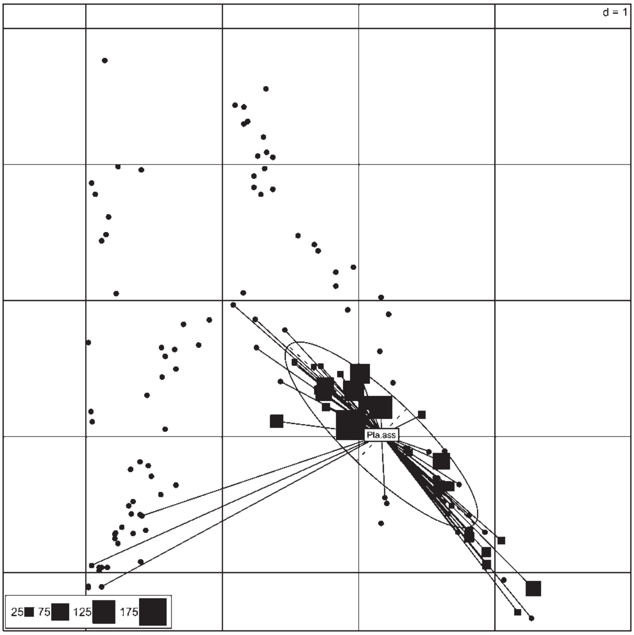

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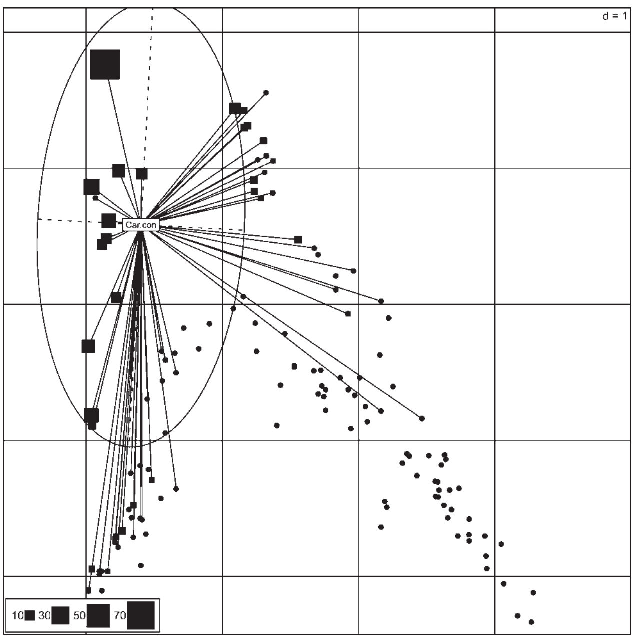

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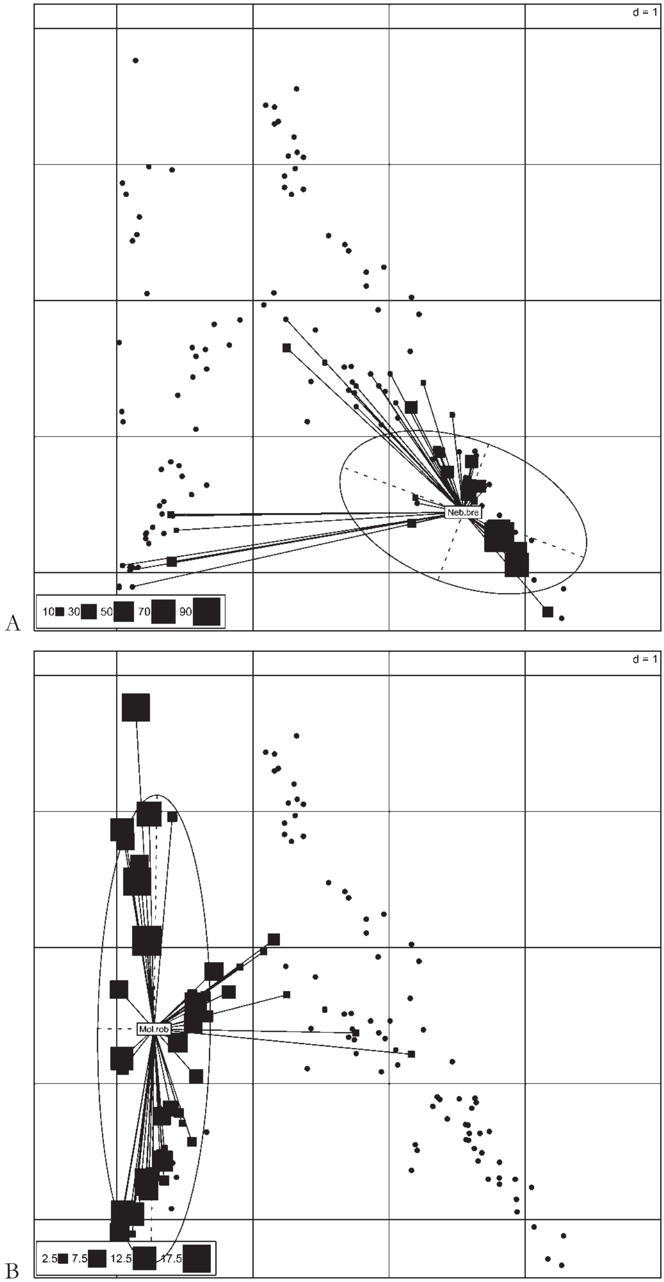
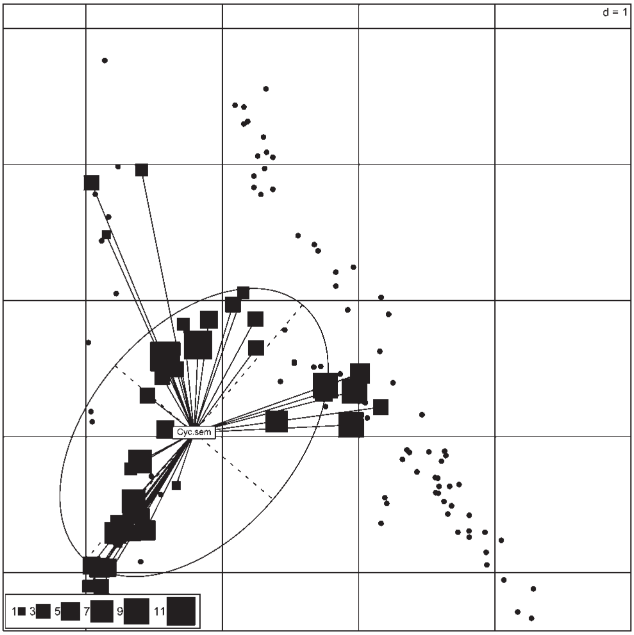


Fig. 6. The distribution of principal carabid beetle species (see Table 2) among the samples on the CA ordination plot. A – *Nebria brevicollis*, B – *Molops robustus parallelus*, C – *Cychrus semigranosus*, D – *Myas chalybaeus*, E – *Carabus hortensis*.



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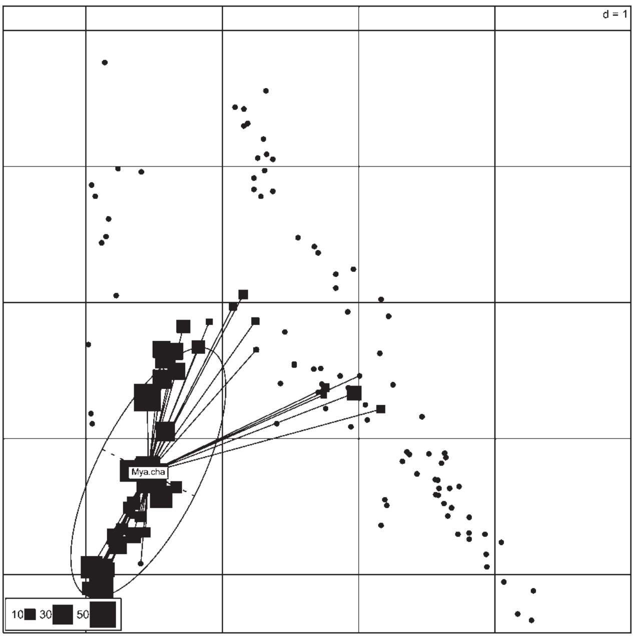

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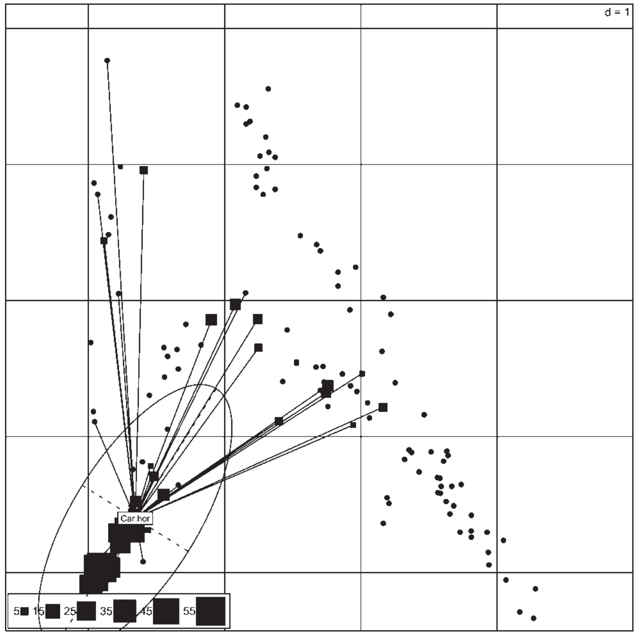

E

Fig. 6. Continued.

1900s, and very irregularly recorded by the first researchers of the ground beetle fauna in the region of the city of Sofia (see Stoyanov, this volume). Since these species were presently not found to be so widely distributed as their eurytopic status may suggest, we assume that these belong to the characteristic zoo-geographic complex of the Sofia kettle. Unfortunately, similar historical information about the other strongly isolated patches is not available, and so we cannot judge if a similar transformation has occurred there too. The only vague hint in this direction may be found in the presence of *Carabus montivagus*, a species considered as being associated with open habitats (Magura *et al.*, 2000), and found predominantly north of Sofia at the most distant forest remnant (R3). The other forest patch strongly influenced by human activities (S1) is most peculiar in its origin, since it is a quite recently planted forest and shows almost no characteristic species, except that it holds a significant population of eurytopics, with preferenc-es towards open habitats, as for example *Pterostichus melanarius* (see Magura *et al.*, 2000), that has most probably invaded from the surrounding regions. The remaining sampling sites are correspondingly marked by the zoogeographic peculiarities of the regions where they pertain, and so increase the difficulties in observing a simple (as outlined above) urban-to-rural gradient. The failure to observe such a (hypothe-sized) structure would be even stronger when a hierarchical clustering technique is applied in a case where the natural structure of the data do not allow a convenient one-dimensional representation (see for example Niemelä *et al.* (2002), where only the 1998 dataset is analyzed at site level, unfortunatelty).

Finally, another striking feature of the analyzed landscape-mosaic is evident from the figure that represents the reciprocal scaling diagram of sample diversity and species tolerance (Fig. 3A, B). Most of the sampling sites show a similar degree of within-site (*alpha*) diversity (i. e. the dispersion among individ-ial samples is similar) at the studied scale, only site R1 shows a somewhat higher diversity, probably caused by natural and/or human-induced heterogeneity, thus not fully supporting the previous results of Niemelä *et al.* (2002). Reciprocally, most of the species scatters overlap, thus indicating that only a few species are specific to each group of samples (except the already discussed clusters containing *Xenion ignitum*, *Carabus intricatus*, *Carabus convexus*, *Calosoma inquisitor*, and *Carabus montivagus*), and that when excluding sites "R1" and "R3" from the analysis, the resulting structure becomes considerably simpler, and allows in turn a better ordination of species along the (already more similar to the initially hypothesized) urban-rural gradient. So it becomes evident, that when such complex structures occur in a gradient analysis, a significant simplification of the picture may be obtained if the second-order zonation is filtered out.

As a conclusion, it may be summarized that when analyzing the full available dataset: 1) no simple (defined as concentrically alternated urban, suburban and rural zones) urban-to-rural gradient is recognizable – the internal organization of the data exhibit a mixture of ordinations and partitions, joined by species with wide and/or bimodal distribution (tolerance). These partitions are most probably a consequence of the interaction between the natural zoogeographical zonation of the investigated area and the human-caused landscape transformations. The only relatively homogeneous zone (both historically and geographically) appears to be the urban core (i. e. the "urban" end of the gradient). 2) The carabid beetle assemblages do not form a *continuum* along the urban-rural gradient – the most important (core and secondary) species are either widespread, or locally confined exposing rather limited tendencies towards a bimodal distribution. This fact favors a zoogeographic diversification within the studied area.

ACKNOWLEDGEMENTS

We would like to thank Dr. Jeff A. Harvey (Netherlads Institute of Ecology, Heteren), who reviewed an early version of the manuscript and contributed many valuable improvements both to the text and the English. We thank also Dr. D.J. Kotze for improving the final version of the English text. This work was partly supported by the National Scientific Research Fund (grant No. B-808/1998).

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Appendix 1. Carabid beetles collected along urban-rural gradient in the city of Sofia. (*)

Species name	Code	R1.1	R1.2	R1.3	R1.4	R1.5	R1.6	R1.7	R1.8	R1.9	R1.10	R1.11	R1.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	3	0	0	3	0	1	4	14	1	0	8	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	0	0	3	0	4	0	0	1	0	1	1	1
Carabus convexus Fabricius 1775	Car.con	17	15	9	14	11	18	10	74	22	5	9	2
Carabus intricatus Linnaeus 1761	Car.int	6	6	5	13	2	7	3	14	9	4	1	7
Carabus violaceus Linnaeus 1758	Car.vio	4	1	2	0	1	3	5	2	6	1	8	1
Carabus coriaceus Linnaeus 1758	Car.cor	7	6	7	8	6	2	5	7	3	6	11	4
Carabus montivagus Pallairdi 1825	Car.mon	2	0	1	0	0	0	2	5	1	0	1	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	0	0	0	0	2	0	1	0	3	0	0	0
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	0	0	0	0	0	0	0	0	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	0	0	0	0	0	0	0	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	19	33	48	30	25	22	51	154	99	17	24	28
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	0	0	0	0	0	0	0	0	0	0
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	1	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	1	0	1	0	0	0	0	0	0	0	10
Abax carinatus (Duftschmid 1812)	Aba.car	2	4	4	8	13	4	7	17	6	3	0	1
Molops piceus bulgaricus Maran 1938	Mol.pic	6	6	5	10	2	8	14	32	10	2	10	3
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	11	7	1	13	2	7	16	16	11	3	18	6
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	1	0	0	0	0	2	0	0	2
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	0	0	0	0	0	0	0	0	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	8	5	12	22	23	17	12	39	15	7	2	5
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	0	0	0	0	0	0	0	0	0	0	0	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	0	0	0	0	0	0	0	0	0	0	0
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	0	0	0	0	0	0	0	0	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	0	0	0	0	1	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	1	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	0	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	1	0	0	1	0	0	0	0	0	1	2	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	1	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	2	0	3	0	0	0	3	0	0	1	7	1
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	1	1	2	1
Harpalus atratus Latreille 1804	Har.atr	2	1	0	4	3	4	3	3	2	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	1	0	1	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	0	0	0	0	0	0	0	0	1	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	158	108	65	32	18	41	65	62	90	98	56	25
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

* (sample codes: sampling site.trap number)

Appendix 1. Continued.

Species name	**Code**	**S1.1**	**S1.2**	**S1.3**	**S1.4**	**S1.5**	**S1.6**	**S1.7**	**S1.8**	**S1.9**	**S1.10**	**S1.11**	**S1.12**
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	0	6	0	2	1	4	0	0	1	1	1	2
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	2	1	0	1	16	10	16	11	3	1	7	15
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	0	0	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	0	0	0	0	0	0	0	0	0	0	0	0
Carabus convexus Fabricius 1775	Car.con	4	5	11	0	2	0	1	1	1	0	1	0
Carabus intricatus Linnaeus 1761	Car.int	1	1	0	0	1	1	0	1	0	1	0	0
Carabus violaceus Linnaeus 1758	Car.vio	2	0	0	0	1	0	1	0	1	2	1	1
Carabus coriaceus Linnaeus 1758	Car.cor	9	12	12	11	4	2	16	17	10	12	6	8
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	0	0	0	0	0	0	0	0	0	0	0	0
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	0	0	0	0	0	0	0	0	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	0	0	0	0	0	0	0	0	1
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	0	0	0	0	0	0	0	0	0	0
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	1	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	0	0	1	1	12	8	21	6	14	21	41	57
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	1
Abax carinatus (Duftschmid 1812)	Aba.car	5	18	11	6	12	4	18	3	4	25	13	17
Molops piceus bulgaricus Maran 1938	Mol.pic	0	0	0	0	0	0	0	0	0	0	0	0
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	0	0	0	0	0	0	0	0	0	0
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	0	0	0	0
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	0	0	0	1	0	0	0	0	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	3	0	0	0	1	1	6	2	0	2	1	1
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	0	0	0	0	0	0	0	0	0	0	0	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	0	0	0	0	0	0	0	0	0	0	0
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	0	0	0	0	0	0	0	0	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	0	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	1	0	0	0	0	0	0	0	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	1	1	0	0	0	0	2	1	0	1	1	2
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	0	0	1	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	1	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	0	0	0	0	0	0	0	0	0	1
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	U1.1	U1.2	U1.3	U1.4	U1.5	U1.6	U1.7	U1.8	U1.9	U1.10	U1.11	U1.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	11	10	13	32	25	14	5	8	8	18	26	0
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	18	48	63	57	17	22	18	7	12	95	26	12
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	1	0
Notiophilus rufipes Curtis 1829	Not.ruf	6	6	7	12	7	9	1	1	5	5	6	9
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	0	0	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	0	0	0	0	0	0	0	0	0	0	0	0
Carabus convexus Fabricius 1775	Car.con	0	0	0	0	0	0	0	0	0	0	0	0
Carabus intricatus Linnaeus 1761	Car.int	0	0	0	0	0	0	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	3	2	0	2	1	3	3	1	1	5	2	0
Carabus coriaceus Linnaeus 1758	Car.cor	4	2	0	1	1	0	0	1	1	3	0	0
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	0	0	0	0	0	0	0	0	0	0	0	0
Loricera pilicornis (Fabricius 1775)	Lor.pil	1	1	4	2	5	0	2	0	0	1	0	15
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	1	2	0	0	0	0	0	0	0	0	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	14	16	6	21	9	16	6	2	2	8	4	18
Bembidion lampros (Herbst 1784)	Bem.lam	8	24	18	12	1	5	0	0	0	2	0	33
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	3	0	0	1	0	0	1	1	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	1	0	0	0	0	0	0	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	0	0	0	0	0	0	0	0	0	0
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	1	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	1	0	1	1	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	1	1	0	0	0	1	0	0	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	10	0	1	2	0	1	0	0	1	0	1	1
Pterostichus melanarius (Illiger 1798)	Pte.mln	8	2	1	2	1	1	0	0	0	2	1	1
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	33	17	14	24	26	32	19	16	26	25	36	8
Molops piceus bulgaricus Maran 1938	Mol.pic	0	0	0	0	0	0	0	0	0	0	0	0
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	0	0	0	0	0	0	0	0	0	0
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	0	0	0	0
Calathus fuscipes (Goeze 1777)	Cal.fus	1	0	3	0	1	3	3	2	2	0	3	3
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	2	5	3	11	2	4	4	2	1	5	3	1
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	61	21	19	16	20	27	13	11	10	22	14	9
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	1	0	3	3	2	2	1	2	3	3	10	2
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	0	0	0	0	0	0	0	0	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	0	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	1	3	1	0	0	4	9	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	1	0	0	0	0	0	0	0	1	0	1
Amara ovata (Fabricius 1792)	Ama.ova	0	0	1	2	18	8	5	0	2	0	7	1
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	1	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	0	2	2	1	0	3	3	1	0	1	0	0
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	1	1	0	0	0	0	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	1	0	1	0	0	2	7	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	3	1	1	1	4	3	1	0	1	4	9	2
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	1	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	1	0	1	0	0	0	0	0	1	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	1	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	1	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	1	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	1	0	0	0	2	1	0

Appendix 1. Continued.

