Environment

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

Lyubomir D. Penev [1], *Ivailo L. Stoyanov* [1], *Ivailo Dedov* [1], *Dimitar Dimitrov* [2], *Maria Grozeva* [3], *Vania Doichinova* [3]

[1] Central Laboratory of General Ecology, 2 Yurii Gagarin Str., 1113 Sofia
[2] National Museum of Natural History, 1 Tzar Osvoboditel Blvd., 1000 Sofia
[3] Forest Research Institute, 132 St. Kliment Ohridski Blvd., 1756 Sofia

Abstract

The present work 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 have 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.

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 the species' behavior in and biotic communities' responses to urbanization processes is one more 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 life conditions for the people. About an extensive summary on the role of soil ecology (and particular soil zoology) in this process see Whiteley (1994).

The urbanization processes seems to be a factor having quite similar characteristics in different parts of the world. Although this statement appears intuitive, some evidence exists, that the landscape structure affected by urbanization retains its specificity at different places over the globe (Reynaud & Thioulouse, 2000), while the globalization leads to a "uniformity" in the look

L. Penev, J. Niemela, J. Kotze & N. Chipev (Eds.) 2003. Ecology of the City of Sofia. Species and Communities in Urban Environment, pp. 3-24
© PENSOFT Publishers
Sofia-Moscow

of big cities around the world, and how they affect the natural flora and fauna. At the same time, the urbanization exists in virtually all floristic/faunistic regions of the Globe, affecting in this way local floras and faunas of rather different features, such as species composition and diversity, age of association, adaptiveness and so on. Hence, the idea of investigation of the impact of "a common factor onto different floras/faunas in different ecological/historical conditions" or "intercontinental community convergence" (Schoener, 1998) finds its very appropriate application in times of a 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 1997 by Jari Niemelä and co-workers at the first GLOBENET-Workshop in Helsinki, Finland (Niemelä et al., 1999; Niemelä & Kotze, 2000). The basic concept lies in the presumption, that monitoring the 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 towards the anthropogenic pressure, about ideas how to estimate, compare, and predict the human effects among the different regions (Niemelä & Kotze, 2000).

The idea has quickly found sympathizants and 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 have been reported at the Second GLOBENET-Meeting carried out 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 etc.

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

The general information about 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 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. The altitude was measured with a portative altimeter. Additionally, data about the tilt, origin, age and height of the tree-stands, measurements were obtained from the database of the Forest Committee. The canopy 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. The thickness of leaf-litter 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 have 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 ones we used the classification of FAO-UNESCO (1988). The chemical and mechanical properties of soil at the sampling sites were obtained as follows: the pH was potentiometrically estimated using a "Practronic MV98"; the organic carbon and humus were assesed with the Turin method (e. g. Arinushkina, 1970); the nitrogen contents of the soil was estimated as Total Kjeldahl Nitrogen (TKN) (Isaac & Johnson, 1976); the mechanical composition was determined following the method of Kachinsky (1958).

In the numerical analyses the data presented in Tables 1-4 (except only 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 the abbreviation 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