Species name	Code	R2.1	R2.2	R2.3	R2.4	R2.5	R2.6	R2.7	R2.8	R2.9	R2.10	R2.11	R2.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	1	0	0	0	0	0	0	0	0	0	0	0
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	1	0	0	0	0	0	0	0	0	0	0	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	0	4	0	0	0	0	0	0	2	1	1	0
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	1	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	1	0	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	1	2	1	0	1	0	0	0	9	13	4	2
Carabus hortensis Linnaeus 1758	Car.hor	26	25	54	30	20	25	23	32	8	8	26	23
Carabus convexus Fabricius 1775	Car.con	4	2	1	0	1	1	3	2	0	2	0	5
Carabus intricatus Linnaeus 1761	Car.int	1	0	0	0	0	1	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	21	31	18	34	27	44	37	21	34	42	20	28
Carabus coriaceus Linnaeus 1758	Car.cor	4	1	2	1	1	1	1	2	2	2	0	4
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	4	4	5	3	3	1	6	2	4	2	1	7
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	0	0	0	0	0	0	0	0	0	1
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	1	0	0	0	0	0	0	0	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	32	14	13	30	17	21	11	12	2	11	9	9
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	2	0	4	1	0	0	3	1	0	2
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	1	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	1	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	2	1	1	1	2	0	4	1	12	16	2	3
Molops piceus bulgaricus Maran 1938	Mol.pic	23	11	13	12	7	8	10	5	19	16	11	8
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	1	0	0	1	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	11	3	10	11	2	8	11	8	9	9	7	4
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	1	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	12	9	4	6	4	1	1	4	4	2	0	2
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	0	0	0	0	0	0	0	0	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	12	1	2	0	0	3	1	2	0	3	0	0
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	1	0	0	0	0	0	0	0	0	0	0	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	2	0	0	0	0	0	0	0	1	1	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	0	0	0	0	0	0	0	0	0	0	0
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	0	0	0	0	0	0	0	0	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	0	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	0	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	1
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	1	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	0	0	2	0	1	0	0	0	0	1	0	0
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	1	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	1	0	0	0	0	0	1	0	0	0	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	348	138	129	135	31	78	90	223	96	207	228	74
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	1	0	0	0	0	0	0	1
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	S2.1	S2.2	S2.3	S2.4	S2.5	S2.6	S2.7	S2.8	S2.9	S2.10	S2.11	S2.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	2	1	0	1	0	0	0	0	0	0	0	4
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	1	0	0	0	0	1	2	0	3	2	2	0
Carabus ullrichi Germar 1824	Car.ull	7	11	6	6	13	10	5	11	3	16	10	10
Carabus hortensis Linnaeus 1758	Car.hor	0	0	0	0	0	0	0	0	0	0	0	0
Carabus convexus Fabricius 1775	Car.con	0	0	0	1	0	0	1	0	0	2	1	1
Carabus intricatus Linnaeus 1761	Car.int	0	0	0	0	0	0	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	2	4	1	0	1	3	0	8	1	3	5	2
Carabus coriaceus Linnaeus 1758	Car.cor	2	1	1	5	6	12	6	11	5	10	6	6
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	7	4	1	2	2	10	1	3	2	11	3	3
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	0	0	0	0	0	0	0	0	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	0	0	0	0	0	0	0	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	7	25	9	32	12	12	20	25	19	27	49	20
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	0	0	0	1	0	0	1	0	0	0	0	0
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	1	0	1	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	15	33	29	9	11	25	4	10	14	5	4	6
Molops piceus bulgaricus Maran 1938	Mol.pic	20	22	10	5	9	15	22	27	18	12	22	16
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	2	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	5	4	1	7	7	4	2	7	2	10	8	3
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	0	0	0	0
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	0	0	0	0	0	0	0	0	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	0	1	1	3	0	0	3	4	4	4	1	1
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	0	0	0	0	0	0	0	0	0	0	0	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	0	0	0	0	0	0	0	0	0	0	0
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	0	0	0	0	0	0	0	0	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	1	0	0	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	1	1	0	0	0	1	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	0	0	0	1	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	4	1	0	0	3	1	0	0	3	0	2	2
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	1	2	0	1	0	0	0	0	0	3	0	0
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	2	4	4	3	7	4	1	7	2	3	7	4
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	1	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	54	39	98	47	0	7	1	13	3	6	4	3
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	U2.1	U2.2	U2.3	U2.4	U2.5	U2.6	U2.7	U2.8	U2.9	U2.10	U2.11	U2.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	16	10	4	2	4	5	19	10	8	10	7	8
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	6	3	1	3	0	1	2	5	2	4	2	9
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	13	6	1	4	4	3	0	2	3	0	1	2
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	0	0	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	0	0	0	0	0	0	0	0	0	0	0	0
Carabus convexus Fabricius 1775	Car.con	0	0	0	1	0	0	0	0	0	0	0	0
Carabus intricatus Linnaeus 1761	Car.int	0	0	0	0	0	0	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	4	3	5	2	2	5	3	5	4	13	6	18
Carabus coriaceus Linnaeus 1758	Car.cor	2	2	7	1	4	0	3	4	4	1	1	2
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	0	0	0	0	0	0	0	0	0	0	0	0
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	1	0	0	3	0	0	1	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	6	5	2	0	0	1	1	0	0	0	0	2
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	1	0	0	0	0	0	1
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	1	0	0	1	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	1	1	1	2	9	5	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	1	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	0	0	1	1	0	1	0	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	0	0	0	0	0	0	0	0	0	0
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	1	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	1	0	0	0	0	0	0	1	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	1	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	2	1	0	1	0	3	15	2	0	1	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	4	5	4	3	2	2	1	0	0	3	1	4
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	0	0	0	11	2	8	4	0	1	6	2	3
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	0	0	1	0	0	1	2	0	0	0	0	0
Molops piceus bulgaricus Maran 1938	Mol.pic	0	0	0	0	0	0	0	0	0	0	0	0
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	0	0	0	0	0	0	0	0	0	0
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	0	0	0	0
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	1	1	0	0	0	0	0	1	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	1	0	0	0	0	0	1	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	0	0	0	0	0	0	0	0	0	0	0	0
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	1	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	4	2	1	13	6	1	3	1	1	1	0	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	4	0	0	0	0	0	0	1	0	1	0	2
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	0	0	0	0	0	0	0	0	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	1	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	0	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	0	1	0	2	1	0	0	0	0	0	0	0
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	1	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	1	0	0	0	0	0	0	0	0	0	1	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	1	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	1	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	1	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	1	0	0	1	0	2	1	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	R3.1	R3.2	R3.3	R3.4	R3.5	R3.6	R3.7	R3.8	R3.9	R3.10	R3.11	R3.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	0	0	1	2	1	1	1	2	1	0	0	1
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	0	0	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	0	0	0	0	0	0	0	0	0	0	0	0
Carabus convexus Fabricius 1775	Car.con	2	1	5	5	3	5	1	2	4	2	4	1
Carabus intricatus Linnaeus 1761	Car.int	0	0	0	0	0	0	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	0	0	0	1	0	0	0	0	0	1	0	1
Carabus coriaceus Linnaeus 1758	Car.cor	22	14	8	11	9	17	12	18	33	11	17	17
Carabus montivagus Pallairdi 1825	Car.mon	3	5	2	1	2	5	5	3	10	3	4	2
Cychrus semigranosus Pallairdi 1825	Cyc.sem	0	0	0	0	0	0	0	0	0	0	0	0
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	0	0	0	0	0	0	0	0	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	1	0	1	1	1	0	0	0	1	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	0	0	0	0	0	0	0	0	0	0
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	1	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	11	5	8	13	25	13	13	16	27	9	8	7
Molops piceus bulgaricus Maran 1938	Mol.pic	0	0	0	0	0	0	0	0	0	0	0	0
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	0	0	0	0	0	0	0	0	0	0
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	36	25	33	49	42	57	57	39	75	28	74	129
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	0	0	0	0
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	0	0	0	0	1	0	0	0	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	3	0	4	7	13	9	13	6	9	1	7	3
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	0	0	0	0	0	0	0	0	0	0	0	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	1	0	0	0	0	0	0	0	0	0	0	0
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	1	0	0	0	0	1	0	0	0	1
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	2	0	0	1	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	0	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	1	0	0	1	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	1	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	1	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	0	1	0	1	1	0	3	0	1	2	0	0
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	0	0	0	0	0	0	1
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	1	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	U3.1	U3.2	U3.3	U3.4	U3.5	U3.6	U3.7	U3.8	U3.9	U3.10	U3.11	U3.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	18	41	14	21	13	14	4	8	23	24	29	14
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	1	0	0	1	4	3	1	9	8
Nebria brevicollis (Fabricius 1792)	Neb.bre	3	1	1	1	1	0	0	0	0	0	0	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	2	0	0	0	1	1	0	1	0	1	3	1
Notiophilus rufipes Curtis 1829	Not.ruf	2	1	3	6	1	1	1	1	1	1	14	3
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	0	0	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	0	0	0	0	0	0	0	0	0	0	0	0
Carabus convexus Fabricius 1775	Car.con	0	0	0	0	0	0	0	0	0	0	0	0
Carabus intricatus Linnaeus 1761	Car.int	0	0	0	0	0	0	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	0	0	0	0	0	0	0	0	0	0	0	0
Carabus coriaceus Linnaeus 1758	Car.cor	12	3	2	11	5	3	9	6	4	0	4	2
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	0	0	0	0	0	0	0	0	0	0	0	0
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	4	1	1	1	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	1	1	0	0	3	1	3	1	1	2
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	1	9	7	4	4	2	19	6	13	4	1	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	0	1	0	0	38	3	5	1	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	1	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	0	0	0	0	0	0	1	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	0	0	0	0	0	0	0	0	0	0
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	2	1	2	1	1	0	2	0	0	1	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	7	10	10	20	8	4	9	3	3	4	3	2
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	10	12	10	2	1	3	0	1	1	0	0	0
Molops piceus bulgaricus Maran 1938	Mol.pic	0	0	0	0	0	0	0	0	0	0	0	0
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	0	0	0	0	0	0	0	0	0	0
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	0	0	0	0
Calathus fuscipes (Goeze 1777)	Cal.fus	1	0	0	6	1	2	0	1	2	0	0	1
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	0	0	0	1	0	0	0	0	0	0	0	0
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	0	1	0	1	0	0	51	1	1	13	2	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	2	0	8	2	2	45	8	28	5	8	14
Synuchus vivalis (Illiger 1798)	Syn.viv	1	1	0	0	0	0	0	1	0	0	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	0	0	1	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	0	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	1	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	7	3	1	2	3	1	1	0	1	0	1	1
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	1	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	1	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	3	4	2	2	0	0	0	0	0	1	1
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	1	1	4	1	1	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	1	1
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	1	1	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	1	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	1	2	2	0	0	0	3	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	1	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	R4.1	R4.2	R4.3	R4.4	R4.5	R4.6	R4.7	R4.8	R4.9	R4.10	R4.11	R4.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	1
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	2	1	0	1	2	4	5	1	0	5	0	1
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	1	0	2	2	2	0	18	8	0	2	0	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	1	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	12	4	0	5	3	2	2	1	0	3	2	4
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	1	0	0	0	0	1	0	8
Carabus ullrichi Germar 1824	Car.ull	5	2	12	21	5	3	10	10	16	6	12	21
Carabus hortensis Linnaeus 1758	Car.hor	2	4	6	8	2	0	5	4	8	6	8	1
Carabus convexus Fabricius 1775	Car.con	0	0	0	0	0	0	1	0	0	0	0	0
Carabus intricatus Linnaeus 1761	Car.int	0	1	0	0	0	0	1	0	1	1	0	0
Carabus violaceus Linnaeus 1758	Car.vio	1	4	4	8	4	0	4	6	5	3	5	4
Carabus coriaceus Linnaeus 1758	Car.cor	6	5	10	12	9	3	6	12	23	13	20	3
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	8	6	4	8	5	8	3	3	3	3	4	2
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	0	0	0	0	0	0	0	0	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	1	3	2	0	2	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	3	1	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	2	0	12	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	1	0	0	0	0	0	0	0	0	0	1	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	1	1	0	0	0	2	5	4	8	4	5
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	3	5	1	14	5	2	4	4	3	6
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	3	2	1	1	4	1	0	1	2	1	3	2
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	1	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	2	2	3	1	0	1	1	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	9	6	6	17	3	2	0	1	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	33	25	53	34	42	14	28	2	1	3	1	4
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	1	0	1	0	1	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	21	40	40	17	31	45	28	26	36	67	12	67
Molops piceus bulgaricus Maran 1938	Mol.pic	22	6	9	23	18	2	4	5	5	13	11	6
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	0	1	0	0	1	1	1	0	1	3
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	1	0	0	2	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	1	2	0	1
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	0	0	0	0	0	0	0	0	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	5	0	0	0	2	1	2	2	0	1	2	6
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	190	37	58	61	85	85	113	1	1	3	0	0
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	0	0	0	0	0	0	0	0	0	0	0
Synuchus vivalis (Illiger 1798)	Syn.viv	0	0	1	1	0	0	0	0	0	0	1	2
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	1	1	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	0	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	3	0	1	5	1	0	1	0	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	1	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	0	0	0	1	0	0	0	0	0	0	0	1
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	1	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	3	0	0	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	50	47	30	5	6	5	7	6	1	5	3	4
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	S4.1	S4.2	S4.3	S4.4	S4.5	S4.6	S4.7	S4.8	S4.9	S4.10	S4.11	S4.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	1	1	0	0	2	3	13	3	7	10	1	7
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	0	5	0	0	0	0	11	2	1	3	0	2
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	0	0	0	0	0	0
Notiophilus rufipes Curtis 1829	Not.ruf	2	12	0	0	1	5	6	6	9	5	7	13
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	1	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	1	0	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	4	2	9	1	2	6	1	2	1	2	8	5
Carabus convexus Fabricius 1775	Car.con	0	1	0	1	0	3	0	0	1	0	3	0
Carabus intricatus Linnaeus 1761	Car.int	0	1	0	0	0	1	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	13	5	8	3	0	6	4	6	2	3	12	5
Carabus coriaceus Linnaeus 1758	Car.cor	11	17	13	3	3	0	4	17	11	12	14	3
Carabus montivagus Pallairdi 1825	Car.mon	0	0	1	0	1	0	1	0	0	1	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	2	1	0	1	0	0	0	0	3	5	7	3
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	0	0	0	0	0	0	0	0	0	0	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	0	0	0	0	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	0	0	0	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	0	0	0	0	0	1	0	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	6	3	3	0	2	3	1	3	2	2	5	1
Myas chalybaeus (Palliardi 1825)	Mya.cha	17	8	34	9	39	59	1	14	2	7	12	40
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	0	0	0	0	0	0	0	1	0	1	0	4
Pterostichus melas (Creutzer 1799)	Pte.mls	12	2	3	2	6	4	0	1	1	1	5	1
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	17	14	20	9	12	3	18	34	38	21	27	27
Molops piceus bulgaricus Maran 1938	Mol.pic	0	2	1	1	1	0	9	11	14	3	6	3
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	8	7	12	3	1	1	15	7	9	5	0	6
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	2	0	2	1	0	0	0	0	1	1
Milops alpestris centralis Mlynar 1977	Mil.alp	0	1	0	1	0	0	0	0	0	1	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	4	0	1	1	4	2	2	2	4	5	1	5
Calathus fuscipes (Goeze 1777)	Cal.fus	7	10	118	40	24	76	1	5	3	1	4	25
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	1	0	1
Laemostenus terricola (Herbst 1783)	Lae.ter	5	9	23	7	21	42	2	9	5	1	3	5
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	0	0	0	0	0	0	0	0	1	0	0	1
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	0	0	0	0	0	0	0	0	0	0	1
Synuchus vivalis (Illiger 1798)	Syn.viv	1	1	0	0	1	0	0	1	0	1	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	1	0	0	0	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	0	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	0	0	0	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	0	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	0	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	1	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	0	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	0	1	0	0	0	0	0	2	0	0	0	1
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	1
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	167	151	36	4	34	31	195	559	178	142	143	580
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	1	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Species name	Code	U4.1	U4.2	U4.3	U4.4	U4.5	U4.6	U4.7	U4.8	U4.9	U4.10	U4.11	U4.12
Cicindela campestris Linnaeus 1758	Cic.cam	0	0	0	0	0	0	0	0	0	0	0	0
Leistus rufomarginatus (Duftshmid 1812)	Lei.ruf	10	3	10	2	4	5	1	1	1	1	6	7
Leistus ferrugineus (Linnaeus 1758)	Lei.fer	0	0	0	0	0	0	0	0	0	0	0	0
Nebria brevicollis (Fabricius 1792)	Neb.bre	1	1	2	1	0	0	0	0	0	1	2	0
Notiophilus palustris (Duftshmid 1812)	Not.pal	0	0	0	0	0	0	4	2	1	2	1	2
Notiophilus rufipes Curtis 1829	Not.ruf	3	5	0	6	1	0	0	2	3	3	2	4
Calosoma sycophanta (Linnaeus 1758)	Cma.syc	0	0	0	0	0	0	0	0	0	0	0	0
Calosoma inquisitor (Linnaeus 1758)	Cma.inq	0	0	0	0	0	0	0	1	0	0	0	0
Carabus ullrichi Germar 1824	Car.ull	0	0	0	0	0	0	0	0	0	0	0	0
Carabus hortensis Linnaeus 1758	Car.hor	0	0	0	0	0	0	0	0	0	0	0	0
Carabus convexus Fabricius 1775	Car.con	0	0	0	0	0	0	0	0	0	0	0	0
Carabus intricatus Linnaeus 1761	Car.int	0	0	0	0	0	0	0	0	0	0	0	0
Carabus violaceus Linnaeus 1758	Car.vio	20	14	34	23	14	23	16	16	21	26	25	36
Carabus coriaceus Linnaeus 1758	Car.cor	4	1	8	9	5	7	3	10	5	5	5	12
Carabus montivagus Pallairdi 1825	Car.mon	0	0	0	0	0	0	0	0	0	0	0	0
Cychrus semigranosus Pallairdi 1825	Cyc.sem	0	0	0	0	0	0	0	0	0	0	0	0
Loricera pilicornis (Fabricius 1775)	Lor.pil	0	0	0	0	0	0	0	0	0	0	0	0
Clivina fossor (Linnaeus 1758)	Cli.fos	0	0	0	0	0	0	0	0	0	0	0	0
Trechus quadristriatus (Schrank 1781)	Tre.qua	1	0	0	1	1	0	1	2	5	1	0	0
Trechus obtusus (Erichson 1837)	Tre.obt	0	0	0	0	0	0	0	0	0	0	0	0
Asaphidion flavipes (Linnaeus 1761)	Asa.fla	0	1	0	0	0	0	1	0	0	0	0	0
Bembidion lampros (Herbst 1784)	Bem.lam	1	0	0	0	0	0	0	0	0	0	0	0
Bembidion tetracolum Say 1823	Bem.tet	0	0	0	0	0	0	0	0	0	0	0	0
Patrobus atrorufus (Stroem 1768)	Pat.atr	0	0	0	0	0	0	0	1	0	1	0	0
Stomis pumicatus (Panzer 1796)	Sto.pum	0	0	0	0	0	0	0	0	0	0	0	0
Xenion ignitum (Kraatz 1875)	Xen.ign	0	0	0	0	0	0	0	0	0	0	0	0
Myas chalybaeus (Palliardi 1825)	Mya.cha	0	0	0	0	0	0	0	0	0	0	0	0
Poecilus cupreus (Linnaeus 1758)	Poe.cup	0	0	1	0	0	0	0	0	0	0	0	0
Pterostichus niger (Schaller 1783)	Pte.nig	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus anthracinus (Illiger 1798)	Pte.ant	0	0	0	0	0	0	0	0	0	0	0	0
Pterositchus nigrita (Paykull 1790)	Pte.nta	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus strenuus (Panzer 1797)	Pte.str	0	1	0	1	0	0	2	0	0	1	0	0
Pterostichus ovoideus (Sturm 1824)	Pte.ovo	1	0	0	0	0	0	0	0	0	0	0	0
Pterostichus oblongopunctatus (Fabricius 1787)	Pte.obl	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus melanarius (Illiger 1798)	Pte.mln	5	9	5	9	5	1	1	1	3	4	2	5
Pterostichus melas (Creutzer 1799)	Pte.mls	0	0	0	0	0	0	0	0	0	0	0	0
Pterostichus brucki Schaum 1859	Pte.bru	0	0	0	0	0	0	0	0	0	0	0	0
Abax carinatus (Duftschmid 1812)	Aba.car	20	31	26	18	18	5	26	19	26	24	17	34
Molops piceus bulgaricus Maran 1938	Mol.pic	0	0	0	0	0	0	0	0	0	0	0	0
Molops dilatatus dilatatus Chaudoir 1868	Mol.dil	0	0	0	0	0	0	0	0	0	0	0	0
Molops robustus parallelus Mlynar 1976	Mol.rob	0	0	0	0	0	0	0	0	0	0	0	0
Milops alpestris centralis Mlynar 1977	Mil.alp	0	0	0	0	0	0	0	0	0	0	0	0
Molops rufipes golobardensis Mlynar 1976	Mol.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Tapinopterus kaufmanni (Ganglbauer 1896)	Tap.kau	0	0	0	0	0	0	0	0	0	0	0	0
Calathus fuscipes (Goeze 1777)	Cal.fus	0	0	0	0	0	0	0	0	0	0	0	0
Calathus melanocephalus (Linnaeus 1758)	Cal.mel	0	0	0	0	0	0	0	0	0	0	0	0
Laemostenus terricola (Herbst 1783)	Lae.ter	7	4	8	0	3	7	4	4	7	2	3	10
Agonum viduum (Panzer 1797)	Ago.vid	0	0	0	0	0	0	0	0	0	0	0	0
Platynus assimils (Paykull 1790)	Pla.ass	39	9	16	25	6	4	1	1	7	15	15	7
Platynus scrobiculatus (Fabricius 1801)	Pla.scr	0	0	0	0	0	0	0	0	0	0	0	0
Anchomenus dorsalis (Pontoppidan 1763)	Anc.dor	0	1	0	0	0	0	0	0	0	0	0	0
Synuchus vivalis (Illiger 1798)	Syn.viv	1	0	0	4	0	2	0	4	5	6	0	0
Platyderus rufus (Duftschmid 1812)	Ptd.ruf	0	0	0	0	0	0	0	0	0	0	0	0
Amara aenea (DeGeer 1774)	Ama.aen	0	0	0	0	1	0	0	0	0	0	0	0
Amara convexior Stephens 1828	Ama.con	0	0	0	0	0	0	0	1	0	0	0	0
Amara eurynota (Panzer 1797)	Ama.eur	0	0	0	0	0	0	0	0	0	0	0	0
Amara familiaris (Duftschmid 1812)	Ama.fam	0	0	0	0	0	0	0	0	0	0	0	0
Amara ovata (Fabricius 1792)	Ama.ova	0	0	0	0	0	0	0	0	1	1	0	0
Amara saphyrea Dejean 1828	Ama.sap	0	0	0	0	0	0	0	0	0	0	0	0
Amara similata (Gyllenhal 1810)	Ama.sim	0	0	0	0	0	0	0	0	0	0	0	0
Amara majuscula (Chaudoir 1850)	Ama.maj	0	0	1	0	0	0	0	0	0	0	0	0
Zabrus tenebrioides (Goeze 1777)	Zab.ten	0	0	0	0	0	0	0	0	0	0	0	0
Scybalicus oblongiusculus (Dejean 1829)	Scy.obl	1	0	0	0	0	0	0	0	0	0	0	0
Gynandromorphus etruscus (Quensel 1806)	Gyn.etr	0	0	0	0	0	0	0	0	0	0	0	0
Diachromus germanus (Linnaeus 1758)	Dia.ger	1	0	0	0	0	0	0	0	0	0	0	0
Acupalpus flavicollis (Sturm 1825)	Acu.fla	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus rufipes (DeGeer 1774)	Har.ruf	1	1	2	2	1	0	0	0	1	3	1	2
Harpalus rubripes (Duftschmid 1812)	Har.rub	0	0	0	0	0	0	1	0	0	0	0	0
Harpalus atratus Latreille 1804	Har.atr	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus quadripunctatus Dejean 1829	Har.qua	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus latus (Linnaeus 1758)	Har.lat	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus luteicornis (Duftschmid 1812)	Har.lut	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus cupreus fastuosus Faldermann 1836	Har.cup	0	0	0	0	0	0	0	0	0	0	0	0
Harpalus caspius (Steven 1806)	Har.cas	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus nitidulus Stephens 1828	Oph.nit	0	0	1	1	0	0	0	0	2	0	0	0
Ophonus rufibarbis (Fabricius 1792)	Oph.rba	0	0	0	0	0	0	0	0	0	0	1	0
Ophonus melletti (Heer 1837)	Oph.mel	0	0	0	0	0	0	0	0	0	0	0	0
Ophonus diffinis (Dejean 1829)	Oph.dif	0	0	0	0	0	0	0	0	0	0	0	0
Panagaeus bipustulatus (Fabricius 1775)	Pan.bip	0	0	0	0	0	0	0	0	0	0	0	0
Badister bullatus (Schrank 1798)	Bad.bul	0	0	0	0	0	0	0	0	0	0	0	0
Lebia humeralis Dejean 1825	Leb.hum	0	0	0	0	0	0	0	0	0	0	0	0
Dromius linearis (Olivier 1795)	Dro.lin	0	0	0	0	0	0	0	0	0	0	0	0
Syntomus obscuroguttatus (Duftschmid 1812)	Snt.obs	0	0	0	0	0	0	0	0	0	0	0	0
Aptinus bombarda (Illiger 1800)	Apt.bom	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus crepitans (Linnaeus 1758)	Bra.cre	0	0	0	0	0	0	0	0	0	0	0	0
Brachinus explodens Duftschmid 1812	Bra.exp	0	0	0	0	0	0	0	0	0	0	0	0

The Ground-Beetle (Coleoptera: Carabidae) Fauna of Sofia, Bulgaria: a Checklist

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Abstract

The presented checklist of the ground-beetles inhabiting the area of the city of Sofia lists 237 species (belonging to 65 genera and 26 tribes) of the family Carabidae (Coleoptera). Besides the old records, new data on 61 species are provided. Nineteen species are newly added to the list of the fauna of the city of Sofia.

Key words

Ground-beetles, Carabidae, fauna, urban, Sofia, Bulgaria.

INTRODUCTION

Despite the fact that the ground-beetle fauna of Bulgaria is considered relatively well known (Guéorguiev & Guéorguiev, 1995; Guéorguiev & Muilwijk, 2000), little or no attention has been paid to the fauna of great cities. This refers also to the fauna of the major city in Bulgaria – its capital, the city of Sofia. Until now, no special investigation on the carabid beetle fauna of this city has been carried out, and all the available data concerning the ground-beetles of the city of Sofia are scattered through the more general taxonomic, faunistic and biogeographic works of Bulgarian and foreign coleopterists.

However, the entomological literature published at the beginning of the 20th century (from 1904 until 1912) and concerning the ground-beetles in our region, reveals a total of 267 individual records from the territory of the city of Sofia. Such records appear to be much scantier in the subsequent literature. Having summarized much data of previous workers, the most productive author from this period (in terms of recorded species) is Rambousek (1912) who, in the framework of a general overwiev of the Bulgarian beetles, provided data on 106 species of ground-beetles inhabiting Sofia. The general lack of focused interest in inventoring the carabid beetles inhabiting the city of Sofia may be demonstrated by the fact that all available records, dealing with the carabid beetle fauna of the city, dating from the second half of the 20th century are only 44, and are published in works not dealing directly with the fauna of the city.

In 1998, GLOBENET – an international initiative primarily focusing on the monitoring of human-related landscape changes (e. g. Niemelä & Kotze, 2000; Niemelä *et al.*, 2002) – was launched and the two-year intensive sampling programme within four parks in Sofia yielded new faunistic data on 62 ground-beetle species.

The aim of the present paper is to summarize all the previously available faunistic data, adding the newly gathered as well, in order to present an up-to-date checklist providing a baseline for future research in the field of urban faunistics of the family Carabidae.

MATERIALS AND METHODS

At the beginning of the 20th century, the outline of the city of Sofia fitted almost perfectly into a circle with a radius of 1 km. Presently, the urbanized area of the city fits in a circle with a radius of at least 10 kilometers. In the present paper the boundaries of the city of Sofia are defined in a slightly conservative manner – only those parts of the city that fall within the ring-road around Sofia are considered as an integral part of the city. Bearing in mind the dynamic nature of the city and the inaccuracy of the old faunistic records, we assigned these records to the fauna of the city only in two cases: 1) if they stated explicitly “Sofia” and 2) if they are located within the present borders of the city (regardless of the fact that sometimes this was not true at the moment of recording). However, we have omitted from the available records in Rambousek (1912) those stating “Sofia: Sv. Ivan” and “Sofia: German” since the former refers to a monastery situated at the foothills of Lozenska Mt., and the latter to a village located well beyond the defined outline of the city (for other omitted, but otherwise valuable, records see “Discussion”). The new data, resulting from our own sampling activities (using twelve randomly scattered pitfall traps of 9 cm diameter, 11.5 cm depth, and partly filled with a 3-4% solution of formaldehyde in commercial vinegar, that were emptied monthly from 07.V to 22.X in 1998, and from 01.IV to 26.X in 1999), are provided in the list under the following abbreviations: U1 denotes the sampling site at “Knyaz Borisovata gradina”, U2 – “Zapaden park”, U3 – “Severen park”, and U4 stands for “Loven park” (for a detailed description of the collecting scheme and the sampling sites see Penev *et al.*, this volume). The ground-beetle species are ordered according to the adopted nomenclature (after Kryzhanovskij *et al.*, 1995).

RESULTS

In the following checklist of the ground-beetles of the city of Sofia, the valid taxon name of each record is followed by the corresponding references (refer to “Materials and methods” for abbreviations).

Cicindelini
Genus *Cicindela* Linnaeus 1758
Cicindela sylvicola Latreille et Dejean 1822 – Rambousek, 1912
Cicindela hybrida hybrida Linnaeus 1758 – Ioakimov, 1904; Rambousek, 1912
Cicindela campestris campestris Linnaeus 1758 – Apfelbeck, 1904; Kantardjieva, 1928
Cicindela trisignata hellenica (Cassola 1973) – Ioakimov, 1904

Omophronini
Genus *Omophron* Latreille 1802
Omophron limbatus (Fabricius 1776) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912

Carabini
Genus *Calosoma* F. Weber 1801
Calosoma inquisitor (Linnaeus 1758) – Buresch & Kantardjieva, 1928; New data: U4
Genus *Carabus* Linnaeus 1758
Carabus (Eucarabus) ullrichi fastuosus Palliardi 1825 – Rambousek, 1912
Carabus (Autocarabus) cancellatus intermedius Dejean 1826 – Nedelkov, 1909; Rambousek, 1912
Carabus (Carabus) granulatus Linnaeus 1758 – Ioakimov, 1904
Carabus (Trachycarabus) scabriusculus Olivier 1795 – Netolitzky, 1912; Georgov, 1915; Buresch & Kantardjieva, 1928; Hieke & Wrase, 1988
Carabus (Oreocarabus) hortensis Linnaeus 1758 – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912
Carabus (Tomocarabus) convexus gracilior Gehin 1885 – Netolitzky, 1912; Hieke & Wrase, 1988; New data: U2
Carabus (Chaetocarabus) intricatus Linnaeus 1761 – Netolitzky, 1912; Buresch & Kantardjieva, 1928; Hieke & Wrase, 1988
Carabus (Megodontus) violaceus azurescens Dejean 1826 – Breuning, 1928; Štěrba, 1945; Hieke & Wrase, 1988; New data: U1, U2, U4
Carabus (Procrustes) coriaceus cerisyi Dejean 1826 – Buresch & Kantardjieva, 1928; Hieke & Wrase, 1988; New data: U1, U2, U3, U4
Carabus (Procerus) gigas (Creutzer 1799) – Nedelkov, 1909; Rambousek, 1912

Cychrini
Genus *Cychrus* Fabricius 1774
Cychrus semigranosus balcanicus Hoffgarten 1881 – Rambousek, 1912

Nebriini
Genus *Nebria* Latreille 1825
Nebria brevicollis (Fabricius 1792) – Ioakimov, 1904; New data: U1, U2, U3, U4
Genus *Leistus* Frölich 1799
Leistus rufomarginatus (Duftschmid 1812) – New data: U1, U2, U3, U4
Leistus ferrugineus (Linnaeus 1758) – New data: U3
Genus *Loricera* Latreille 1802
Loricera pilicornis (Fabricius 1775) – New data: U1

Notiophilini

Genus *Notiophilus* Dumeril 1806

Notiophilus aquaticus (Linnaeus 1758) – Nedelkov, 1909; Rambousek, 1912

Notiophilus palustris (Duftschmid 1812) – Nedelkov, 1909; Rambousek, 1912; New data: U1, U3, U4

Notiophilus laticollis Chaudoir 1850 – Netolitzky, 1912

Notiophilus rufipes Curtis 1829 – Ioakimov, 1904; New data: U1, U2, U3, U4

Notiophilus biguttatus (Fabricius 1779) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912

Elaphrini

Genus *Elaphrus* Fabricius 1775

Elaphrus (Neoelaphrus) uliginosus Fabricius 1775 – Nedelkov, 1909; Rambousek, 1912

Elaphrus (Elaphroterus) aureus P. Müller 1821 – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912

Scaritini

Genus *Scarites* Fabricius 1775

Scarites (Scarites) terricola Bonelli 1813 – Ioakimov, 1904

Clivinini

Genus *Clivina* Latreille 1802

Clivina fossor (Linnaeus 1758) – New data: U2, U3

Dyschiriini

Genus *Dyschirius* Bonelli 1810

Dyschirius (Dyschirius) latipennis Seidlitz 1867 – Rambousek, 1912

Dyschirius (Dyschirioides) importunus (Schaum 1857) – Ioakimov, 1904

Dyschirius (Dyschirioides) aeneus Dejean 1825 – Vassilev, 1992

Dyschirius (Dyschirioides) nitidus Dejean 1825 – Rambousek, 1912; Apfelbeck, 1904

Dyschirius (Dyschirioides) pusillus Dejean 1825 – Lemos-Pereira, 1983

Trechini

Genus *Perileptus* Schaum 1860

Perileptus areolatus (Creutzer 1799) – Rambousek, 1912

Genus *Trechus* Clairville 1806

Trechus quadristriatus (Schrank 1781) – Nedelkov, 1909; Rambousek, 1912; Netolitzky, 1912; New data: U1, U2, U3, U4

Trechus obtusus (Erichson 1837) – New data: U2

Trechus subnotatus Dejean 1831 – Netolitzky, 1912; Jeannel, 1927

Tachyini

Genus *Tachys* Stephens 1829

Tachys (Paratachys) bistriatus (Duftschmid 1812) – Ioakimov, 1904; Rambousek, 1912

Tachys (Paratachys) micros (Fischer von Waldheim 1828) – Rambousek, 1912

Genus *Elaphropus* Motschulsky 1839
Elaphropus (Tachyura) quadrisignatus (Duftschmid 1812) – Netolitzky, 1912
Elaphropus (Tachyura) diabrachys bisbimaculatus (Chevrolat 1860) – Rambousek, 1912

Bembidiini
Genus *Asaphidion* Gozis 1886
Asaphidion pallipes (Duftschmid 1812) – Rambousek, 1912
Asaphidion cyanicorne (Pandelle 1867) – Vassilev, 1988
Asaphidion flavipes (Linnaeus 1761) – Rambousek, 1912; Netolitzky, 1912; New data: U1, U2, U3, U4
Genus *Bembidion* Latreille 1802
Bembidion (Odontium) striatum (Fabricius 1792) – Netolitzky, 1918
Bembidion (Bracteon) argenteolum (Ahrens 1812) – Ioakimov, 1904
Bembidion (Bracteon) litorale (Olivier 1790) – Apfelbeck, 1904
Bembidion (Eurytrachelus) laticolle (Duftschmid 1812) – Netolitzky, 1912; Netolitzky, 1917
Bembidion (Chlorodium) splendidum Sturm 1825 – Netolitzky, 1912
Bembidion (Metallina) lampros (Herbst 1784) – Ioakimov, 1904; Rambousek, 1912; New data: U1, U2, U3, U4
Bembidion (Princidium) punctulatum Drapiez 1820 – Nedelkov, 1909; Rambousek, 1912
Bembidion (Bembidion) quadripustulatum (Serville 1821) – Ioakimov, 1904
Bembidion (Bembidion) quadrimaculatum (Linnaeus 1761) – Ioakimov, 1904
Bembidion (Leja) articulatum (Panzer 1796) – Rambousek, 1912
Bembidion (Notaphus) varium (Olivier 1795) – Nedelkov, 1909; Rambousek, 1912
Bembidion (Emphanes) tenellum Erichson 1837 – Rambousek, 1912
Bembidion (Synechostictus) elongatum tarsicum Peyron 1858 – Rambousek, 1912
Bembidion (Nepha) tetragrammum illigeri Netolitzky 1914 – Rambousek, 1912
Bembidion (Bembidionetolitzkya) fasciolatum (Duftschmid 1812) – Nedelkov, 1909; Rambousek, 1912
Bembidion (Bembidionetolitzkya) concoeruleum Netolitzky 1943 – Rambousek, 1912; Netolitzky, 1912
Bembidion (Bembidionetolitzkya) tibiale (Duftschmid 1812) – Rambousek, 1912
Bembidion (Bembidionetolitzkya) varicolor (Fabricius 1803) – Ioakimov, 1904; Netolitzky, 1912
Bembidion (Peryphanes) dalmatinum Dejean 1831 – Apfelbeck, 1904; Netolitzky, 1912
Bembidion (Ocydromus) subcostatum javurkovae Fassati 1943 – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912; Netolitzky, 1912; New data: U2, U3
Bembidion (Ocydromus) femoratum Sturm 1825 – Ioakimov, 1904
Bembidion (Ocydromus) andreae bualei Jacquelin du Val 1852 – Ioakimov, 1904; Rambousek, 1912; Netolitzky, 1912
Bembidion (Ocydromus) testaceum Duftschmid 1812 – Netolitzky, 1912
Bembidion (Ocydromus) decorum (Zenker in Panzer 1801) – Rambousek, 1912; Netolitzky, 1912
B*embidion (Ocydromus) modestum* (Fabricius 1801) – Netolitzky, 1912
Bembidion (Euperyphus) fulvipes Sturm 1827 – Ioakimov, 1904

Patrobini
Genus *Patrobus* Dejean 1821
Patrobus atrorufus (Ström 1768) – Kühnelt, 1941; New data: U1, U4

Pterostichini

Genus *Stomis* Clairville 1806

Stomis pumicatus (Panzer 1796) – New data: U1, U2, U3

Genus *Poecilus* Bonelli 1810

Poecilus lepidus (Leske 1785) – Rambousek, 1912

Poecilus cupreus (Linnaeus 1758) – Nedelkov, 1909; Rambousek, 1912; New data: U1, U4

Genus *Pterostichus* Bonelli 1810

Pterostichus (Pedius) inquinatus (Sturm 1824) – Guéorguiev, 1992

Pterostichus (Pedius) longicollis (Duftschmid 1812) – Ioakimov, 1904; Rambousek, 1912

Pterostichus (Phonias) strenuus (Panzer 1797) – New data: U1, U2, U3, U4

Pterostichus (Phonias) ovoideus (Sturm 1824) – New data: U2, U4

Pterostichus (Argutor) cursor (Dejean 1828) – Guéorguiev, 1992

Pterostichus (Bothriopterus) oblongopunctatus (Fabricius 1787) – New data: U1

Pterostichus (Adelosia) macer thessalonicus Schatzmayr 1943 – Ioakimov, 1904

Pterositchus (Melanius) nigrita (Paykull 1790) – Ioakimov, 1904; New data: U2

Pterostichus (Melanius) anthracinus (Illiger 1798) – Ioakimov, 1904; Nedelkov, 1909; New data: U1, U2

Pterostichus (Platysma) niger (Schaller 1783) – Netolitzky, 1912; New data: U2

Pterostichus (Morphnosoma) melanarius bulgaricus Lutschnik 1915 – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912; Netolitzky, 1912; New data: U1, U2, U3, U4

Pterostichus (Feronidius) melas depressus (Dejean 1828) – Ioakimov, 1904; Netolitzky, 1912

Pterostichus incommodus Schaum 1858 – Hieke & Wrase, 1988

Genus *Abax* Bonelli 1810

Abax parallelus (Duftschmid 1812) – Rambousek, 1912

Abax ovalis (Duftschmid 1812) – Guéorguiev & Guéorguiev, 1995

Abax carinatus (Duftschmid 1812) – New data: U1, U2, U3, U4

Genus *Molops* Bonelli 1810

Molops robustus parallelus Mlynař 1977 – Netolitzky, 1912

Platynini

Genus *Agonum* Bonelli 1810

Agonum (Agonum) sexpunctatum (Linnaeus 1758) – Ioakimov, 1904

Agonum (Agonum) viridicupreum (Goeze 1777) – Ioakimov, 1904

Agonum (Agonum) gracilipes (Duftschmid 1812) – Vassilev, 1988

Agonum (Agonum) muelleri (Herbst 1784) – Nedelkov, 1909; Rambousek, 1912

Agonum (Agonum) versutum (Sturm 1824) – Ioakimov, 1904

Agonum (Agonum) viduum (Panzer 1797) – Nedelkov, 1909; Rambousek, 1912; New data: U2

Agonum (Agonum) duftschmidi Schmidt 1994 – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912

Agonum (Agonum) angustatum Dejean 1828 – Schmidt, 1994

Agonum (Europhilus) gracile (Sturm 1824) – Vassilev, 1988

Genus *Platynus* Bonelli 1810

Platynus (Platynus) assimile (Paykull 1790) – Ioakimov, 1904; Rambousek, 1912; New data: U1, U2, U3, U4

Platynus (Platynus) scrobiculatus (Fabricius 1801) – Netolitzky, 1912
Genus *Oxypselaphus* Chaudoir 1843
Oxypselaphus obscurum (Herbst 1784) – Vassilev, 1992
Genus *Anchomenus* Bonelli 1810
Anchomenus dorsalis (Pontoppidan 1763) – Ioakimov, 1904; Nedelkov, 1909; New data: U1, U2, U3, U4
Genus *Synuchus* Gyllenhal 1810
Synuchus (Synuchus) vivalis (Illiger 1798) – Guéorguiev & Guéorguiev, 1995; New data: U3, U4

Sphodrini
Genus *Calathus* Bonelli 1810
Calathus (Calathus) fuscipes (Goeze 1777) – Nedelkov, 1909; Rambousek, 1912; New data: U1, U2, U3
Calathus (Neocalathus) melanocephalus (Linnaeus 1758) – Nedelkov, 1909; New data: U2
Calathus (Neocalathus) ochropterus (Duftschmid 1812) – Hieke & Wrase, 1988
Calathus (Neocalathus) micropterus (Duftschmid 1812) – Ioakimov, 1904
Calathus (Neocalathus) erratus (C. R. Sahlberg 1827) – Nedelkov, 1909; Rambousek, 1912
Calathus (Dolichus) halensis (Schaller 1783) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912
Genus *Sphodrus* Clairville 1806
Sphodrus leucophthalmus (Linnaeus 1758) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912
Genus *Laemostenus* Bonelli 1810
Laemostenus (Pristonychus) terricola punctatus (Dejean 1828) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912; New data: U1, U3, U4

Amarini
Genus *Amara* Bonelli 1810
Amara (Zezea) tricuspidata Dejean 1831 – Nedelkov, 1909; Rambousek, 1912
Amara (Zezea) fulvipes (Serville 1821) – Hieke, 1970; Hieke & Wrase, 1988
Amara (Amara) similata (Gyllenhal 1810) – Nedelkov, 1909
Amara (Amara) ovata (Fabricius 1792) – New data: U1, U4
Amara (Amara) convexior Stephens 1828 – New data: U1, U4
Amara (Amara) communis (Panzer 1797) – Nedelkov, 1909
Amara (Amara) curta Dejean 1828 – Hieke & Wrase, 1988
Amara (Amara) aenea (DeGeer 1774) – Rambousek, 1912; Netolitzky, 1912; New data: U2, U3, U4
Amara (Amara) familiaris (Duftschmid 1812) – Nedelkov, 1909; New data: U1
Amara (Amara) anthobia A. Villa et G. B. Villa 1833 – Rambousek, 1912
Amara (Amara) lucida (Duftschmid 1812) – Ioakimov, 1904
Amara (Amara) tibialis (Paykull 1798) – Hieke & Wrase, 1988
Amara (Celia) bifrons (Gyllenhal 1810) – Hieke & Wrase, 1988
Amara (Celia) brunnea (Gyllenhal 1810) – Ioakimov, 1904
Amara (Celia) sabulosa Serville 1821 – Hieke & Wrase, 1988
Amara (Paracelia) serdicana Apfelbeck 1904 – Nedelkov, 1909; Rambousek 1912

Amara (Bradytus) apricaria (Paykull 1790) – Ioakimov, 1904
Amara (Braditus) majuscula (Chaudoir 1850) – New data: U4
Amara (Bradytus) crenata Dejean 1828 – Hieke & Wrase, 1988
Amara (Bradytus) fulva (O. Müller 1776) – Nedelkov, 1909; Rambousek, 1912
Genus *Zabrus* Clairville 1806
Z*abrus (Zabrus) tenebrioides* (Goeze 1777) – Nedelkov, 1909; Rambousek, 1912; New data: U3
Zabrus (Pelor) balcanicus Heyden 1883 – Drenski *et al.*, 1951
Zabrus (Pelor) spinipes (Fabricius 1798) – Nedelkov, 1909