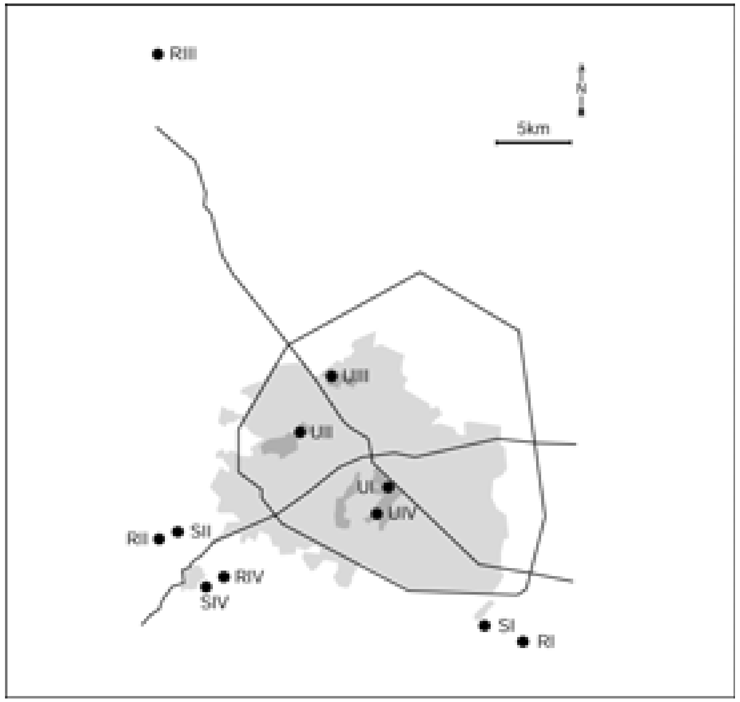


Fig. 1. The Sofia GLOBENET sites: U1 – Knyaz Borissovata Gradina; U2 – Zapaden Park; U3 – Severen Park; U4 – Loven Park; S1 – SE of German Village; S2 – locality Vilite (Lyulin Mt.); S4 – SE of Vladaya Village (Vitosha Mt.); R1 – S of Germanski Monastery (Lozenska Mt.); R2 – N of locality "Manastirski 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 modifying effect 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 radial trough 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 the 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 Sofia city is comparatively milder, than in 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 the sites Knyaz Borisova Gradina (U1) and Zapaden Park (U2), are characterized by a reach humus horizon with 5-6 % content of 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. The 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) posses typical anthropogenic features. Their chemical reaction is

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

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 previousli 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 increasing the altitude up to 700–800 m a. s. l., thinner maroon soils become prevailing at the sites "R3" and "R4". The site near German Monastery (R1) differs by the low alkaline reaction (pH 6–8) of its soils, due to the carbonate basic rocks prevailing in that area. In the negative forms of the relief, as it is the case at the 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 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 three 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 Planina Region – "R2". All this reflects in some 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). The sites "S2", "R2", "S4" and "R4" approach the beech-woods belt.

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

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* prevail. 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 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 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). The 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 ploycarpae). 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* dominating, while *Carpinus betulus* being also very common (formation Querceta sessiliflorae). The plot "R2" is a mixed deciduous forest dominated by *Carpinus betulus* and *Quercus polycarpus* (formation Querceta ploycarpae). The highly isolated forest, where the sampling site "R3" is located, is dominanted by *Quercus cerris*. Finally, the 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 most clear support of our initial working

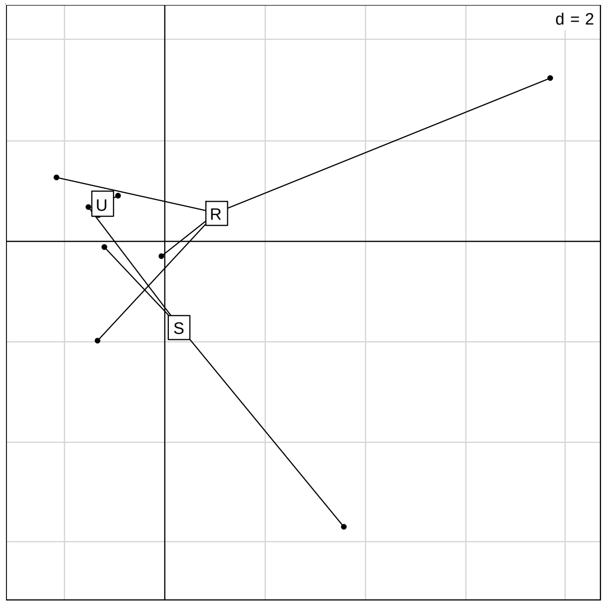


Fig. 2. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of grasses.

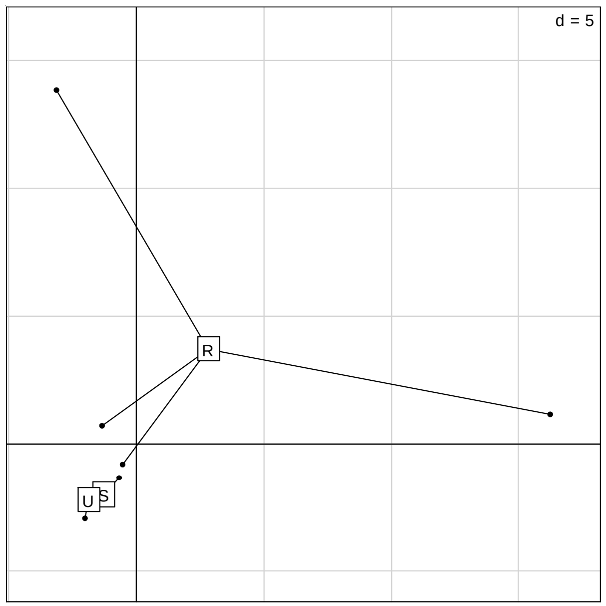


Fig. 3. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of herbs.