Harpalini
Genus *Scybalicus* Schaum 1862
Scybalicus oblongiusculus (Dejean 1829) – New data: U4
Genus *Anisodactylus* Dejean 1829
Anisodactylus (Anisodactylus) signatus (Panzer 1797) – Ioakimov, 1904; Rambousek, 1912
Anisodactylus (Anisodactylus) nemorivagus (Duftschmid 1812) – Ioakimov, 1904; Netolitzky, 1912
Anisodactylus (Anisodactylus) binotatus (Fabricius 1787) – Nedelkov, 1909; Rambousek, 1912
Genus *Gynandromorphus* Dejean 1829
Gynandromorphus etruscus (Quensel 1806) – Nedelkov, 1909; Rambousek, 1912
Genus *Diachromus* Erichson 1837
Diachromus germanus (Linnaeus 1758) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912; New data: U4
Genus *Stenolophus* Stephens 1828
Stenolophus (Stenolophus) mixtus (Herbst 1784) – Guéorguiev & Guéorguiev, 1995
Stenolophus (Stenolophus) discophorus Fischer von Waldheim 1823 – Nedelkov, 1909; Rambousek, 1912
Stenolophus (Stenolophus) teutonus (Schrank 1781) – Nedelkov, 1909; Rambousek, 1912
Stenolophus (Stenolophus) abdominalis Gené 1836 – Guéorguiev & Guéorguiev, 1995
Genus *Acupalpus* Latreille 1829
Acupalpus (Acupalpus) meridianus (Linnaeus 1767) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912
Acupalpus (Acupalpus) parvulus (Sturm 1825) – Rambousek, 1912
Acupalpus (Acupalpus) maculatus Schaum 1860 – Rambousek, 1912
Acupalpus (Acupalpus) exiguus (Dejean 1829) – Ioakimov, 1904
Acupalpus (Acupalpus) flavicollis (Sturm 1825) – New data: U1
Genus *Bradycellus* Erichson 1837
B*radycellus (Bradysellus) harpalinus* (Serville 1821) – Ioakimov, 1904
Genus *Ophonus* Dejean 1821
Ophonus (Ophonus) stictus Stephens 1828 – Nedelkov, 1909; Rambousek, 1912
Ophonus (Ophonus) sabulicola ponticus Schauberger 1926 – Nedelkov, 1909
Ophonus (Ophonus) diffinis (Dejean 1829) – New data: U1
Ophonus (Hesperophonus) similis (Dejean 1829) – Rambousek, 1912
Ophonis (Hesperophonus) azureus (Fabricius 1775) – Ioakimov, 1904; Rambousek, 1912

Ophonus (Metophonus) nitidulus Stephens 1828 – Nedelkov, 1909; Rambousek, 1912; New data: U1, U2, U3, U4
Ophonus (Metophonus) cordatus (Duftschmid 1812) – Vassilev, 1992
Ophonus (Metophonus) rupicola (Sturm 1818) – Ioakimov, 1904
Ophonus (Metophonus) rufibarbis (Fabricius 1792) – Rambousek, 1912; New data: U1, U2, U3, U4
Ophonus (Metophonus) melleti (Heer 1837) – New data: U3
Genus *Harpalus* Latreille 1802
Harpalus cephalotes (Fairmaire et Laboulbene 1854) – Rambousek, 1912
Harpalus rufipes (DeGeer 1774) – Rambousek, 1912; Netolitzky, 1912; New data: U1, U2, U3, U4
Harpalus griseus (Panzer 1797) – Apfelbeck, 1904; Hieke & Wrase, 1988
Harpalus calceatus (Duftschmid 1812) – Nedelkov 1909; Rambousek, 1912
Harpalus hospes Sturm 1818 – Rambousek, 1912
Harpalus affinis (Schrank 1781) – Nedelkov, 1909; Rambousek, 1912; Netolitzky, 1912
Harpalus oblitus Dejean 1829 – Rambousek, 1912
Harpalus saxicola Dejean 1829 – Rambousek, 1912
Harpalus distinguendus (Duftschmid 1812) – Ioakimov, 1904; Rambousek, 1912
Harpalus cupreus fastuosus Faldermann 1835 – Rambousek, 1912; New data: U1
Harpalus smaragdinus (Duftschmid 1812) – Rambousek, 1912
Harpalus caspius (Steven 1806) – Hieke & Wrase, 1988; New data: U3
Harpalus dimidiatus (Rossi 1790) – Nedelkov, 1909; Rambousek, 1912
Harpalus rubripes (Duftschmid 1812) – Hieke & Wrase, 1988; New data: U2, U4
Harpalus latus (Linnaeus 1758) – Ioakimov, 1904; New data: U1
Harpalus luteicornis (Duftschmid 1812) – Nedelkov, 1909; Rambousek, 1912; New data: U1, U3
Harpalus albanicus Reitter 1900 – Hieke & Wrase, 1988
Harpalus tardus (Panzer 1797) – Rambousek, 1912
Harpalus serripes (Quensel 1806) – Hieke & Wrase, 1988
Harpalus autumnalis (Duftschmid 1812) – Rambousek, 1912
Harpalus atratus Latreille 1804 – New data: U1
Harpalus neglectus Serville 1821 – Guéorguiev & Guéorguiev, 1995
Harpalus pygmaeus Dejean 1829 – Rambousek, 1912
Harpalus anxius (Duftschmid 1812) – Netolitzky, 1912
Harpalus taciturnus Dejean 1829 – Rambousek, 1912
Harpalus servus (Duftschmid 1812) – Nedelkov, 1909; Rambousek, 1912
Harpalus pumilus (Sturm 1818) – Hieke & Wrase, 1988
Harpalus picipennis Duftschmid 1812 – Rambousek, 1912
Harpalus flavescens (Piller et Mitterpacher 1783) – Guéorguiev & Guéorguiev, 1995
Genus *Parophonus* Ganglbauer 1892
Parophonus (Parophonus) maculicornis (Duftschmid 1812) – Nedelkov, 1909; Rambousek, 1912
Parophonus (Tachyophonus) mendax (Rossi 1790) – Rambousek, 1912
Genus *Carterus* Dejean 1829
Carterus (Pristocarterus) angustipennis Chaudoir 1852 – Rambousek, 1912

Genus *Dixus* Billberg 1820
Dixus clypeatus (Rossi 1790) – Guéorguiev & Guéorguiev, 1995

Callistini
Genus *Dinodes* Bonelli 1810
Dinodes decipiens (Dufour 1820) – Nedelkov, 1909; Rambousek, 1912
Genus *Chlaenius* Bonelli 1810
Chlaenius (Trichochlaenius) aenocephalus Dejean 1829 – Hieke & Wrase, 1988
Chlaenius (Claenites) spoliatus (Rossi 1790) – Guéorguiev & Guéorguiev, 1995
Chlaenius (Chlaenius) festivus (Panzer 1796) – Ioakimov, 1904
Chlaenius (Chlaeniellus) tristis (Schaller 1783) – Rambousek, 1912
Chlaenius (Chlaeniellus) nigricornis (Fabricius 1787) – Ioakimov, 1904; Rambousek, 1912;
Chlaenius (Chlaeniellus) flavipes Menetries 1832 – Guéorguiev & Guéorguiev, 1995
Chlaenius (Chlaeniellus) vestitus (Paykull 1790) – Ioakimov, 1904; Nedelkov 1909; Rambousek 1912
Chlaenius (Agostenus) sulcicollis (Paykull 1798) – Ioakimov, 1904

Oodini
Genus *Oodes* Bonelli 1810
Oodes (Oodes) gracilis A. Villa et G. B. Villa 1833 – Vassilev, 1992

Licinini
Genus *Badister* Clairville 1806
Badister (Badister) bullatus (Schrank 1798) – Ioakimov, 1904; New data: U2
Badister (Badister) unipustulatus Bonelli 1813 – Nedelkov, 1909; Rambousek, 1912
Badister (Trimorphus) sodalis (Duftschmid 1812) – Rambousek, 1912
Genus *Licinus* Latreille 1802
Licinus (Licinus) cassideus (Fabricius 1792) – Rambousek, 1912

Panagaeini
Genus *Panagaeus* Latreille 1802
Panagaeus cruxmajor (Linnaeus 1758) – Ioakimov, 1904
Panagaeus bipustulatus (Fabricius 1775) – New data: U2

Lebiini
Genus *Lebia* Latreille 1802
Lebia (Lamprias) cyanocephala (Linnaeus 1758) – Ioakimov, 1904; Nedelkov, 1909
Lebia (Lamprias) chlorocephala (Hoffmann 1803) – Nedelkov, 1909; Rambousek, 1912
Lebia (Lebia) humeralis Dejean 1825 – Rambousek, 1912; New data: U3
Lebia (Lebia) cruxminor (Linnaeus 1758) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912
Lebia (Lebia) trimaculata (Villers 1789) – Guéorguiev & Guéorguiev, 1995
Lebia (Lebia) scapularis (Fourcroy 1785) – Nedelkov, 1909
Genus *Demetrias* Bonelli 1810
Demetrias (Demetrias) atricapillus (Linnaeus 1758) – Ioakimov, 1904

Genus *Dromius* Bonelli 1810
Dromius (Dromius) fenestratus (Fabricius 1794) – Nedelkov, 1909; Rambousek, 1912
Dromius (Dromius) quadrimaculatus (Linnaeus 1758) – Rambousek, 1912
Genus *Paradromius* Fowler 1886
Paradromius (Manodromius) linearis (Olivier 1795) – Rambousek, 1912; New data: U3
Genus *Calodromius* Reitter 1905
Calodromius spilotus (Illiger 1798) – Rambousek, 1912
Genus *Philorhizus* Hope 1838
Phylorhizus (Philorhizus) notatus (Stephens 1827) – Netolitzky, 1912
Genus *Lionychus* Wissmann 1846
Lionychus quadrillum (Duftschmid 1812) – Nedelkov, 1909; Rambousek, 1912; Netolitzky, 1912
Genus *Microlestes* Schmidt-Göbel 1846
Microlestes plagiatus (Duftschmid 1812) – Ioakimov, 1904
Microlestes maurus (Sturm 1827) – Ioakimov, 1904
Microlestes fissuralis Reitter 1901 – Vassilev, 1992
Genus *Syntomus* Hope 1838
Syntomus obscuroguttatus (Duftschmid 1812) – Ioakimov, 1904; Rambousek, 1912; New data: U1, U2, U3
Genus *Cymindis* Latreille 1806
Cymindis (Cymindis) humeralis (Fourcroy 1785) – Hieke & Wrase, 1988;
Cymindis (Cymindis) lineata (Quensel 1806) – Hieke & Wrase, 1988;

Zuphiini
Genus *Polystichus* Bonelli 1809
Polystichus connexus (Fourcroy 1785) – Nedelkov, 1909; Rambousek 1912

Brachinini
Genus *Brachinus* F. Weber 1801
Brachynus (Brachunus) crepitans (Linnaeus 1758) – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912; New data: U3
Brachynus (Brachunus) psophia Serville 1821 – Rambousek, 1912
Brachynus (Brachunus) nigricornis Gebler 1829 – Guéorguiev & Guéorguiev, 1995
Brachynus (Brachunus) explodens Duftschmid 1812 – Ioakimov, 1904; Nedelkov, 1909; Rambousek, 1912; New data: U1

DISCUSSION

237 species are recorded from the territory of the city of Sofia so far. These species belong to 65 genera and 26 tribes. According to Guéorguiev & Guéorguiev (1995), two of the records (i.e. *Bembidion fulvipes* and *Amara brunea*) should be considered with caution (since these are most probably based on misidentification, and should be excluded from the list of Bulgarian Carabidae until new evidence becomes available), but are included in the list for the sake of completeness.

A striking peculiarity of the fauna of the city of Sofia is its relatively high richness – the territory of the city (22 989.8 ha, after Kovachev, 2001) is only about 0.2% of the territory of the whole country (11 091 200 ha), but it harbors about 30% of the entire Bulgarian fauna. This high species-richness may be interpreted as a result of the diverse and patchy landscape in the region of the city. But since the temporal dynamics of the fauna in the context of the relatively well-documented urban development of the city is extremely poorly studied, this observation (i. e. the high number of species relative to area) could also be an artifact resulting from the insufficient research activities through time and space. So, for example the highest numbers of faunistic records are concentrated mainly during the period 1904-1912 – shortly before the intensive growth pulse of the city of Sofia, when for a period of 14 years (between 1920 and 1934) the population of the city almost doubled from 154 000 to about 287 000 inhabitants (Kovachev, 2001). During this high growth-process of the city structures, many of the previously recorded ground-beetle species might have declined or even become extinct, but the lack of special subsequent faunistic investigations do not permit very exact statements on this topic. Fortunately, in one of the works (Ioakimov, 1904), the author has made some scarce notes about the commonness of particular species in the investigated area, but without specifying the exact localities at which the observations were made (some of the localities were undoubtedly identified as pertaining to the area of the city of Sofia, while others were not closer described – e. g. "situated S, NE, NW, W and SW of Sofia" (Ioakimov, 1904)). For example, his records of *Calosoma sycophanta*, *Carabus convexus*, *Carabus scabriusculus*, *Carabus coriaceus*, *Trechus quadristriatus*, *Bembidion decorum*, *Poecilus cupreus*, *Pterostichus niger*, *Calathus fuscipes*, *Calathus melanocephalus*, *Amara aenea*, *Pseudophonus rufipes*, *Harpalus affinis* and *Harpalus rubripes* come without exact localities (designated with "everywhere"; for *C. convexus* – "here and there"), and while not acknowledged as valid records in the previous section, they contain valuable information about the past status of these species. According to the same author, *Carabus ullrichi* and *Clivina fossor* were found "around Sofia", so these records were also not included in the present list since they also failed to fulfil condition 1) defined in "Materials and methods". However, Ioakimov (1904) has published a further, very interesting record – that of *Carabus granulatus* – from one of the present sampling sites, situated in one of the greatest and oldest parks in Sofia ("Borissovata gradina"). This record has not been subsequently confirmed, and our two-year sampling program in the park "Borissovata gradina" was also not successful in capturing this species – so we may hypothesize that *Carabus granulatus* has disappeared from the fauna of the city of Sofia. Other species that are most likely extinct and no longer inhabit the area of the city are the forest species *Carabus (Procerus) gigas*, *Cychrus semigranosus balcanicus* and *Molops robustus parallelus*.

In his work from 1912, Rambousek has also mentioned *Omophron limbatum*, *Tachys bistriatus*, *Agonum duftschmidi*, *Anisodactylus signatus*, *Harpalus cephalotes*, *Ophonus similis*, *Ophonus rufibarbis*, *Pseudophonus calceatus*, *Harpalus smaragdinus*, and *Brachinus psophia* from the park "Borissovata gradina". The first of the mentioned species was found only at the beginning of the 20th century, and bearing in mind its preferences for riverside habitats, it seems most likely that this species has gone extinct in the territory of Sofia along with the canalizing of the small rivers that run through the city. Amongst all the rest of these species, only the presence of *O. rufibarbis* was confirmed in the present study, while some of the others, being associated with open habitats, are likely to be found in the future.

Another interesting example is *Nebria brevicollis*, which was recorded only by Ioakimov (1904), and was presumably relatively rare in the early 1900s, but the new sampling results clearly show that this species is very abundant at all the sampling sites within the city parks. The same refers to *Leistus rufomarginatus* which, together with *N. brevicollis*, was found to be a dominant species in the urban parks of Sofia but was not recorded until now. Besides such generalist species, urban parks can also support the existence of some rare species. This is the case of the species *Scybalicus oblongiusculus*, which was previously recorded only from the southern Black Sea coast (e. g. Guéorguiev & Guéorguiev, 1995), and was collected presently in "Loven park". Another rare ground-beetle species hitherto known only from the Black Sea coast and Vitosha Mt. (Guéorguiev & Guéorguiev, 1995) is *Amara majuscula* – this species was newly sampled from "Loven park". The species *Loricera pilicornis*, previously known from Rila Mt. and the West Rhodope Mts. (Guéorguiev & Guéorguiev, 1995), is also considered as rare for the Bulgarian fauna (B. Guéorguiev, pers. comm.), but was regularly sampled in the park "Borissova gradina".

The fact that open habitat types dominate within the city of Sofia (according to Kovachev (2001) only about 1 895 ha, or 8.2% of the total area of the city are still covered with forest-like vegetation) is also reflected by the taxonomic structure of its fauna. Genera represented by the highest numbers of species are: *Harpalus* (29 species), *Bembidion* (26), *Amara* (20), *Pterostichus* (13), *Carabus* (10), *Ophonus* (10), *Agonum* (9), *Chlaenius* (8), *Calathus* (6), *Lebia* (6), *Notiophilus* (5), *Dyschirius* (5), *Cicindela* (4), *Acupalpus* (5), *Brachinus* (4), *Trechus* (3), *Asaphidion* (3), *Anisodactylus* (3), *Stenolophus* (4), *Badister* (3), *Microlestes* (3), and *Zabrus* (3 species). The remaining 42 genera are represented by only 1 or 2 species. The top-ten ranked genera contain mainly open-habitat, generalist or opportunistic species. The only exception is the genus *Carabus* which comprise mainly forest species, but out of 10 formerly recorded species, only the occurrence of three (one of them – *Carabus convexus* – was represented by only one specimen in the two-year catches) was confirmed by the present study. The present investigation confirmed the presence of 42 (about 18%) of the already recorded species in the area of Sofia and has added 19 new records to the fauna of the city – so, from the sampling sites (see "Materials and methods") that cover about 1.8% (or 405.6 ha) of the area of Sofia, about one fifth of the ground beetle species (or 26.4%) inhabiting the city have been recorded.

In comparison to the quite intensively researched carabid fauna of other cities such as, for example, Prague (Veselý, 2002 – 284 registered species), Warsaw (Czechowski, 1982 – 276 species), Berlin (Brandt *et al.*, 1991 – 267 species), and Leipzig (Klausnitzer, 1983 – 103 species), the ground-beetle fauna of Sofia (with the currently known 231 species) ranks fourth. However, if we consider the fact that the research of the urban fauna of Sofia has been heavily neglected, and the well known rule that the regional fauna in Southern Europe generally tend to be more species-rich, it is expected that a considerable number of species remains to be added to the list in the future, despite of the presently added 19.

On the basis of the increasing knowledge on the ecological processes in fragmented landscapes and urban areas (e. g. Halme & Niemelä, 1993; Niemelä, 1999), it may be predicted that many more open-land species from the tribes Amarini and Harpalini may be found to be a part of the city's fauna, and the probable extinction of some large-bodied representatives of the genus *Carabus* (e. g. *Carabus ullrichi*, *Carabus intricatus*, *Carabus hortensis*, and *Carabus (Procerus) gigas*) and some forest specialists may be reasonably suggested (Niemelä *et al.*, 2002).

ACKNOWLEDGEMENTS

I would like to thank Prof. Todor Genov and Dr. Vlada Peneva for encouraging me to write this survey. Thanks are also due to Dr. Borislav Guéorguiev for the invaluable help with gathering the faunistic records from literature sources and for his kind opinion sharing. I would also like to thank Dr. Ivailo Dedov for his help during the field-work, and to Dr. Lyubomir Penev for constructive discussions on several drafts of the manuscript. I also wish to thank Dr. Johan Kotze for correcting my English and adding many valuable comments to a later version of the manuscript, thus helping me to improve the text once again. This work was partly supported by the National Scientific Research Fund (grant No. B-808/1998).

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A Faunistic Investigation of the Ants (Hymenoptera, Formicidae) in the City of Sofia

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Abstract

A two-year-long investigation of the myrmecofauna of five parks in the city of Sofia (Boris Garden, Hunting Park, South Park, West Park and North Park), resulted in the collection of 31 species from 12 genera in 4 subfamilies. Eighteen species were herpetobionts, six were dendrobionts, five were geobionts and two were stratobionts. The zoogeographical structure of the studied ant communities is as follows: Transpalaearctic - 15 species, Amphipalaearctic - 5, Euro-West-Siberian - 4, Euro-Caucasian - 3, South-European - 2 and Mediterranean - 2.

Key words

Formicidae, urban communities, Bulgaria.

INTRODUCTION

Despite the relatively thorough research on the myrmecofauna in Bulgaria, no special studies have been made on urban ant communities. Such investigations become important with growing anthropogenic impact. The purpose of this study was to initiate faunistic and ecological investigations on city myrmecofauna, the results of which would help us clarify ant composition and structure, as well as the degree of anthropogenic effects on urban ecosystems.

Ants were collected during 1998-1999 from five large parks in Sofia using the transsect method and pitfall traps. Pitfall trap material was obtained from the participants of the "Globenet" project (Niemelä *et al.*, 2000) financed by the National Scientific Research Fund.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 417-422

RESULTS

In the faunistic list we have included the systematic position of the species, the established habitats and the dates of collection, brief notes on the biology and the ecology of the species as per reference data and personal observations, as well as their zoogeographical classification.

Subfamily Ponerinae

1. *Ponera coarctata* (Latreille, 1802): South Park - 29.05.1999. A nest under a stone.

A typical geobiont with a reduced number of eye facets. With respect to humidity - a mesophile.

Distribution: Amphipalaearctic.

Subfamily Myrmicinae

2. *Myrmica rubra* (Linnaeus, 1758): Boris Garden - 30.04.1999. A nest under a stone.

Herpetobiont. A common species in anthropogenic habitats. The most hygrophilic species of the genus (Radchenko e*t al.*, 1997).

Distribution: Transpalaearctic.

3. *Myrmica ruginodis* Nylander, 1846: Boris Garden - 05.06.1998, 03.08.1998, 04.09.1998, 12.10.1998, 19.04.1999, 26.04.1999; West Park - 03.09.1998; Hunting Park: - 05.06.1998, 03.07.1998, 10.08.1998, 04.09.1998, 12.10.1998. Nests under stones, in tindery tree stumps, under the bark.

Herpetobiont. The least termophilic species of the genus (Radchenko e*t al.*, 1997).

Distribution: Transpalaearctic.

4. *Myrmica rugulosa* Nylander, 1849: Boris Garden - 12.10.1998, 29.05.1999; North Park - 02.07.1998, 03.08.1998. Nests in the soil.