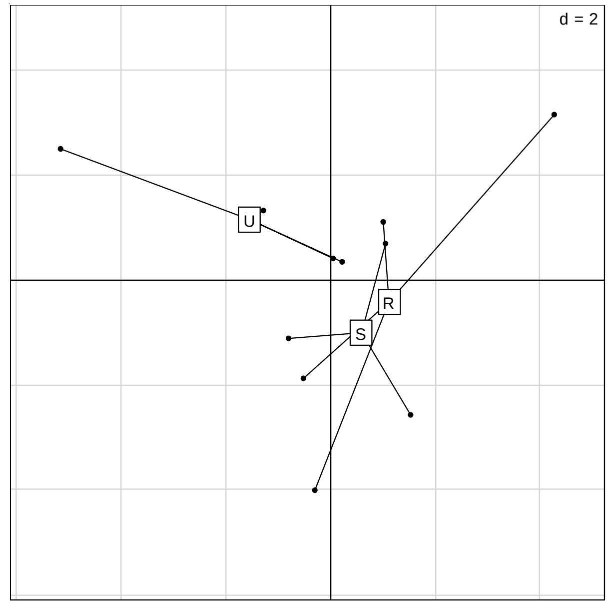


Fig. 4. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of shrubs.

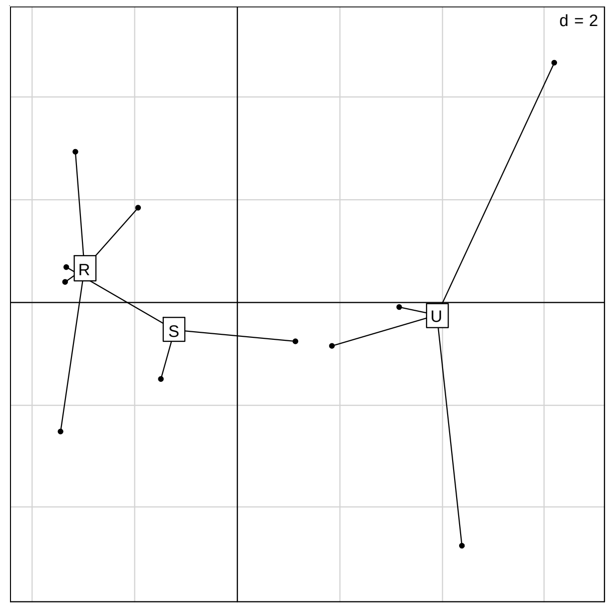


Fig. 5. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on species composition of trees.

hypothesis (i. e. the urban-to-rural gradient) show the tree stratum of the vegetation communities (Fig. 5). As the plant-size decrease (resp. its edification role), trough 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 one. 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 (while the already discussed vegetation data remaining in the analysis), the picture of the urban-to-rural gradient becomes even more clearer (Fig. 7). The urban zone is again clearly opposing 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 twice less variation of the dataset, and is most strongly correlated with the 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

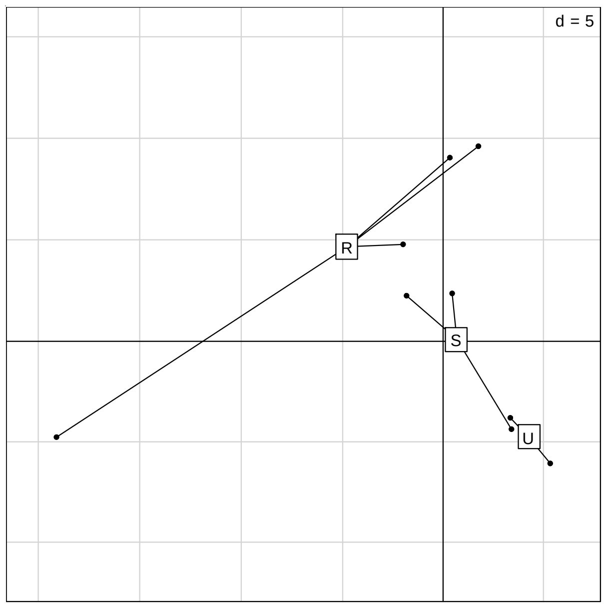


Fig. 6. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on all plant species.