Herpetobiont. Termophilic species in dry, open habitats. This is the most common species of the genus in Central European anthropogenic habitats (Radchenko e*t al.*, 1997).

Distribution: Euro-West-Siberian species.

5. *Myrmica scabrinodis* Nylander, 1846: Boris Garden - 04.09.1998, 26.04.1999; West Park - 03.09.1998, 19.05.1999; North Park - 02.06.1998. Nests in dead wood and the soil.

Herpetobiont. A mesotermophilic species in damp habitats. The species occurs both in open areas and in forests (Radchenko e*t al.*, 1997).

Distribution: Transpalaearctic.

6. *Myrmica sabuleti* Meinert, 1861: South Park - 29.05.1999. A nest under a stone.

Herpetobiont. A moderately xerotermophilic species which prefers drier and warmer habitats as compared to *M. scabrinodis* (Radchenko e*t al.*, 1997).

Distribution: Euro-West-Siberian species.

7. *Myrmica schencki* Viereck, 1903: Boris Garden - 03.07.1998. A nest in the soil.

Herpetobiont. An inhabitant of dry habitats. This is one of the most termophilic species of the genus in Central Europe (Radchenko e*t al.*, 1997).

Distribution: Transpalaearctic.

8. *Stenamma westwoodi* Westwoodi, 1840: Hunting Park - 10.08.1998, 12.10.1998, 03.08.1999, 03.10.1999. Nests in the soil.

Stratobiont. Mesophilic, preferring darkness, semiblind forest inhabitants.

Distribution: Amphipalaearctic.

9. *Leptothorax (Myrafant) crassispinus* Karawajew,1926: Boris Garden - 04.09.1998, 15.04.1999; South Park - 29.05.1999; West Park - 03.09.1998, 19.05.1999. Nests in dead wood and dead foliage covering.

Herpetobiont. Mesophilic species, typical of deciduous forests.

Distribution: Euro-Caucasian species.

10. *Leptothorax unifasciatus* (Latreille, 1798): Boris Garden - 03.08.1998, 04.09.1998.

Herpetobiont. A mesophilic species. The nests are mainly built in dry tree branches.

Distribution: South-European species.

11. *Tetramorium caespitum* (Linnaeus, 1758): Boris Garden - 28.04.1999, 05.05.1999; South Park - 29.05.1999; West Park - 19.05.1999.

Herpetobiont. It prefers dry soils.

Distribution: Transpalaearctic.

12. *Tetramorium forte* Forel, 1903: West Park - 02.06.1999. A nest under a stone.

Herpetobiont. It prefers open areas with sandy soils.

Distribution: Euro-Caucasian species.

13. *Tetramorium semilaeve* Andre, 1881: West Park, 02.06.1999. A nest under a stone.

Herpetobiont. It builds its nests in the soil under stones in open sites.

Distribution: Mediterranean.

14. *Diplorhoptrum fugax* (Latreille, 1798): Boris Garden - 01.10.1998, 30.04.1999. A small-domed nest.

Geobiont. It occurs as a guest in the nests of a large number of ants where it steals larvae and pupae. It prefers warm, sunny biotops, most frequently in forest outskirts, along river valleys and cultivated landscapes.

Distribution: South-European species.

15. *Myrmecina graminicola* (Latreille, 1802): Boris Garden - 04.09.1998, 12.10.1998; North Park - 22.10.1998.

Stratobiont. A forest inhabitant, its nests are made under the forest canopy, sometimes under stones.

Distribution: Amphipalaearctic. So far known only from southern Bulgaria.

Subfamily Dolichoderinae

16. *Hypoclinea quadripunctata* (Linnaeus, 1771): Boris Garden - 04.09.1998, 30.04.1999, 21.05.1999; Hunting Park - 12.10.1998. Its nests are found under pine tree bark.

Dendrobiont. An inhabitant of low-mountain deciduous forests, a common species in city parks.

Distribution: Amphipalaearctic.

17. *Tapinoma erraticum* (Latreille, 1798): South Park - 29.05.1999. A nest under a stone.

Herpetobiont. It prefers open, sunny and dry places in mixed deciduous and beech forests. It also occurs in cultivated countryside.

Distribution: Euro-West-Siberian species.

Subfamily Formicinae

18. *Camponotus (Camponotus) vagus* (Scopoli, 1763): Boris Garden - 01.06.1999. Nests in dead trees.

Typical dendrobiont. It occurs predominantly in the deciduous forest zone being mainly connected with oak and has also penetrated into the mixed forest zone. Most often it populates open, dry places in meadows, wood-cutting areas, forest outskirts, stony and sunny habitats (Atanasov, 1952).

Distribution: Euro-Caucasian species.

19. *Camponotus (Colobopsis) truncatus* (Scopoli, 1808): Boris Garden - 21.05.1999, 02.06.1999. Nests in trees.

Dendrobiont.

Distribution: Mediterranean.

20. *Camponotus (Myrmentoma) fallax* (Nylander, 1856): Boris Garden - 04.09.1998, 12.10.1998; Hunting Park - 12.10.1998; South Park - 29.05.1999. Nests in trees

Dendrobiont. A rare species in Bulgaria according to Atanassov & Dlusskij (1992).

Distribution: Amphipalaearctic.

21. *Lasius (Lasius) niger* (Linnaeus, 1758): Boris Garden - 05.06.1998, 03.08.1998, 04.09.1998, 12.10.1998, 19.04.1999, 26.04.1999, 30.04.1999; West Park - 02.06.1998, 03.09.1998, 19.05.1999; North Park - 02.06.1998, 02.07.1998, 03.08.1998, 03.09.1998, 12.10.1998; Hunting Park - 10.08.1998; South Park - 29.05.1999. Nests under the bark of the silver pine tree, under stones, under the bark of stumps, within the covering of a copper oak forest.

Herpetobiont. A very common species in open areas, along roads, river valleys, cultivated landscapes and houses.

Distribution: Transpalaearctic.

22. *Lasius (Lasius) alienus* (Foerster, 1850): Boris Garden - 04.09.1998, 25.04.1999, 26.04.1999; West Park - 02.06.1998, 03.09.1998, 19.05.1999; Hunting Park - 05.06.1998, 10.08.1998, 04.09.1998; South Park - 29.05.1999. Nests under stones and under the bark of trees.

Herpetobiont. Widely occurring species at altitudes up to 1500 m above sea level. It inhabits dry places in meadows, lawns and forests.

Distribution: Transpalaearctic.

23. *Lasius (Lasius) brunneus* (Latreille, 1798): Boris Garden - 04.09.1998, 15.04.1999, 30.04.1999; South Park - 29.05.1999; West Park - 19.05.1999. Nests under the bark of dead silver pine trees and spruce *(Picea excelsa)*.

Dendrobiont. It inhabits open, dry sites in mixed forests (Atanassov, 1952).

Distribution: Transpalaearctic.

24. *Lasius (Cautolasius) flavus* (Fabricius, 1781): Boris Garden - 30.04.1999. The nests are with a soil dome.

Geobiont. It occurs in open and damp sites in mixed, beech and coniferous forests.

Distribution: Transpalaearctic.

25. *Lasius (Dendrolasius) fuliginosus* (Latreille, 1798): West Park - 02.06.1998, 11.08.1998; North Park - 02.07.1998, 03.08.1998; Hunting Park - 05.06.1998, 03.07.1998; Boris Garden - 26.04.1999. Nests in deciduous and coniferous trees.

Dendrobiont. It prefers damp habitats.

Distribution: Transpalaearctic.

26. *Lasius (Chthonolasius) affinis* (Schenck, 1852): West Park - 02.06.1999. Nests under the bark of dead birch trees.

Geobiont. It prefers dry, open terrains.

Distribution: Transpalaearctic.

27. *Lasius (Chthonolasius) umbratus* (Nylander, 1846): West Park - 09.07.1999 (1 female).

Geobiont. Its nests are in the soil or in dead wood.

Distribution: Transpalaearctic.

28. *Formica (Serviformica) balcanina* Petrov & Collingwood, 1993: Boris Garden - 03.07.1998, 04.09.1998, 12.10.1998, 26.04.1999, 30.04.1999; West Park - 11.08.1998; South Park - 29.05.1999; West Park - 19.05.1999. Nests under stones.

Herpetobiont. This is the most wide spread species of the family in low, sunny, cultivated landscapes. Its nests are found in sandy soils along roads, forest outskirts and meadows.

Distribution: Euro-West-Siberian species.

29. *Formica (Serviformica) rufibarbis* Fabricius, 1793: Boris Garden - 04.09.1998; 30.04.1999; South Park - 29.05.1999; West Park - 19.05.1999. The nests are opened and under stones.

Herpetobiont. The habitats are similar to those of *F. cinerea*.

Distribution: Transpalaearctic.

30. *Formica (Serviformica) cunicularia* Latreille, 1798: Boris Garden - 01.10.1999.

Herpetobiont. A termophilic species inhabiting dry, sunny places in lawns, meadows and road-side biotops.

Distribution: Transpalaearctic.

31. *Formica (Formica) rufa* Linnaeus, 1758: Student city - 03.05.1996. The nest with a dome.

Herpetobiont. It prefers sunny meadows, glades, forest outskirts and roadside habitats in beech, oak, mixed and coniferous forests.

Distribution: Transpalaearctic.

DISCUSSION

We collected 31 species belonging to 12 genera in 4 subfamilies. With respect to species composition, the most wide spread species in the study area were: *Formica balcanina* Petrov & Collingwood, *Formica rufibarbis* F., *Lasius niger* (L.), *Lasius alienus* (For.), *Lasius fuliginosus* (Latr.), *Lasius brunneus* (Latr.), *Tetramorium caespitum* (L.), *Leptothorax crassispinus* Karaw., *Myrmica ruginodis* Nyl. and *Myrmica scabrinodis* Nyl. These species are typical of both natural ecosystems and cultivated landscapes.

Species were classified into biomorphs (life forms) (using the classification of Arnoldi (1968)), allowing us to characterize the ant structure in terms of morphofunctional and ecological specific features. The biomorphs of the ants reflect the nest location within the spatial biocenosis structure and their eating habits. Results showed that the herpetobionts predominate considerably over the other biomorphs at all sites - 18 species belong to this group. These species live in open areas on the surface of the soil. The dendrobionts, inhabiting dying or living trees or stumps, were mainly represented by species of the genera *Camponotus* and *Lasius* (six species in total). The geobionts group was represented by five species. These are soil inhabitants coming to the surface only during the swarming period. The workers are usually blind. *Myrmecina graminicola* (Latr.) and *Stenamma westwoodi* West represent the stratobionts. They inhabit the foliage cover. The latter were captured only by the trapping method.

The most numerous species collected in the pitfall traps was *Myrmica ruginodis*. Six species were collected only using this method. They include *Myrmica schencki* Viereck, *Myrmecina graminicola* (Latr.), *Stenamma westwoodi* West., *Leptothorax unifasciatus* (Latr.), *Lasius umbratus* (Nyl.) and *Formica cunicularia* Latr., while *Ponera coarctata* (Latr.), *Myrmica rubra* (L.), *Tetramorium forte* Forel, *Tetramorium semilaeve* Andre, *Tapinoma erraticum* (Latr.), *Camponotus vagus* (Scopoli), *Camponotus truncatus* (Spinola), *Lasius flavus* (F.) and *Lasius affinis* (Sch.) were not collected using pitfall traps.

We established 22 species in Boris Garden, 14 species in West Park, 11 species in South Park and five species in North Park. We think that the ratio between species diversity in the abovementioned parks may be changed in further studies.

Our work showed that Sofia is the northern most distribution point for *Myrmecina graminicola* (Latr.) in Bulgaria. According to Atanassov & Dlusskij (1992), *Camponotus fallax* (Nyl.) is a rare species in Bulgaria, but in this investigation we collected it in three parks in Sofia. The finding of *Formica rufa* L. in Sofia is very unusual, because this species typically prefers natural habitats.

ACKNOWLEDGEMENTS

We thank the GLOBENET project participants and our colleagues Denis Gradinarov and Ilia Gjonov for providing some of the material presented in this study. This work was partly supported by the National Scientific Research Fund (grant No. B-808/1998).

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Compound Nests and Mixed Colonies of Ant Species (Hymenoptera, Formicidae) in Sofia, Bulgaria

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Abstract

Seven nests of coexisting ant species in the city of Sofia and its vicinity were discovered. Five of these were reported from Zapaden park, one from Knyaz Borisova Gradina and one from Vladaja village. Two of the nests represented mixed colonies probably with temporary parasitic interaction between species of the genus *Lasius*. The compound nests included species from the genera *Lasius*, *Leptothorax, Myrmica* and *Formica*. *Solenopsis fugax* was found in lestobiotic interaction with two species of the genus *Lasius* within one of the mixed colonies.

Key words

Formicidae, ants, compound nests, mixed colonies, social interactions, Bulgaria.

INTRODUCTION

Hundreds of cases of interspecific symbioses have been revealed among over 8800 described ant species in the World. These symbioses are mainly related to comensalism and parasitism (Hölldobler & Wilson, 1990). About 3% of the described ant species are known as socially parasitic (Schlick-Steiner *et al.*, 2002a). True cooperation is rare or nonexistent and there are no verified examples of mutualism (Hölldobler & Wilson, 1990). Although many experts for over 200 years searched for answers about various causes and essences of social parasitism, the studies are in their infancy (Stuart, 2002). The complexity is caused by the large number of ant species included into some forms of parasitic interactions with each other and by the different evolutionary routes of these relationships (Wilson, 1974). Not much information is available on the ant species involved in social parasitic interactions.

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Compound nests are common in nature and include relationships from accidental to total parasitism (plesiobiosis, cleptobiosis, lestobiosis, parabiosis, xenobiosis). Their feature is the separation of the brood of the species (two or more) included. These ant speices live very close to each other and even use common galleries. Mixed colonies are rare and are usually a result of social parasitism (temporary social parasitism, dulosis=slavery, inquilinism=permanent parasitism). The individuals of the different species live together and their brood is mingled (Wilson, 1974).

In the current study some examples of coexistence of different ant species in mixed colonies and compound nests in Sofia are given. The reasons for these coexistences and the exact relationships are not clear and will be a subject of further studies. It is difficult to plan such an observation (i.e. in some subterranean socially parasitic subgenera, for example *Chthonolasius*, discussed here), so even incidental observation of details is valuable (Schlick-Steiner *et al.*, 2002a).

MATERIAL AND METHODS

Ant nests were studied during April-June of 2002 in two parks in Sofia and in an orchard of Vladaja village.

The direct sampling method was used for data collection. This method is spatially extensive and allows to encompass different kinds of ant nests in different microhabitats (Bestelmeyer *et al.*, 2000).

Only workers of the recorded ant species were found. Their identification followed Atanassov & Dlussky (1992), Czechowski *et al.* (2002) and Arnoldi & Dlussky (1978).

The names of the ant species are given after Czechowski *et al.* (2002). For *Formica balcanina* see Petrov & Collingwood (1993).

The terms of social interactions are used according to Wilson (1974) and Hölldobler & Wilson (1990).

RESULTS

Ten ant species included in social interactions with each other were found (see Table 1). Four of them belong to the genus *Lasius*, two to *Leptothorax*, two to *Myrmica* and one each to *Solenopsis* and *Formica*.

Two classes of myrmecobioses were distinguished according to the spatial location of the species' galleries within each nest.

The presence of *Lasius citrinus* in both mixed colonies and in two from five compound nests is interesting. *Lasius niger* was present in one mixed colony and two compound nests and *Myrmica sabuleti* – in two compound nests. *Lasius fuliginosus* was present in one mixed colony, so far was *Solenopsis fugax*, but as the "thief ant". The other species – *Lasius alienus*, *Leptothorax crassispinus*, *Leptothorax unifasciatus*, *Myrmica sulcinodis* and *Formica balcanina* were found once as members of compound nests.

In Zapaden park we found both mixed colonies and three of the compound nests. In Knyaz Borisova Gradina and Vladaja village I found two compound nests (one per location).

Table 1. Distribution of ant species in different habitats

No	Species	Myrmecobiosis	Type and size of the nest	Location, date, altitude	Habitat
1	*Lasius* (*Chtonolasius*) *citrinus* Emery, 1922 (=*Lasius affinis*) *Lasius* (*Dendrolasius*) *fuliginosus* (Latreille, 1798)	mixed colony	soil mound with grass (Poaceae); D=70 cm, H=40 cm	Zapaden park 14 April, 2002; 525 m	grassland with scattered trees (*Betula* sp.)
2	*Lasius* (*Lasius*) *niger* (Linnaeus, 1758) *Leptotxorax* (*Myrafant*) *unifasciatus* (Latreille, 1798)	compound nest	soil mound near a stump	Zapaden park 14 April, 2002; 525 m	grass, bushes and moss
3	*Lasius* (*Lasius*) *niger* (Linnaeus, 1758) * *Leptothorax* (*Myrafant*) *crassispinus* Karawaev, 1926 (=*Leptothorax nylanderi*)	compound nest	nest in dry stump	Zapaden park 14 April, 2002; 525 m	deciduous forest (*Quercus* spp.)
4	* *Lasius* (*Lasius*) *niger* (Linnaeus, 1758) * *Lasius* (*Chtonolasius*) *citrinus* Emery, 1922 *Solenopsis fugax* (Latreille, 1798) (=*Diplorhoptrum fugax*)	mixed colony	soil mound with grass (Poaceae); D=40 cm, H=10 cm	Zapaden park 14 April, 2002; 525 m	grassland near a deciduous forest
5	* *Lasius* (*Chtonolasius*) *citrinus* Emery, 1922 *Myrmica sabuleti* Meinert, 1861	compound nest	soil mound; D=35 cm, H=20 cm	Zapaden park 14 April, 2002; 525 m	deciduous forest (*Quercus* spp., *Betula* sp.)
6	**Formica balcanina* Petrov & Collingwood, 1993 (=*Formica cinerea*) * *Lasius* (*Chtonolasius*) *citrinus* Emery, 1922 *Myrmica sabuleti* Meinert, 1861	compound nest	nest in rotten stump	Knyaz Borisova Gradina 16 April, 2002; 550 m	deciduous forest
7	*Lasius* (*Lasius*) *alienus* (Förster, 1850) *Myrmica sulcinodis* Nylander, 1846	compound nest	nest under a stone	Vladaja quarter 1 June, 2002; 1100 m	orchard

* – species with prevalent abundance in the nest; D – diameter; H - high

Both mixed colonies were found in grassland habitat, while the compound nests occurred in grasslands, deciduous forests and orchard depending on the biology of the species.

DISCUSSION

Lasius (*Chtonolasius*) *citrinus* was present in both mixed colonies. According to Czechowski *et al.* (2002), almost nothing is known on the biology of this species. It is known that *Lasius brunneus* is its possible host (Seifert, 1996). *Lasius citrinus* was found with *Lasius fuliginosus* in nest No.1 and with *Lasius niger* in nest No 4 (see Table 1). We may assert that the interaction within both mixed colonies is a temporal social parasitism (see Wilson, 1974). This relation is one of the ways of founding a new nest where the host queen is eliminated by her own workers or by the parasite queen. Compared to the gynes of the subgenera *Lasius* and *Cautolasius*, with independent foundation of their nests, all known gynes of the subgenus *Chthonolasius* have special cephalic and mandibular morphology that considerably increases the potency for lethal biting of the host queen (Seifert & Buschinger, 2001). Such a behaviour is observed for the queens of *L. umbratus*, *L. distinguendus*, *L. citrinus*, *L. meridionalis* (Seifert & Buschinger, 2001) and *L. mixtus* (Schlick-Steiner *et al.*, 2002a). Seifert (1996) pointed out that temporal parasitic interactions of *L. fuliginosus* occur more often with *L. umbratus* and less with *L. mixtus*, *L. brunneus* and *L. niger*. Liu *et al.* (2000) mentioned another undetermined species of the genus *Lasius* as a temporary parasite of *L. fuliginosus*. They proposed three hypotheses on the reasons of nestmate recognition.

Species from the genera *Leptothorax*, *Stenamma* and *Myrmica* may search for food in the forage territory of *L. fuliginosus* (Seifert,1996).

One of these mixed colonies included a third species – *Solenopsis fugax*. This species is in cleptobiotic interactions with the hosts *Formica rufa*, *Formica cinerea* (=*balcanina*) and *Lasius alienus* (Atanassov & Dlussky, 1992). Wilson (1974) noted that *S. fugax* (thief ant) is in lestobiotic interaction with larger sized ant species. Czechowski *et al.* (2002) specified the lestobiotic relationship with species from the genera *Tapinoma*, *Myrmica*, *Tetramorium*, *Formica*, *Camponotus* and *Lasius*. We did not find differentiated nests of *S. fugax* (which is a feature of cleptobiosis). Thus, the most probable explanation of the presence of *S. fugax* is the lestobiotic interaction with *Lasius niger* and *Lasius citrinus*.

Concerning the compound nests No 2 and No 3 (see Table 1) we do not have enough information to evaluate the real relationships. We did not find any data of previous cases of interactions between species of the genera *Lasius* and *Leptotxorax*. Different species of the genus *Leptotxorax* are reported in xenobiotic, dulotic and inquilinic interactions with species of other genera (Hölldobler & Wilson, 1990).

Two of the compound nests (No 5 and No 6) included *Lasius citrinus* and *Myrmica sabuleti*. In dry habitats *M. sabuleti* often exists as inhabitants in the soil mounds of *Lasius flavus* (Atanassov & Dlussky, 1992). Examples of coexistence of other species from these genera are reported in Czechowski *et al.* (1990). In this study a few cases of coexisting ant colonies of different species in one tree were registered. Some of these were *Lasius brunneus* with *Myrmica laevinodis* (=*rubra*) and *Lasius niger* with *M. laevinodis*. Competitive relationships for food and nesting places are known between the species from these pairs. Czechowski *et al.* (1990) consider that few cases of coexsistence of two species indicate a strong competition between them. In our case, we do not have sufficient data to suggest such a relation between the species of the genera *Lasius* and *Myrmica* (see also the examples below), but the possibility of competitive interaction can not be excluded. According to Hölldobler & Wilson (1990) and Seifert (1996), *Myrmica sabuleti* is reported as host of other species of the same genus mainly in interactions of permanent parasitism. In our case the compound nest No 6 included also *Formica balcanina* as a third species. Czechowski & Czechowska (2000) pointed out few cases of plesiobiosis between *Formica cinerea* and *Lasius flavus*. A similar interaction can not be excluded in nest No 6, between *Formica balcanina* and *Lasius citrinus*.

In compound nest No 7 *Lasius alienus* and *Myrmica sulcinodis* were found together. About *L. alienus* Czechowski *et al.* (2002) mentioned the independent foundation of its nests by young queens and also its main social parasite – *Lasius jensi* (not known in Bulgaria). Schlick-Steiner *et al.* (2002b) suggested *L. alienus* as a host of *L. distinguendus* (especially in Bulgaria according to Seifert, unpublished data). *Myrmica sulcinodis* tolerates neighborhoods with *Formica lemani*, *Camponotus herculeanus* and *Lasius flavus* according to Atanassov & Dlussky (1992). We suggest that the coexistence of *Lasius alienus* and *Myrmica sulcinodis* provide new data on their possible relationship.

AKNOWLEDGEMENTS

The author thank Dr. A. Radchenko (Institute of Zoology, Kiev, Ukraine) and A. Lapeva-Gjonova (Faculty of Biology, Sofia University) for help in determining some species; also Dr. G. Elmes (CEH, Dorset, UK) for the submitted comparative material of *Myrmica* species and Dr. V. Delov (Faculty of Biology, Sofia University) for his help in sampling the material and for the valuable advices. Special thanks to my supervisor Dr. Lyubomir Penev (Central Laboratory for General Ecology, Sofia) and to Dr. W. Czechowski (Institute of Zoology, Warsaw) for critical notes and editing the manuscript. The work is supported by National Scientific Research Fund (grant No: B-1305/03).

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Scuttle Flies (Diptera: Phoridae) from Urban and Suburban Areas in the Sofia Plain

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Summary

A review of the scuttle flies from the urban and suburban areas of Sofia and its near surroundings was made. Thirty eight species from ten genera were collected. Here are presented the chorotype and food spectrum of each of the species. The genus *Phalacrotophora* and the species *Borophaga germanica*, *Diplonevra glabra*, *Megaselia abdita*, *M. hirtiventris*, *M. pectoralis*, *M. scalaris*, *M. stichata*, *M. tarsella* and *M. tergata* are new to the Balkan Peninsula. *Megaselia scalaris* was reported for the first time from the Greek and Serbian fauna as well. Two species (*Megaselia ciliata* and *M. pectoralis*) were established from the food of swifts (*Apus pallidus*). These two species were represented by four individuals and made up 0.7 % of the total Diptera meal of swifts (582 specimens altogether).

Key words

Phoridae, Sofia Plain, urban environment, faunistic, new data, Balkan Peninsula, enemies.

INTRODUCTION

Only three articles have been published so far in which some species from the family Phoridae, collected from urban and suburban areas in Bulgaria, were listed (Nedelkov, 1912; Beshovski & Langourov, 1997; Langourov, 2002). These publications contain only very short notices on Phoridae. Eleven species from Sofia were listed in these publications and are mentioned below. Recently new data on the scuttle flies from these areas have been accumulated. The aim of this paper is to list the known scuttle fly species in and around Sofia City and to provide some distributional and feeding habit information.

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MATERIAL AND METHODS

Material was collected with Malaise traps (mesh size above 1 mm), sweeping netting and individual samplings mainly on windows. For each species I provide information on localities, chorotype and diet. New species for the Balkan Peninsula are indicated with two asterisks, and for the Bulgarian fauna – with a single asterisk. All specimens are deposited in the author's collection at the Institute of Zoology, BASc (Sofia).

Localities and abbreviations (in order - locality, altitude, UTM-code – grid zone 34T):

Urban

Sf: Sofia, 550 m, FN83

SfC: Sofia - centrum, 550 m, FN 83

SfD: Sofia - Gotse Delchev Quarter, 580 m, FN 82

SfM: Sofia - 1A Mladost Quarter, 585 m, FN 92

SfS - Sofia - Hristo Smirnenski Quarter, 560 m, FN 93; leg. A. Antonov & D. Atanasova

Suburban

SfB: Sofia - Boyana Quarter, 750 m, FN 82

SfH: Sofia - Hladilnika Quarter, experimental field of Faculty of Biology, 600 m, FN 92; Malaise trap, leg. P. Atanasova

SfZ: Sofia - Zoological garden, 600 m, FN 92

K: Kostinbrod - Institute of Plant Protection, 535 m, FN 84

RESULTS

Subfamily Phorinae

*1. *Anevrina urbana* (Meigen, 1830)

New data: SfH, 25.6.-25.7.1997, 1 ♀.

Holarctic species known from Europe, Asia (West Siberia) and North America.

Saprophage.

2. *Borophaga femorata* (Meigen, 1830)

New data: SfH, 25.6.-25.7.1997, 1 ♂.

Palaearctic species known from Europe, Asia (Russian Far East) and North Africa.

**3. *Borophaga germanica* (Schmitz, 1918)

New data: SfH, 25.6.-25.7.1997, 1 ♂.

European species known until now from Middle Europe.

Zoophage.

4. *Conicera dauci* (Meigen, 1830)

New data: SfH, 25.6.-25.7.1997, 1 ♂.

Holarctic species known from Europe, Macaronesia, Asia (Russian Far East, Japan) and North America.

Mycetophage.

5. *Diplonevra concinna* (Meigen, 1830)
Literature data: Sf - Nedelkov (1912) as *Phora concinna* Meigen.
European species.
Saprophage.

*6. *Diplonevra crassicornis* (Meigen, 1830)
New data: SfH, 29.5.-25.6.1997, 1 ♂.
European species known until now from Middle and South Europe.

7. *Diplonevra florescens* (Turton, 1801)
Literature data: SfZ - Beschovski & Langourov (1997) as *Diplonevra florea* (F.).
New data: SfH, 29.4.-29.5.1997, 1 ♂; 29.5.-25.6.1997, 1 ♂.
Palaearctic species known from Europe and Asia (Caucasus and Russian Far East).
Saprophage.

8. *Diplonevra funebris* (Meigen, 1830)
New data: SfH, 25.6.-25.7.1997, 1 ♂ + 1 ♀.
Holarctic species known from Europe, Macaronesia, North Africa, Asia (Israel) and North America.
Saprophage.

**9. *Diplonevra glabra* (Schmitz, 1927)
New data: SfD, 20.5.1997, 1 ♂, at light; SfH, 29.4.-29.5.1997, 1 ♂.
European species known until now from Middle and North Europe.

10. *Diplonevra nitidula* (Meigen, 1830)
Literature data: Sf - Beschovski & Langourov (1997).
New data: SfH, 29.5.-25.6.1997, 2 ♂♂ + 2 ♀♀; 25.6.-25.7.1997, 1 ♂.
Holarctic species known from Europe and North America.
Zoophage.

11. *Dohrniphora cornuta* (Bigot *in* de la Sagra, 1856)
Literature data: SfZ - Beschovski & Langourov (1997).
New data: SfC, 15.11.1992, 1 ♂, on decayed *Solanum tuberosum*; 06.8.2001, 1 ♂; SfD, 11.9.1994, 1 ♀, on meat; 01.8.1998, 1 ♂, on sugar; SfZ, 08.11.1994, 1 ♂ + 1 ♀ in copula.
Cosmopolitan species.
Saprophage.

*12. *Phora atra* (Meigen, 1804)
New data: SfH, 29.4.-29.5.1997, 2 ♂♂; 29.5.-25.6.1997, 2 ♂♂; 25.6.-25.7.1997, 1 ♂; 02.8.-02.9.1997, 4 ♂♂.
Holarctic species known from Europe, Macaronesia, North Africa, Asia (Israel) and North America.
Saprophage.

*13. *Phora edentata* Schmitz, 1920
New data: SfH, 29.5.-25.6.1997, 1 ♂; 02.8.-02.9.1997, 2 ♂♂.
Palaearctic species known from Europe and Asia (Japan).

*14. *Phora holosericea* Schmitz, 1920

New data: K, 13.7.1993, 1 ♂ + 1 ♀ in copula.

Holarctic species known from Europe, Asia (Israel, Mongolia, China, Japan) and North America.

Zoophage.

15. *Spiniphora bergenstammi* (Mik, 1864)

Literature data: SfB, SfD - Beschovski & Langourov (1997).

New data: SfC, 20.11.1997, 1 ♂; 05.7.2001, 1 ♂, on decayed organics; SfZ, 22.9.1994, 1 ♀, ovipositing on dead *Arion lusitanicus* Mabille, 1868 (det. I. Dedov).

Cosmopolitan species.

Saprophage.

16. *Triphleba distinguenda* (Strobl, 1892)

Literature data: SfC - Beschovski & Langourov (1997).

European species.

Saprophage.

17. *Triphleba hyalinata* (Meigen, 1830)

Literature data: SfZ - Langourov (2002).

European species.

Saprophage.

18. *Triphleba trinervis* (Becker, 1901)

Literature data: Sf - Beschovski & Langourov (1997).

Holarctic species known from Europe and North America.

Saprophage.

Subfamily Metopininae

**19. *Megaselia abdita* Schmitz, 1959

New data: SfC, on windows, 05.1.1997, 1 ♂; 28.4.2000, 1 ♂; SfD, 20.3.1993, 2 ♂♂ + 2 ♀♀, on tainted meat; SfZ, 11.11.1994, 1 ♂ + 1 ♀ in copula.

Holarctic species known from Europe (Austria, Germany, Great Britain and Poland), Macaronesia, Asia (Afghanistan) and North America.

Saprophage.

*20. *Megaselia altifrons* (Wood, 1909)

New data: SfC, 23.4.1998, 1 ♂.

European species.

*21. *Megaselia basispinata* (Lundbeck, 1920)

New data: SfC, 22.6.2001, 4 ♂♂, on windows.

Holarctoneotropical species known from Europe, Macaronesia, North and South America.

*22. *Megaselia ciliata* (Zetterstedt, 1848)

New data: SfS, 22.9.-02.10.1999, 2 ♂♂ + 1 ♀, diet of *Apus pallidus* (Shelley, 1870).

European species.

Zoophage.

*23. *Megaselia emarginata* (Wood, 1908)

New data: SfH, 29.4.-29.5.1997, 1 ♂.

European species known until now from Middle and South Europe.

Zoophage.

24. *Megaselia fenestralis* (Schmitz, 1919)

New data: SfC, on windows, 11.6.2000, 2 ♂♂; 27.6.2001, 3 ♂♂; 06.7.2001, 3 ♂♂; SfD, 09.6.1998, 6 ♂♂ + 2 ♀♀, one pair - in copula.

Palaearctic species known from Middle and South Europe and Asia (Japan).

*25. *Megaselia giraudii* (Egger, 1862)

New data: SfC, 01.-14.6.2000, 1 ♂, on window; 14.6.2000, 1 ♂ + 1 ♀, on dead larva of *Arctia villica* L. (Lepidoptera: Arctiidae, det. S. Beshkov); 22.6.2001, 1 ♂, on window; SfH, 29.5.-25.6.1997, 3 ♂♂ + 1 ♀.

Holarctooriental species known from Europe, Macaronesia, Asia (Israel, Nepal, Russian Far East) and North America.

Saprophage.

26. *Megaselia halterata* (Wood, 1910)

Literature data: SfC - Langourov (2002).

Holarctic species known from Europe, Macaronesia, North Africa, Asia (Israel) and North America.

Mycetophage.

**27. *Megaselia hirtiventris* (Wood, 1909)

New data: SfC, 13.5.2000, 1 ♂, on window; SfH, 29.4.-29.5.1997, 1 ♂.

European species known until now from Middle Europe.

Mycetophage.

**28. *Megaselia pectoralis* (Wood, 1910)

New data: SfS, 22.9.-02.10.1999, 1 ♀, diet of *Apus pallidus* (Shelley, 1870).

European species.

29. *Megaselia pleuralis* (Wood, 1909)

Literature data: SfB, SfC - Langourov (2002).

Holarctic species known from Europe, Macaronesia, Asia and North America.

Saprophage.

*30. *Megaselia plurispinulosa* (Zetterstedt, 1860)

New data: SfH, 02.8.-02.9.1997, 2 ♀♀.

Palaearctic species known from Europe and Asia (Turkey, China).

Mycetophage.

31. *Megaselia rufipes* (Meigen, 1804)

Literature data: Sf - Nedelkov (1912) as *Aphiochaeta heracleelae* [sic] Bouche and *Aphiochaeta rufipes* (Meigen); SfC, SfD - Langourov (2002).

Cosmopolitan species.

Saprophage.

**32. *Megaselia scalaris* (Loew, 1866)

New data: SfC, 03.10.1997, 4 ♂♂ + 18 ♀♀, guest on pupae of *Scoliopteryx libatrix* L. (Lepidoptera: Noctuidae), leg. M. Subchev & T. Toshova; GREECE, Syar (Seres), urban habitat, 50 m, 10.9.1994, 1 ♂, on window; YOUGOSLAVIA (SERBIA), Obedska Bara Nature Reserve, inundated wood, 160 m, 14.9.1996, 1 ♂.

Cosmopolitan species known until now in Europe from Belgium, Germany, Great Britain, Italy and Poland.

Saprophage.

**33. *Megaselia stichata* (Lundbeck, 1920)

New data: SfH, 29.4.-29.5.1997, 1 ♂.

Westpalaearctic species known from Europe, Macaronesia and Asia (Israel).

**34. *Megaselia tarsella* (Lundbeck, 1921)

New data: SfH, 29.5.-25.6.1997, 1 ♂.

European species known until now from Middle Europe and Spain.

**35. *Megaselia tergata* (Lundbeck, 1920)

New data: SfH, 29.5.-25.6.1997, 2 ♂♂.

European species known until now from Denmark, Great Britain and Holland.

**36. *Phalacrotophora berolinensis* Schmitz, 1920

New data: SfH, 29.5.-25.6.1997, 1 ♂.

European species.

Zoophage.

**37. *Phalacrotophora fasciata* (Fallen, 1823)

New data: Sf, July 1934, 2 ♂♂ + 1 ♀, leg. P. Drensky.

European species.

Zoophage.

**38. *Phalacrotophora pictofasciata* Schmitz, 1919

New data: SfH, 29.5.-25.6.1997, 1 ♂.

Southeuropean species known until now only from the type-locality in Roumania (Mehadia).

Zoophage.

DISCUSSION

This investigation increased the number of scuttle fly species recorded in the urban area of the city of Sofia and its near surroundings to 38, belonging to 10 genera. One genus (*Phalacrotophora*) and 12 species are new to the Balkan Peninsula, while 11 more species are new to Bulgaria. *Megaselia scalaris* was reported for the first time for the Greek and Serbian fauna as well.

Twenty species (6 genera) were collected from urban areas, while 25 species (10 genera) from suburban areas. Using two Malaise traps in a suburban garden and a gravel pit in Cologne (Germany) Prescher & Weber (1996) collected 55 species, belonging to 8 genera. Also, Durska (1981) reported 36 species (12 genera) in urban green areas of Warsaw (Poland). Twelve species (*Anevrina urbana*, *Borophaga femorata*, *Conicera dauci*, *Diplonevra glabra*, *Phora atra*, *Megaselia altifrons*, *M. basispinata*, *M. ciliata*, *M. emarginata*, *M. giraudii*, *M. pleuralis*, *M. plurispinulosa*) are common for both Sofia and Cologne and 11 for Sofia and Warsaw (*Conicera dauci*, *Diplonevra glabra*, *D. nitidula*, *Dohrniphora cornuta*, *Phora atra*, *Spiniphora bergenstammi*, *Triphleba distinguenda*, *Megaselia giraudii*, *M. haltera-*

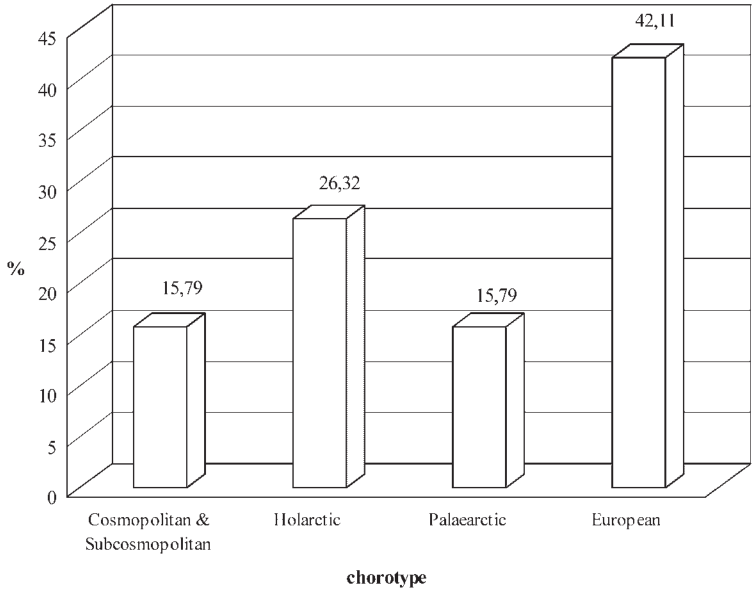

Fig. 1. Proportions of chorotypes in scuttle flies of urban and suburban areas in Sofia.

ta, *M. rufipes*, *Phalacrotophora fasciata*). This indicates that all these species are ecologically polyvalent and common in urban environments. Of special interest are the species *Dohrniphora cornuta* and *Megaselia scalaris,* which have a tropical origin (Disney, 1983; Disney, 1989), but have considerably expanded their ranges because of human activities. *Dohrniphora cornuta* is common throughout Europe, while *Megaselia scalaris* is still expanding throughout the continent. The three new localities reported here for *Megaselia scalaris* are the first for this species in South-Eastern Europe, all of which are near big commercial centres (Sofia and Syar) or transport junctions (Sava River).

As regards to diet (which is not known for 11 species), saprophagy is predominant in the city (15 species, 39 %), followed by zoophagy (8 species, 21 %) and mycetophagy (4 species, 11 %). Polyphagous saprophages *Dohrniphora cornuta*, *Spiniphora bergenstammi*, *Megaselia abdita*, *M. giraudii*, *M. pleuralis* and *M. rufipes* are the most common species.

Two species (*Megaselia ciliata* and *M. pectoralis*) were collected from the food of swifts (*Apus pallidus*). These two species were represented by four individuals and made up 0.7 % of the total Diptera meal of the swifts (582 specimens altogether).

According to their chorologycal classifications, in the city of Sofia the widespread species (Cosmopolitan and Subcosmopolitan, Holarctic and Palaearctic) prevail over the European ones (Fig. 1).

ACKNOWLEDGMENTS

I want to thank all colleagues who collected scuttle flies (noted in the text). Special thanks to Dr S. Abadjiev and MSc S. Beshkov for their help and co-operation during the preparation of this article.

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The Diurnal and Nocturnal Birds of Prey (Falconiformes and Strigiformes) Nesting in the Territory of Sofia

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Summary

This study was carried out in urban Sofia, an area of 181 km^2, from 1979 to May 2001. Data are based on the authors' investigations, on literature data since the 1950's and on unpublished communications with ornithologists. The aim here is to give a general review of the species composition, territorial distribution and the process of synanthropisation (colonization of the urban areas) by birds of prey (Falconiformes and Strigiformes) during the breeding period in Sofia.

Five diurnal birds of prey, nesting in Sofia, were recorded: *Accipiter gentilis*, *Accipiter nisus*, *Buteo buteo*, *Falco tinunculus* and *Falco subbuteo*. The nocturnal birds of prey were represented by four species: *Otus scops*, *Athene noctua*, *Strix aluco* and *Asio otus*.

Three species have become extinct from the nesting ornithofauna of Sofia during the twentieth century: *Falco naumanni*, *Tyto alba* and *Asio flameus*. *Falco tinunculus* and *Asio otus* have increased in number during the 1990's. Both these species, as well as *Athene noctua*, are the most widely distributed species in Sofia. The negative factors affecting breeding of birds of prey in Sofia are outlined and discussed.

Key words

Synanthropisation, birds of prey, Falconiformes, Strigiformes, breeding period, Sofia.

INTRODUCTION

Human-altered landscapes and in particular the urban environment attracted considerable scientific attention in the latter part of the twentieth century, in particular with respect to bird studies. This is partly due to the fact that birds are a popular group of vertebrates and seemingly respond quickly to environmental changes. For example, in his monograph "Ecology of the

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 437-450

Urban Fauna" Klausnitzer (1990) summarized numerous studies on different aspects of urban ornithofauna during the last decades. Also Galushin (1982) provided a perspective on the adaptation of the diurnal birds of prey to contemporary anthropogenic pressure. Similar studies are also found in the Bulgarian literature – mainly during the last two decades of twentieth century (Nankinov, 1981, 1982; Yankov, 1983; Donchev & Yankov, 1989; Gerassimov, 1993). These studies dealt with species composition, nesting biology and the status and trends to synanthropization of Falconiformes and Strigiformes. Kyutchukov (1995) studied the distribution patterns of these groups and some additional information are found in Kyutchukov (2000).

The present study offers a general survey of the species composition, territorial distribution, the manner of colonisation and habitation of urban landscapes by birds of prey, recorded in Sofia during the breeding period.

MATERIAL AND METHODS

The present study is based on the authors' own data, collected during the period 1979 to May 2001. Sampling was performed in Sofia, in the urban area of the city. The total study area is 181 km^2, similar to the area studied by Yankov (1983). Observations were made using the route and point methods. We also included information provided by other ornithologists. Birds were observed by walking transects, by bicycle, and to a lesser extent, by car. Using these approaches we were able to cover 40-60 km per day. We, furthermore, made night observations to assess nocturnal birds of prey - both through direct observation and sound, using suitable electric lighting to assist our observations and movements. In the field we used binoculars with the following parameters: 7x35, 7-14x40 and 15x50. In particular regions some high-elevation points were chosen, such as hills and apartment blocks, offering a better view to the surrounding landscape. For the terrain work we used different maps of the city of Sofia, the newest one being the edition of Smilenova and Bozhilova (1999).