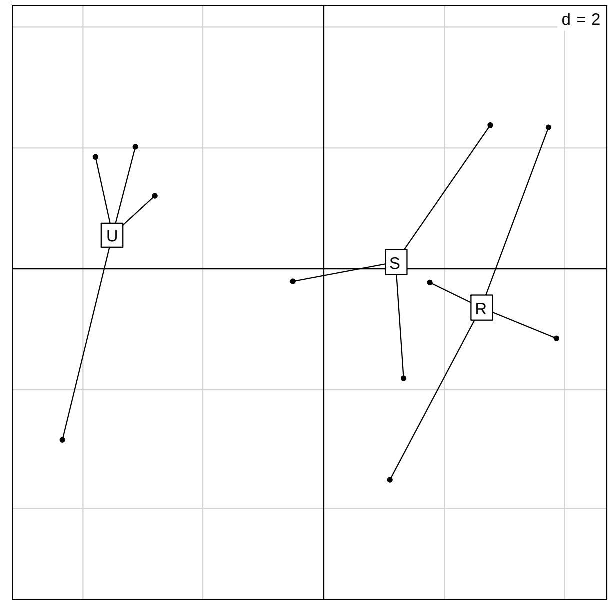


Fig. 7. PCA ordination of the Sofia GLOBENET sites (grouped by zone), based on environmental variables.

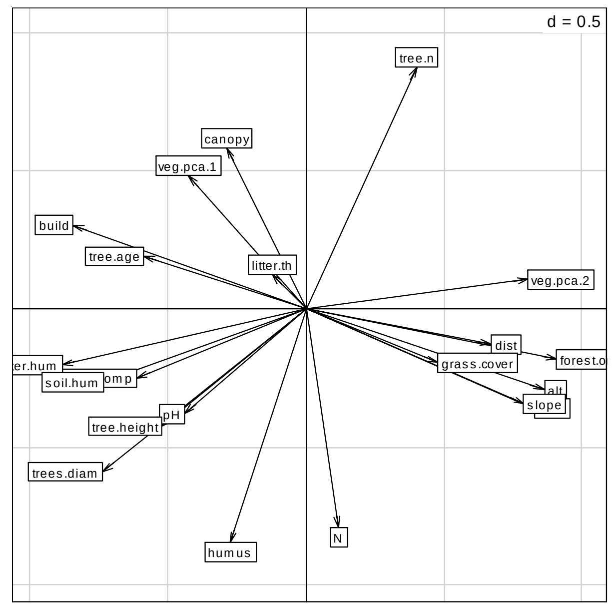


Fig. 8. PCA ordination of the environmental variables measured at the Sofia GLOBENET sites (F1=40.5%, F2=19.6%).

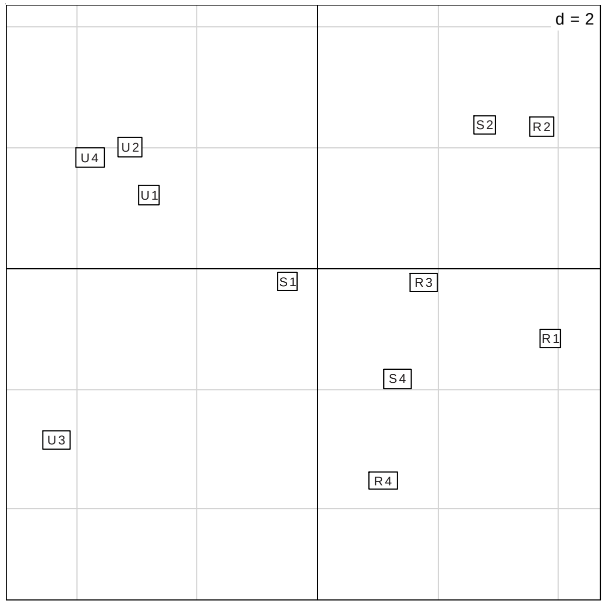


Fig. 9. PCA ordination of the Sofia GLOBENET sampling sites, based on environmental data (the factorial plane summarizes 60.1% of the total dataset variability).