Much unpublished personal data are reported here. Biologists, bird watchers and local people kindly provided this information. We also used some data concerning birds of prey, which were captured in the region of Sofia and brought to the Sofia Zoo between 1950 and 2000. We used the following criteria to indicate reliable nesting: breeding flights and specific breeding songs in a territory suitable for nesting; copulation, inhabited nest built by a couple, sitting on eggs, feeding of juvenile birds, observation of recently fledged juvenile birds. The presence of one of these criteria was considered sufficient to prove nesting. No exact nest localities are reported in this paper because of illegal egg collection and falconers' activities (it is important to note that any hunting on birds of prey and owls, their catching and/or keeping in captivity for whatever purpose except in zoos and licensed breeding centers is strictly prohibited by the Hunting Act (2001) of Bulgaria).

RESULTS

What follows is the species composition of birds belonging to the orders Falconiformes and Strigiformes, recorded during the breeding period in the territory of Sofia:

Goshawk (*Accipiter gentilis*)

The first nesting was observed in 1987 in the forested area of "Borissova gradina" park, in a remote and seldom visited part (Stoyanov *et al.*, 1988). The same couple built a nest in the autumn of 1986 (Kyutchukov, 1995), and then again in 1988 and 1989. In all three cases, there were attempts to take the birds out of the nest. On 2 June 1988 a strong storm destroyed the nest and three juvenile birds at the stage of neoptile plumage died. During the spring of 1989 the couple left the area temporarily because of forest thinning and the presence of people (some of which tried to collect bird eggs) and machines. Gerassimov (1993) reported nesting of Goshawk in the above-mentioned park during the period 1992-1993. After 1995 these birds established in another forested area in "Borissova Gradina" park. There the couple nested in dense and tall (about 15 m) broadleaved trees. These birds are still breeding there (May 2001). There were also attempts to destroy this nest, i.e. a tree was cut to collect the juvenile birds.

At the beginning of 1990 another pair nested in a forested area in southeastern Sofia. Once again, the juvenile birds were collected. During the same time birds looking for food were observed several times in another four localities in the southern parts of the city. In one of these cases there is reliable information for nesting of a pair in a guarded and fenced forest area. The remaining cases concern pairs nesting in the Vitosha Mountains, while feeding in the vicinity of Sofia. During post-nesting migrations at the end of summer, several young birds were captured in hen coops and on pigeon farms in southern Sofia.

Goshawks prefer forested territories in the city. These forested areas are mainly dense and tall plantations, more than 10 m in height. The species prefers conifer stands of Silver Fir, Scots Pine and Black Pine. Goshawks feed mainly in a mosaic landscape i.e. open areas and forest massifs and tree groups, and light forests in parks. Goshawk diet consisted mainly of pigeons (*Columba livia* var. *domestica*), making up 75 % of the prey (Stoyanov et al., 1988). Other species forming part of the pair's diet include *Garrulus glandarius*, *Pica pica, Columba palumbus, Columba oenas, Streptopelia decaocto, Turdus merula, Turdus philomelos, Sturnus vulgaris, Picoides major, Asio otus*, together with a mammal - *Sciurus vulgaris*. Numerous unsuccessful attacks on bats (*N. noctula*) were observed, mainly at the end of the day and close to the nesting territory.

Sparrow Hawk (*Accipiter nisus*)

The Sparrow Hawk is reported to be the most frequent bird of prey species for the region of Sofia during the whole year (Nankinov, 1982). The same author reported nesting of this species in the "Suhodol" complex in 1973 and in the "Mladost" complex at the end of the 1970's. Yankov (1983) assumed nesting of some pairs in the vicinity of the city, and Gerassimov (1993) found Sparrow Hawks in four localities within the city, where it was probably nesting. Kyutchukov (1995) reported nesting in a dense stand of Norway spruce in the Western Park during the periods 1989-1993 and 1995-2001. The number of nesting pairs increased during the period 1979-2001 in the Centrum and areas surrounding Sofia. The species was found in five localities during the period 1979-1990 and in four sites during the period 1991-2001.

Sparrow Hawks prefer nesting in forested areas of large city parks. Nesting has also been observed within smaller groups of trees within the city, in military zones, former industrial zones and other special territories. As a whole, the species prefers nesting in dense and quiet sectors in park areas that are not visited by people. However, Sparrow Hawks also occur in areas frequently used by people, i.e. in "Borissova Gradina" park in 1996, a nest in a Scots Pine tree at 12 m above the ground along a road. They also nest in the vicinity of Sofia in small forests along rivers, or in tree groups within open fields.

Sparrow Hawks mainly feed on small and medium-sized birds, i.e. *Passer domesticus*, *Passer montanus*, *Sturnus vulgaris, Turdus merula, Motacilla alba* and others. Some pairs also hunt in typical urban area during the breeding period. Such cases were observed in the large living complexes – Lyulin, Mladost and Serdika, in spaces between buildings, in some gardens and in stadiums. Otherwise, birds prefer to hunt near the city, in open areas with trees and shrubs, along rivers and other small streams and in the park areas of the city.

The large parks established during different periods in Sofia have already reached significant height and stand density, which is a prerequisite for nesting of the Sparrow Hawk. Also, during the autumn and winter periods, numerous individuals enter the city. Some of them belong to the local population, while others are migrants. Later on, some of these birds remain in the city area and build nests of their own in suitable habitats.

Common Buzzard (*Buteo buteo*)

A pair of this species has been observed many times during the period 1988 to May 2001 in the southwestern part of Sofia. The nest is within a forest area, far from people. The "Lyulin" complex is close to the nest area and the birds sometimes visit the city, perhaps looking for food. This species nests in territories not far from the city, for example, the mountains around Sofia, Vitosha, Lyulin etc. Nesting was observed in small forests to the north of Sofia. Donchev & Yankov (1989) classified this species into the lowest category of synanthropous birds: "Seasonal synanthrope in the settlements of Bulgaria, nesting outside settlements and single birds or pairs visit the cities and villages during the breeding period. The bird is found at single localities, and no changes did occur in its synanthropous status". Our study confirms the above statement, but we consider that adaptation of this species to urban areas is even higher than described by the above authors (Donchev & Yankov, 1989).

Kestrel (*Falco tinunculus*)

Currently, this is the most abundant diurnal bird of prey in Sofia. It has increased in Sofia, especially between 1992 and 2001. Before 1990 this species was frequently found to nest in the city surroundings (Nankinov, 1982; Yankov, 1983).

During the period between 1999 and May 2001, 37 to 42 pairs nested in urban Sofia. The birds prefer large building complexes mainly on high buildings (25 to 55 m above ground level) in 90 % of the cases. This is also true for the rest of the city, where high buildings or other high constructions are found.

Kestrels nest, for example, in roof vents, roof cornices and small windows. In these nesting places, birds usually lay eggs directly on the concrete substrate and subsequently the food litter form a soft cover. Nest building is rarely detected. Several cases of nesting have been registered in elevator shafts, where the birds used paper and cloth for their nests. Another case of nesting was registered in a broken street lamp along a street in Mladost. Nankinov & Kuzmanov (1987) registered a single case of nesting in central Sofia, in a park area above the Southern Park. The species sometimes uses old nests of Magpie (*Pica pica*) on electricity towers in Mladost and Druzhba. Kestrels also use Magpie nests in fields around Sofia (Delov & Stoyanov, 1994).

Kestrels are distributed mainly along the periphery of Sofia, in large grassy inter-building spaces: Mladost – 8 pairs, Lyulin – 4 pairs, Druzhba – 3 pairs, Darvenitza, Stefan Karadzha and Pavlovo – 2 pairs each. The inter-nest distances here are rather short, in some cases 30-150 m from each other.

Several nest-defending attacks were recorded in Sofia. They were against the following species: *Larus argentatus*, *Accipiter nisus*, *Corvus corone cornix*, *Pica pica* and *Corvus corrax*. Also, numerous aggressive attacks against domestic cats and people have been recorded.

The species feeds in various open areas in different parts of the city. These include inter-building spaces, meadows and fields in the peripheral parts of the city, in industrial zones, stadiums and other sport areas, on the roofs of buildings, in streets and in smaller gardens and even in the central urban area of Sofia.

The food spectrum was studied by direct observations, and by analyzing food remnants around the nests. The diet of the Kestrel consists mainly of vertebrates, which include small birds (*Passer domesticus, Passer montanus, Sturnus vulgaris*), mammals (*Microtus arvalis* and *Mus musculus*) and lizards (*Lacerta* sp.). Rare attacks on passerine birds in cages have been recorded. An isolated case of an attack on a nest of *Delichon urbica* was also observed. Evidently, Kestrels find enough food within the city. This statement is supported by the clutch size of a pair observed in Krasna polyana complex, where seven juvenile birds were recorded. This is higher than the previous maximum number reported for Bulgaria before, which was 4-6 eggs (Simeonov *et al.*, 1990).

The colonization of the urban territories by the Kestrel can be divided into three periods. The first period started during the 1960's and continued until the beginning of the 1980's. At this time the city already had its modern physiognomy. Since the end of 1960's few nests of this species were recorded in the central and peripheral parts of Sofia (Spiridonov, 1980; Nankinov, 1982; Yankov, 1983, our unpublished data). The second period is between 1980 and 1990. During this period Kestrel nests were often recorded on buildings and other constructions within the city. During 1992-1993 Gerassimov (1993) recorded the species in 23 localities during the breeding season. In six of these recordings the species was breeding, in 11 it was evaluated as "probably breeding", and in six "possibly breeding". Delov & Stoyanov (1994) found twelve reliable nests. During this period the main population was still situated outside the city.

The third period of colonization started in the mid 1990s to present. Kestrels were recorded in the large complexes, Mladost and Lyulin, and in some cases the number of nesting pairs here exceeded that of the adjacent peripheral territories. Kestrels are still less populated in other peripheral parts of Sofia (without high buildings) than agricultural fields and meadows in the surroundings of Sofia. Here the species mainly uses unused nests of Magpies (*Pica pica*) and Hooded Crow (*Corvus corone cornix*) in trees and electricity towers. During the same period, the number of pairs nesting in the inferior parts of the city also increased, but here the species was represented mainly by single pairs. Salvati *et al.* (1999) reported opposite trends of distribution of urban pairs in Italy. Here Kestrels were most numerous in the central part of the city, and decreased in number in the peripheral parts and agricultural fields. This difference can be explained by lower nesting opportunities in Sofia, as compared to Rome. Another reason can be the earlier stage of synanthropism of the Kestrel in Sofia. Donchev & Yankov (1989) classified Kestrels as "initial synurbanist" in Bulgaria, represented by single pairs in many localities, but that they are increasing in number. A permanent urban population is present in Sofia, which is different from the natural one.

Lesser Kestrel (*Falco naumanni*)

Arabadzhiev (1962) reported the first record of nesting of this species in Sofia. On 6-7 August 1959 he found three juvenile birds. Arabadzhiev supposed that the nest of these birds was probably on a roof in the vicinity. He also recorded nesting in Slivnitza, about 35 km northwest from Sofia. After these reports, no confirmed records exist regarding the nesting of this species in the region of Sofia. Barov (1996) supposed that this species does not nest in Eastern Rhodopes anymore. Eastern Rhodopes is the most favourable habitat for the Lesser kestrel, therefore we suggest that it must probably be excluded from the list of nesting birds of prey in Sofia. As a whole, information concerning nesting of this species in Bulgaria is controversial and insufficient. Furthermore, this species has decreased in number in Europe during the last three decades (Biber, 1996).

Hobby (*Falco subbuteo*)

Nankinov (1982) and Yankov (1983) reported that this species rarely nests in and around Sofia. Gerassimov (1993) also did not found this species in Sofia during the breeding period. Our observations showed that the Hobby can be observed in some peripheral parts of Sofia during the nesting period. Some of these observations are: 1) 17 July 1990, a flying pair in the Students town; 2) in the summer of 1991 and 1992; a pair in Darvenitza, but no nest was found; 3) 14 and 19 June 1996, a bird flying above Mladost complex and "Vartopa" park; 4) 9 June 1998, a pair flying above Lyulin complex. During the study period, single birds were observed in summer in agricultural landscapes, near the villages of Gorni Bogrov, Chepintzi, Chelopechene, close to Dragalevtzi, Simeonovo and Gorublyane. During the nesting period, this species was mainly observed outside the city, in open fields and close to forests. Hobbies are more abundant in elevated territories, such as the Western Stara planina and Samokov fields. In Samokov fields it was found in a Hooded Crow nest with five eggs in June 1979. Juvenile birds that left the nest were observed in July-August in the region of Ponor Mountains.

Peregrine (*Falco peregrinus*)

During the breeding period Nankinov (1982), Yankov (1983) and Gerassimov (1993) recorded this species in Sofia. Nankinov (1982) suggested that this species nested near the city. During the period 1993 to May 2001 this species was observed many times within the city, but observations during the breeding period (March–June) are of particular interest. During the winter period of 1997-1998 a pair inhabited a high hotel in Sofia. The birds remained there until April 1998, but no nesting was recorded. Another pair was observed on a high building in the industrial area of the city, but the presence of birds was not confirmed by the following subsequent observations. Single birds were recorded flying or sitting on high buildings (i.e. hotels, administrative and industrial buildings, and churches) in different regions of the city, mainly during the period 1997 to May 2001. Some birds were observed hunting for pigeons (*Columba liva* var. *domestica*) and Alpine swifts (*Apus melba*). Some also used the roofs as observation points, looking for food.

A nesting pair was recorded close to the city in the Vitosha Mountain region during the period 1999 to May 2001. Many times the birds were observed hunting in Sofia, 7 km away from the nest. On 23 and 28 March 1999 the birds demonstrated specific wedding flights and songs in the nest territory. We recorded copulation two times, however, the pair was not found hereafter. It was probably due to increased human pressure, i.e. rock climbers and noisy tourist groups. We also observed a pair close to the same mountain in an area characterized by steep rocks. The birds did not express typical nesting behaviour.

Three juvenile birds (10-14 days old) were found on 8 May 2000 on a rock terrace in Vitosha Mountain. One juvenile bird was recorded on 14 May 2000, but no birds were found in the nest on 25 May 2000. The juvenile birds were probably captured by poachers or carnivores or succumbed to unfavourable environmental conditions. On 11 March 2001 the same pair copulated in a tree close to the previous year's nesting terrace. Rock climbers caused the pair to leave the region for several hours. Breeding behaviour was recorded in an adjacent rocky area on 14 April 2001. We observed food exchange and the female bird issued calls in an old nest of *Corvus corrax*. The same pair or single birds were observed several times in May 2001, but the breeding cycle was unsuccessful. It is probably due to the same reasons, i.e. collecting of eggs by poachers or disturbance caused by rock climbers.

Nesting was not observed in the region of Sofia. Nesting platforms can be constructed in some appropriate places in the city, for example high buildings. It is possible that the non-breeding pairs observed had difficulties in finding suitable nesting sites. Alternatively, some of the single birds observed could have escaped from falconers because several young birds had belts on their legs. This species is increasing in number in the city, as well as in Bulgaria in general (personal observations).

Barn-Owl (*Tyto alba*)

Barn Owls nested in Sofia until the middle of the twentieth century (1945-1955). Nests with eggs and juvenile birds had been found in some garrets in the central part of Sofia (Simeonov *et al.*, 1981; Nankinov, 1982; Yankov, 1983). At the beginning of the 1990's, Gerassimov (1993) did not find the species in Sofia during the nesting period. We failed to show nesting of Barn Owls in Sofia, but it is possible that they can nest in agricultural areas near the city or in some of its suburbs.

Scops-Owl (*Otus scops*)

This species is rare during the nesting period (Nankinov, 1982), but Yankov (1983) and Gerassimov (1993) considered it very rare, with only five nesting pairs established in Sofia.

During the nesting period we recorded this species in old parks and forested areas, in gardens, squares and in roadside and riverside forests in different parts of the city. We recorded 21 localities in Sofia during the breeding period. Singing males and individuals belonging to pairs were observed. Trunk holes, where the birds nest, were also recorded. Several juvenile birds were observed in July and the beginning of August during most years of study. The most preferred territories are the areas of Borissova Gradina Park and the adjacent territories, Hunting Park, the court of the Religous School and the Southern and Western Parks. The species was also found in smaller areas where old trees with holes grow, local small gardens and in the central part of the city (i.e. "Doktorska Gradina" Park). The species was also recorded along the Perlovska and Boyanska rivers and in old riverside trees. Scops Owls breed in the peripheral city areas rich in trees, i.e. Pavlovo, Boyana, Dragalevtzi, Simeonovo and Boyana residence. Scops-Owls use trunk holes to nest in both natural and made, mainly by Green Woodpecker (*Picus viridis*). These Owls were often found in holes in Poplar, Plane tree, Horse Chestnut and Lime trees. During the breeding period singing males were observed on buildings in the Emil Markov complex. But although these buildings have many holes suitable for nesting, no nesting was observed here.

The distribution of this species in Sofia is fragmentary, possibly because of a lack of trunk holes. Recently the Scops-Owl and other hole-nesting birds have been negatively affected because of forest cuttings.

Little Owl (*Athene noctua*)

Nankinov (1982) considered the Little Owl as the most abundant species in Sofia among all Strigiformes. Yankov (1983) reported 140 nesting pairs in Sofia, however Gerassimov (1993) reported the species in only 18 localities. Contrary to Gerassimov, Ignatov (1993) reported 160-180 nesting pairs in Sofia.

We found that *Athene noctua* is a widespread species in Sofia. We estimated about 120 pairs in densely populated areas alone. This species prefers areas of large living complexes of high panel buildings, like Lyulin, Mladost, Obelya and others. These areas have large inter-building spaces and are close to fields. Here the species nests in unused space below the roofs of buildings. Nesting was recorded mainly on buildings not exceeding 20-25 m in height. Little Owl prefers small holes in the upper parts of buildings and nests are in the internal dark areas. They were also found in old parts of the city, with up to 2-4 nesting pairs per 0.5-1 km^2. Ignatov (1993) even recorded nesting in the basement of an old building in the center of the city. A nest was also found in an old nest of a Magpie in a tree in Borissova Gradina Park, and in a Magpie nest in an electric tower in Chepintzi, in an agricultural field. Evidently Little Owls use this manner of nesting in areas without sufficient nesting habitats, but rich in food. A single case was recorded in Lyulin where this species nested in a broken street lamp. The most frequent prey items of the Little Owl during the nesting period in Sofia are small mammals (*Mus musculus* and *Microtus arvalis* - in the peripheral zone), and birds (*Passer domesticus* and *Passer montanus*). They also feed on nocturnal insects near street lamps. In densely human populated parts this species feeds above roofs and near building walls. Little Owls also prey on little birds in bird cages.

Tawny Owl (*Strix aluco*)

Nankinov (1982) did not find this species in Sofia during the breeding period, but argued for the possibility of nesting. Yankov (1983) shared his opinion and argued for the possibility of nesting of several pairs in the city. He reported the presence of this species in Borissova Gradina Park during May 1982 (recorded by voice). Gerassimov (1993) confirmed nesting in the northernmost part of Sofia. Kyutchukov (1995) recorded a pair in a dense forested area in Western Park (3 July 1988).

Single birds were observed in a forested area near Suhodol (5-6 May 1999) and in a similar habitat with some huts near Boyana (25 May 2000). Three recently fledged juvenile birds (in mesoptile plumage) were observed several times in Gorna Banya during the period 12-16 June 2000. Adult birds fed juveniles ones on electric wire lines and in hybrid poplar trees. The pair in this region used an old nest of *Corvus corone cornix*, but nesting in a ceiling space or trunk hole is also possible. The territory where these observations took place is a peripheral part of a village, with houses and farm animal buildings. Tree groups, open fields and riverside poplar and willow formations are situated close to the place of observation. The pair may have come from Lyulin Mountain.

Long-eared Owl (*Asio otus*)

Nankinov (1982) reported this species as very abundant in Sofia (second only to the Little Owl). Nankinov also recorded breeding in the peripheral parts of the city and the adjacent zone. In inferior parts of Sofia it was only observed outside the breeding period. According to Yankov (1983) and Gerassimov (1993), the species rarely nest within the city. Only single nesting pairs have been recorded.

We recorded Long-eared Owls often in the city in appropriate habitats of the large city parks - Borissova Gradina and Southern and Western Park. They were also recorded in small park territories, tree groups along small rivers, large courts with trees planted, cemeteries, military zones and hospital parks. Long-eared owls increased in number during the 1990's. Ten nesting pairs were recorded in Borissova Gradina Park in 1999 and 2000. There are approximately 40 pairs in the city during the breeding period. The Long-eared Owls are also abundant in the surrounding vicinities of Sofia. Here, the species uses old nests of Corvidae. The availability of such nests is one of the main limiting factors in the species' distribution. Nests of *Pica pica*, *Corvus corone cornix* and *Garrulus glandarius* are important in the city landscape. These three species have increased in number in Sofia. This, together with the food availability promotes the colonization and increase in number of Long-eared Owl in the city

Competitive relationships have been recorded between *Asio otus* and *Falco tinunculus*. A female Long-eared Owl was chased away by a *Falco tinunculus* pair in May 1981 near Suhodol. A pair nesting in Borissova Gradina Park became victims of a *Accipiter gentilis* pair nesting nearly.

Short-eared Owl (*Asio flameus*)

Boev & Simeonov (1967) reported nests of this species close to the city. Several observations confirmed Short-eared Owl nesting in the peripheral parts of Sofia. Two juvenile birds in neoptile plumage were recorded near Krasno selo (23 May 1952) and another two in transitional neoptile-mesoptile plumage near Gorna Banya (15 May 1960). Both these areas were, however, villages outside the city until the middle of the twentieth century, with a different environment, compared to the present.

Short-eared Owls have not been recorded confidently since the above mentioned recordings in the whole of Bulgaria. During the last decades many marshes in the region of Sofia, suitable for nesting, had been drained (Nankinov, 1982), and the species has not been recorded in Sofia during the nesting period. Yankov (1983) and Gerassimov (1993) also failed to confirm nesting of this species in the remaining suitable regions in and around Sofia.

We observed single individuals near Gorni Bogrov village at the end of August during the whole period of study. No nests were observed. Simeonov *et al.* (1990) considered August as the beginning of migrations through Bulgaria. The southern border of the species' nesting territory crosses Bulgaria (Simeonov, 1985), and it is, therefore among the 19 diurnal and nocturnal birds of prey, represented in Bulgaria by their "skeletal" (remnant or relic) populations (Boev, 1990).

DISCUSSION

Our study (1979 to May 2001) confirmed the nesting of five diurnal bird of prey species in the region of Sofia: *Accipiter gentilis, Accipiter nisus, Buteo buteo, Falco tinunculus* and *Falco subbuteo*.

Among them, *Falco tinunculus* is the most widespread species. This species has increased in number and in area of distribution in the region of Sofia since the 1990's. In some large living complexes (for example Lyulin) the number of individuals and nesting pairs is equal to that of the surrounding territories. As a whole, *F. tinunculus* is the most abundant bird of prey in the open territories around Sofia and in Bulgaria (Delov & Stoyanov, 1994; Nankinov *et al.*, 1991). The Sparrow-Hawk (*Accipiter nisus*) has also increased in number of nesting pairs in the city, but not as much as *F. tinunculus*.

The Goshawk was recorded for the first time as a nesting species in the city. This species uses nesting habitats in forested areas in the city. It is also among the most abundant nesting birds of prey in the surrounding mountains. Bogdanov (1993) recorded seven nesting pairs close to Sofia. Our results showed that in the 1980's 15 nesting pairs were established around the Sofia plains. At the end of the 1990's the number of nesting pairs decreased in these regions, as well as in other regions of Bulgaria. The reasons for this are not clear, but possibly include illegal hunting, anthropogenic pressure on forests, forest fires, and collection of medicinal plants and mushrooms.

Sparrow Hawks increased in number during the 1980's and 1990's, particularly in park areas. They were also found in guarded places with many trees, like military and industrial zones and residence parks.

Nesting of the Common Buzzard was recorded only once in the southwestern part of the city, in a forest territory close to open fields near buildings. This case and the case reported by Gerassimov (1993) are the first two records of nesting pairs in Sofia.

Falco naumanni was not found to nest in the city and the surrounding territories, and is therefore considered to be extinct in Sofia.

The Hobby was recorded only once, a recently fledged juvenile bird. It may be that nesting does occur in the peripheral parts of the city. Nevertheless, this species is rare in the region of Sofia, and its occurrence is restricted mainly to territories outside the city.

Although Peregrine nesting was recorded outside the city, it uses the city territory for feeding. Pairs were, however, recorded on high buildings in Sofia at the beginning of the breeding period. It was more frequently observed in the city, and is expected to start nesting within the city in the near future. Nests can be promoted by building of nesting platforms on high buildings.

Four nocturnal birds of prey, nesting in the territory of Sofia, were recorded. These are Scops Owl, Little Owl, Tawny Owl and the Long-eared Owl. Little Owl is the most abundant and widespread species with 120 pairs recorded all over the city. Highest densities, 3-4 pairs per km^2 were recorded in the peripheral living complexes like Lyulin and Mladost. This species is also similarly abundant in certain central parts of the city, characterized by densely built houses, old houses, or a combination of the two.

Second in abundance and area of distribution is the Long-eared Owl. This species shows a patchy distribution, because of the patchy availability of parks, forests or tree groups near open fields. During the 1980's and 1990's this species colonized new territories. These are small gardens in the city. This species also increased in density in already colonized territories like Borissova Gradina Park and Hunting Park. The availability of old nests of Corvidae represents a limiting factor for this species' abundance and area of distribution. The considerable increase in number of *Pica pica*, *Corvus corone cornix* and *Garrulis glandarius* caused an increase in number of the Long-eared Owl. We expect this species to continue to increase in density in Sofia.

We recorded the Tawny Owl for only the second time in Sofia (see Gerassimov, 1993). *Tyto alba* and *Asio flammeus* were not recorded here and we therefore consider that they do not nest in Sofia anymore.

For the Barn owl it can be suggested that in the future it will be reported again as a nesting species in Sofia.

A number of factors influence colonization success of diurnal and nocturnal birds of prey in Sofia, for example, city expansion and changes in the physiognomy of many living complexes built after the 1960's. Examples include some new complexes consisting mainly of high concrete buildings, which are a new and specific nesting habitat for many bird species. *Falco tinunculus* and *Athene noctua* in particular use these new nest areas.

Kestrels prefer 25-50 m high buildings. Here the Kestrel uses large and deep platforms and bays 30-40 cm wide, 25 cm high and 25 cm deep. Kestrels also nest in the numerous high buildings under construction, towers and cranes.

In the urban environment, many park areas of different types are important prerequisites for colonization by dendrophyllous birds of prey. In particular, during the last 50 years most park areas obtained their current characteristics i.e. stand height and density, and availability of food and nesting habitats.

The numerous holes in high buildings are very suitable for pigeons and are therefore called "big pigeon farms" (Nankinov *et al.*, 1990). Pigeons (*Columba livia* var. *domestica*) are a food source for some birds of prey (Goshawks, Peregrines and in some cases the Sparrow Hawk). Other species are also important food sources, like *Passer domesticus*, *Passer montanus*, *Sturnus vulgaris*, *Pica pica* and others. Rodents also increased in number during the last decades. These include *Mus musculus, Rattus norvegicus* and *Microtus arvalis* in grass landscapes. The reason for this is the low level of hygiene in urban areas, as well as irregular mowing of grass fields (Dr. Tamara Lazarova, National Institute of Parasitology, pers. comm.). The most active hunters in urban territories are *Falco tinunculus* and *Athene noctua*. These species feed on rooftops and near walls in densely populated areas.

Of further interest is the observation that the most abundant species in Bulgaria are also the most abundant species in Sofia. These include *Falco tinunculus*, *Athene noctua* and *Asio otus*. These species can be considered generalists. The colonization of urban areas by *Asio otus* is probably because of the high number of *Pica pica, Corvus corone cornix* and *Garrulus glandarius* in Sofia. Birds of prey also find many appropriate nesting habitats close to the city. Individuals are, therefore in close contact with the urban environment and colonization of the urban landscapes appears easy.

Park areas and riverside trees within the city are important for forest-related (dendrophyllous) species. These are natural corridors, promoting the colonization of urban areas from the surrounding landscapes. On the other hand, dendrophylous species (i.e. the Goshawk, Sparrow Hawk and Long-eared Owl) prefer large forested park areas.

Bird houses and nesting platform installations on different types of buildings, electricity poles (especially the non-active ones) and suitable trees can significantly promote the nesting of some species in urban areas and closer suburbs. These include Peregrines, Kestrels, Little Owls, Scops Owls and Tawny Owls. This is important because in many places in Sofia the food source is sufficient, while appropriate nesting sites are insufficient or lacking.

Some of the birds of prey recorded in Sofia during the breeding period may have escaped from "falconists" or other people, who kept them in cages. In many cases people brought these young birds of prey to the Sofia Zoo. These mainly include *Accipiter gentilis*, *Falco peregrinus*, *Falco tinunculus* and *Accipiter nisus*. Many birds of prey have also been recorded flying above the Sofia Zoo, being attracted by birds in the Zoo. Some species, therefore, were recorded, even though they were not breeding in the city. These include *Aquilla chrysaetos*, *Aquilla pomarina* and *Bubo bubo*, who nest in the mountains around Sofia.

The following factors influence nesting in Sofia negatively:

1. Anthropogenic factors

- direct decease of birds as a result of accidents and flying into cars, electric wires and windows;
- closing and covering up of small entrances and holes in buildings, and thus reducing nest sites;
- cutting of old trees with trunk holes (mainly poplars) in many parts of the inner city, along the roads and in parks (often with no acceptable reason and during the breeding season of birds), as well as by reducing green areas;
- performing "sanitary cuts" (i.e. removing dead trees) in the city forests during the breeding period;
- egg loss from steep nesting platforms. In many cases this is because of a limited choice of nesting sites in high buildings;
- falling of young from the nests before or during first flight attempts – this has been observed many times and is largely typical for the Kestrel and the Little Owl; in most cases such an accident is a result of a lack or shortage of suitable alighting places for the young, still hardly well flying birds;
- construction and repair work on buildings during the breeding period;
- architectural changes in buildings, providing less nesting sites;
- egg and juvenile bird collection by "falconists" or other people;
- killing of birds of prey feeding on chickens or pigeons;
- killing of birds of prey due to superstition, hygienic reasons and others;
- dying of birds after enrolling in synthetic wires (used for straw balling). We recorded such cases in Kestrel, Long-Eared Owl and Little Owl. They concerned both adults and juveniles in nests. Such synthetic wires are often used in nest building of Magpie in roofs in city surroundings, whose nests are used by the above mentioned birds.

2. Natural factors
- juvenile birds killed during severe storms;
- in some cases smaller birds are part of the diet of larger birds. For example, the Long-eared Owl forms part of the diet of Goshawk in Borissova Gradina Park.
- falling of feeding birds of prey into dense tree and shrub vegetation. As a result they die or are being captured by people. For example, Sparrow Hawks falling down on spines of a Hawthorn while feeding on passerine birds.

ACKNOWLEDGEMENTS

We would like to thank to all people, who provided unpublished data: Prof. D. Nankinov, B. Nikolov, V. Delov, St. Yotov, V. Bozhilov, N. Minchev, P. Dimitrov, R. Kolchagov, A. Stoyanov, B. Petrov, Z. Boev, St. Bogdanov, P. Tenchev, N. Davidkov, V. Mustakerski, S. Cheshmedzhiev, Y. Muhtarov, A. Dutzov, R. Kostov, N. Chakarov and T. Lazarova. P. Zhelev helped with the English translation. Special thanks are due to Johan Kotze and Lyubomir Penev for the numerous suggestions that improved considerably the earlier draft of manuscript, as well as to Stoyan Yotov for the final proof –reading and amendments to the English translation of this paper.

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Magpie (*Pica pica*) Population Density and Habitat Distribution in the City of Sofia

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Summary

Research on the Magpie (*Pica pica*) was carried out in the territory of Sofia during the summer periods of 1998/99, and the winter periods of 1997/98 and 1998/99. The number of breeding Magpies was estimated to be 690 pairs. Density of the pairs varied widely, between 0,07 and 3,04 pairs/10ha. The average density for the entire study area was 0,41 pairs/10ha. The density of breeding Magpies in the seven investigated habitat types ranged from 0,09 to 1,59 pairs/10ha and the highest density was recorded in natural biotopes and in riverside belts. It, therefore, appears that Magpies colonize the city along natural corridors, i.e. rivers and parks. Breeding Magpies were scarce (0,09 pairs/10ha) in the city centre, probably because of human pressure and living conditions in Sofia.

Key words

Magpie *Pica pica*, breeding density, habitat distribution, urban habitat.

INTRODUCTION

In Bulgaria the Magpie is a common bird species in and around urban habitats, such as cities, towns and rural areas (Donchev, 1958). Although anthropogenic landscapes of big cities are not typical living conditions for this species, it has succeeded in adapting to some new habitat types created by humans. According to Nankinov (1981,1982) and Iankov (1983) the mass movement of Magpies into anthropogenic landscapes of towns and villages began in the 1960-s, mostly along river valleys and suburban parks. Many European authors (Tatner, 1982; Bokotey, 1997; Gorski, 1997; Jersak, 1997; Witt, 1997) noted that the population density of Magpie was highest in parks and city suburbs and gradually increased in central parts of the cities/towns. The colonization of new urban territories appeared to be mainly along natural ecological corridors (rivers and parks), moving from the periphery of city to its centre.

L. Penev, J. Niemelä, D. J. Kotze & N. Chipev (Eds.) 2004. Ecology of the City of Sofia. Species and Communities in an Urban Environment, pp. 451-455

The aims of this study were to obtain information on the population density of Magpies in the territory of Sofia and to map Magpie pairs in different habitats in Sofia.

MATERIALS AND METHODS

The present study was carried out in the territory of the city of Sofia. The size of the study area was approximately 170 square kilometres. Field observations were made from November 1997 to May 1999. Fieldwork was mainly conducted during the Magpie breeding period. Territory mapping was used to estimate Magpie number and density. The study area was divided into 180 UTM grid squares 1 km^2 each (Iankov, 1983). Standardized sampling took place in each grid square. The number of breeding Magpies was determined on the basis of built and inhabited nests, and most positions were marked on the map. Observations were made during the morning (between 8 and 11 o'clock) and in the afternoon (between 4 and 6 o'clock). Each plot was visited at least twice.

I also calculated the density of breeding Magpies in pairs per 10 ha. A similar study was conducted by Iankov (1983) and I compared his nests density reported in 117 plots with the number of nests found here.

Seven biotopes were to determine the density of breeding pairs of Magpies in different habitats of the city, i.e housing estates, open areas, natural and modified riverside belts, parks and gardens, industrial zone, rural zone and the city centre.

RESULTS AND DISCUSSION

Density of breeding pairs in plots

690 breeding pairs were recorded in Sofia. The highest density reported was 3,04 pairs/10ha and the lowest was 0,07 pairs/10ha. Density differences are shown in Fig. 1.

The highest density was recorded in plot J16 – 3,04 pairs/10ha. This square covers an industrial district, a small part of a housing estate and a large part of an open area. Its high density was due to the presence of a large number of suitable sites for nesting, i.e. tall tree species (*Populus sp.*) in the yards of the industrial complexes. The open areas in this square provide possible food sources.

Nineteen plots had no breeding pairs, while three plots were characterized by low Magpie density. These plots cover two zones in the territory of the city with exceptionally low density.

One of these zones is the central part of the city of Sofia. The low density and absence of breeding pairs here are due mainly to the following factors: a) densely built-up area with little natural habitat, b) insufficient number of trees suitable for nesting, and c) absence of places for finding food.

The second zone was the southwestern part of the city that includes housing estates with low buildings (houses and villa districts). These housing estates are located in thick forest lands, avoided by Magpies.

In the remaining plots, the density of breeding pairs varied betwen 0,11 and 1,59 pairs/10ha.

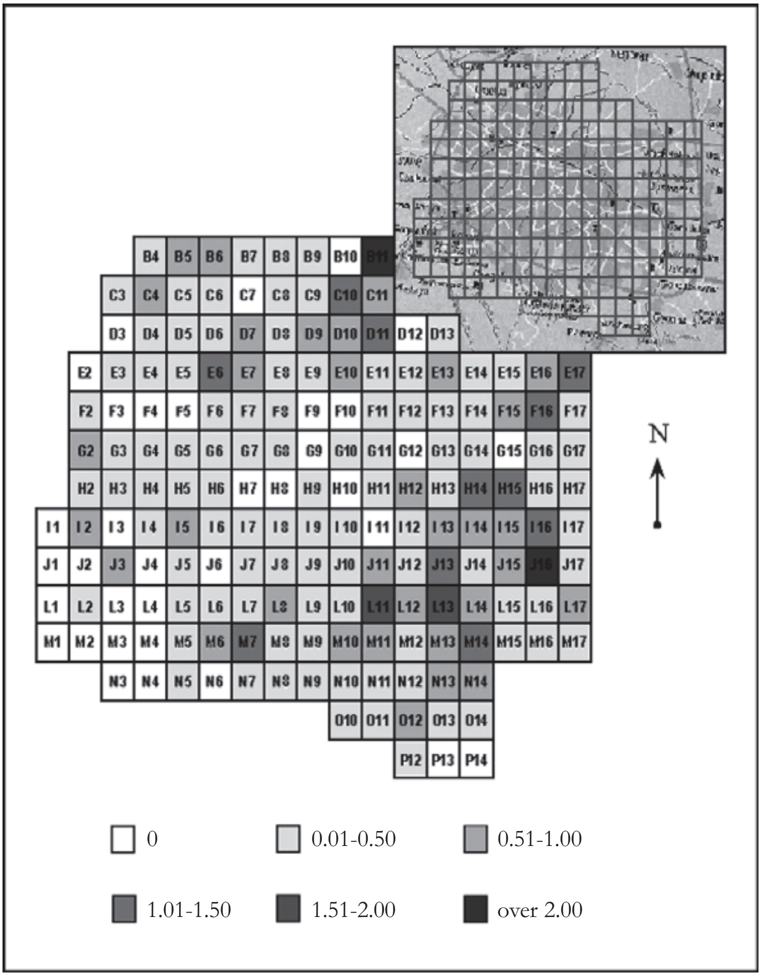

Fig.1. Magpie density, pairs/10 ha, in the territory of the city of Sofia.

Iankov (1983) studied the distribution of Magpie in Sofia and reported 268 pairs in 117 plots. 564 pairs were reported in these plots - more than doubling in pairs over a 17-year period. This increase was probably gradual and is likely to continue in the future, since non-breeding Magpies have regularly been observed in the central parts of the city. In 80% of the plots compared, a considerable increase (four times) in number of breeding pairs was observed (from 1983 to 1999), and in only 20% of the plots there was a decrease during this time. The decrease is most likely explained by an increase in built-up areas and human settlement. Nevertheless, our data showed mass colonization by Magpies in the city of Sofia.

My results are in agreement with other studies done in Europe. For example, in Berlin Witt (1997) showed a density increase in Magpies of more than three times over a seven year period.

In Lvov (Ukraine) the density of breeding Magpies was 0,8 pairs/10ha (Bokotey, 1997). In Poland Gorski (1997) studied 11 towns and 6 areas of farmland in Koszalin Region. Gorski reported that the breeding population of the Magpie in towns almost doubled in the period between 1978-82 and in 1992. In Warsaw the density of breeding Magpies was estimated to be 0,6-0,8 pairs/10ha (Luniak *et al.*, 1997).

Density of breeding Magpies in different habitat types

Various habitat types are presented in big cities, with some still in their original condition (river banks in the suburbs), and others characterized by natural vegetation (parks and forest parks). Other parts are completely changed (housing estates, city centre) or have originated as a specific anthropogenic region (industrial zones). Magpie distribution was studied in seven different biotopes of the anthropogenic landscape.

Housing estates

This biotope is characterized by multi-storeyed buildings, streets, lanes, open-air kindergartens as well as various tree species. Newly built housing estates and houses built about 20-30 years ago are also in this biotope type.

Five plots had a highest density of Magpies (between 2,04 and 3.04 pairs/10ha). These plots include parts of old housing estates with many suitable nest sites and grassy areas nearby, suitable for finding food. Most of the plots in this biotope had relatively low breeding densities (0,13-0,96 pairs/10ha) with the biotope average being 0,38 pairs/10ha. This low value is possibly because of the densely built-up nature of this biotope. There are suitable sites for nesting, but they appear to be unattractive for Magpies.

Open areas

Open areas are expansive areas among housing estates and in the suburbs, characterized by grassy vegetation with some trees. The average density of breeding pairs of Magpies here was 0,26 pairs/10h, which is about half the average value for the whole area studied. This is mainly because of a lack of trees appropriate for nesting. Open areas were often visited by Magpies to find food and nest material.

Natural and modified riverside belts

This biotope with its riverside vegetation and its adjacent green areas provides an environment similar to natural habitats for Magpies, and was therefore one of the most attractive biotopes for Magpies. The highest density of breeding pairs (1,59 pairs/10ha) was observed here, which was almost four times higher than the study area average (0,41 pairs/10ha). The highest density of Magpie pairs was observed along the riverbanks of Suhodolska and Darvenishka rivers (between 6,38 and 20,83 pairs/10ha). These areas were also favourable for Magpies since they pass through housing estates and rural houses where additional sources of food are found. Colonization of new territories in the city seems to take place along natural corridors, i.e. rivers and parks, dispersing from the periphery to the city centre (Nankinov, 1982; Iankov, 1983).

Parks and gardens

This biotope is quite similar to natural habitats for Magpies. A high density of breeding pairs was observed in four small parks. It shows that Magpies prefer single or small groups of trees located near open areas. For example, a high pair density was recorded in Yuzhen Park (1,00 pairs/10ha) which is characterized by woody areas alternating with open areas. Parks without open areas, however, had low Magpie pair-density (Loven and Zapaden parks). The mean density of Magpies for this biotope was 0,37 pairs/10ha. Salaj (1991) also noted that the highest density of Magpie nests was in gardens and cemeteries of villages and lowest in town centres.

Industrial zone

This biotope is not typical for Magpies (many large buildings, noisy areas and poor vegetation), nevertheless some Magpies occurred here. However in Sheffield (England) in 1977, a study showed that the only territory where Magpies were missing or their density was very low, were the industrial districts of towns (Gilbert, 1991). In spite of this, the author observed a quick invasion of Magpies in unfavourable industrial regions. In the present study, the density of breeding pairs in this biotope was 0,59 pairs/10ha, one of the highest in the area studied. Possible reasons include the availability of single and small groups of poplars (*Populus sp.)*, preferred by Magpies for nesting, and large grassy territories located nearby which are appropriate for finding food.

Rural zone

This biotope is characterized by one-family houses with big yards, grassy areas, shrubs and various fruit trees, and also appears to be one of the most favourable areas for Magpies. In this biotope the highest number of breeding pairs (182 numbers) was recorded. However this area is large (3175,62 ha), and the density of Magpie pairs was therefore relatively low, 0,57 pairs/10ha. One of the most important factors for the settlement of Magpies in this biotope is the possibility of finding food near houses and in agricultural areas.

City centre

The city centre is a densely built-up area, with few open areas between buildings. The ground surface is covered with asphalt, pavement and other solid materials, with almost no green spaces with vegetation. It is therefore not surprising that the density of breeding pairs in this biotope was very low, i.e. 0,09 pairs/10ha. This very low density of breeding pairs in the centre of Sofia is due to strong human pressure caused by vehicles, noise, air pollution, and the absence of nesting and feeding sites. Bokotey (1997) showed that the highest density of breeding Magpies was in parks and in areas of one-family houses (1,2 pairs/10ha), and the lowest in city centres and industrial districts (0,4 pairs/10ha).

ACKNOWLEDGEMENTS

I want to thank Prof. B. Ivanov for valuable and useful advice during the research, Dr. P. Iankov for his participation in the inventory work, my colleagues who helped me in field investigations, and my sister for translaing this manuscript into English, as well as to Dr. D.J. Kotze for editing the English text.

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