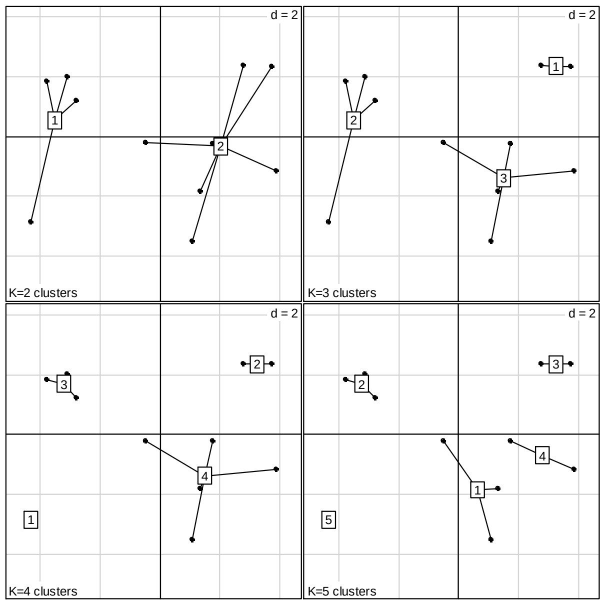


Fig. 10. Sequential "K-means" (starting from K=2 to K=5) clustering of the PCA ordination of Sofia GLOBENET sites, based on environmental data.

landscape 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 the isolated position of the sites at Lyulin Mt. – S2 and R2). The urban cluster becomes parted until 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 as 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 PC 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).

REFERENCES

Arinushkina E.V. 1970. *Manual for Chemical Analysis of Soils*. 2nd Ed., State University, Moscow, 487 pp. [In Russian]

Bluskova, D., Zlatkova, L., Lingova, S., Modeva, Z., Subev, L. & Teneva, M. 1983. *Climate and Microclimate of Sofia*, Sofia, Publishing House of the Bulgarian Academy of Sciences, 153 pp. [in Bulgarian]

Bondev, I. 1991. *Vegetation of Bulgaria*. Sofia, "St. Kliment Ohridsky" Publishing House. 183 pp.

FAO-UNESCO 1988. Soil Map of the World, Revised Legend, Rome.

Gencheva, S. 1995. Classification and peculiarities of the anthropogenic soils. PhD Thesis, Sofia, University of Forestry, 48 pp.[in Bulgarian]

Hartigan, J.A. & Wong, M.A. 1979. A K-means clustering algorithm. *Applied Statistics* 28: 100–108.

Ihaka, R. & Gentleman, R. 1996. R: A Language for Data Analysis and Graphics. – *Journal of Computational and Graphical Statistics* 5(3): 299-314.

Isaac, R. A. & Johnson, W. C. 1976. Determination of total nitrogen in plant tissue, using a block digestor. – J. Assoc. Off. Anal. Chem. 59: 98–100.

Jordanov, D. 1966. Flora Bulgarica, vol. III, Sofia, Publishing House of the Bulgarian Academy of Sciences, 635pp. [in Bulgarian]

Kachinsky, N.A. 1958. *Mechanical and micro aggregate composition of soils and methods for their investigation*, MGU-Press, Moscow, 192 pp. [in Russian]

Niemelä, J., Kotze, J., Ashworth, A., Brandmayr, P., Desender, K., New, T., Penev, L., Samways, M., & Spence, J. 1999. The search for conmmon anthropogenic impacts on biodiversity: a global network. *Journal of Insect Conservation* 3: 1-7.

Niemelä, J. & Kotze, J. 2000. GLOBENET: the search for common anthropogenic impacts on biodiversity. In: *Natural History and Applied Ecology of Carabid Beetles, Proceedings of the IX European Carabidologists Meeting, Cosenza, Italy, 26-31 July, 1998*. (Brandmayr, P., Lövei, G., Brandmayr, T. Z., Casale, A., Vigna Taglianti, A., Eds.), pp. 187-196, Sofia-Moscow, Pensoft Publishers.

Ninov, N. 1997. Soil-geographic regioning. – In: *Geography of Bulgaria*. (Yordanova, M. & Donchev, D., Eds.), pp. 251-257, Sofia, Bulgaria, "Prof. Marin Drinov" Academic Publishing House. [in Bulgarian]

Reynaud, P.A. & Thioulouse, J. 2000. Identification of birds as biological markers along a neotropical urban-rural gradient (Cayenne, French Guiana), using co-inertia analysis. – *Journal of Environmental Management* 59: 121-141.

Smilenova, L., Bozhilova, M., Starikova, L. (Eds.) 1996. Sofia/Vitosha maps (1:20000/1:50000), Sofia, Kartografia, 47 pp. [in Bulgarian]

Stoyanov, N. 1937. The vegetational relationships in the Sofia kettle. – *Agronomo-lesowudski Godishnik* 1: 1-40. [in Bulgarian]

Vaptzarov, I., Alexiev, G. Vlaskov, V. 1997. Geomorphologic regioning, In: *Geography of Bulgaria*. (Yordanova, M. & Donchev, D., Eds.), pp. 103-105, Sofia, Bulgaria, "Prof. Marin Drinov" Academic Publishing House. [in Bulgarian]

Velev, S. 1997. Climatic regioning, In: *Geography of Bulgaria*. (Yordanova, M. & Donchev, D., Eds.), pp. 127-130, Sofia, Bulgaria, "Prof. Marin Drinov" Academic Publishing House. [in Bulgarian]

Whiteley, D. 1994. The state of knowledge of the invetrebrates in urban areas in Britain with examples taken from the city of Sheffield. – *Memorabilia Zoologica* 49: 207-220.

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.						+	+	+	+	+	+

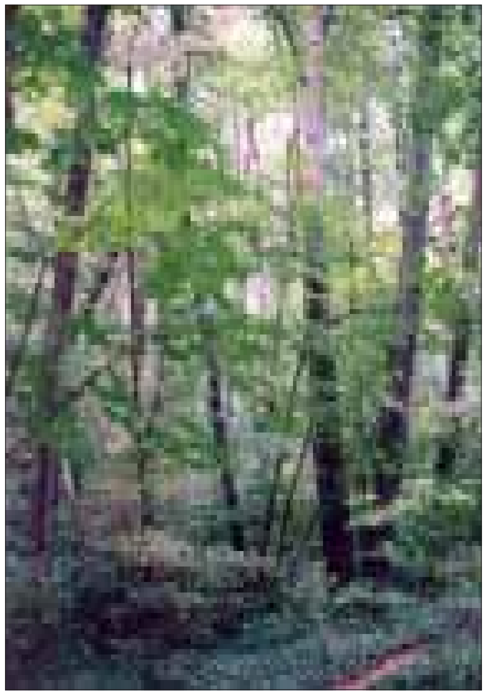
Appendix I. Continued.

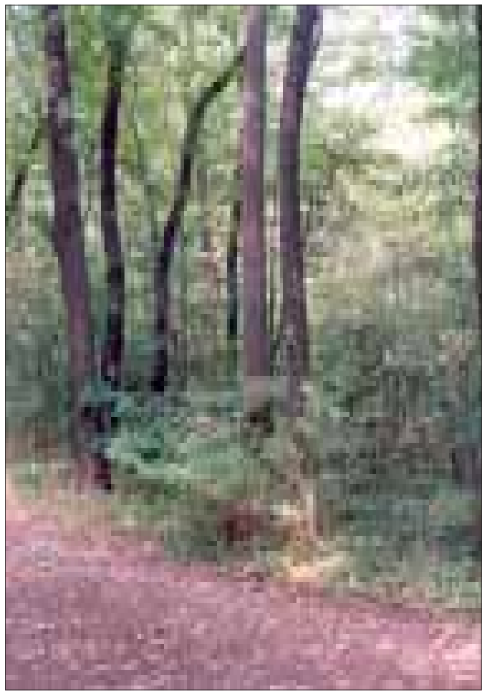
	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4
Hieracium laevigatum Willd.											+
Hieracium umbellatum L.											+
Hypericum perforatum L.	+										+
Knautia drymeja Henff.					+				+	+	+
Lamium purpureum L.						+					
Lapsana communis L.											+
Lathyrus laxiflorus (Desf.)							+	+	+		
Lathyrus niger 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.

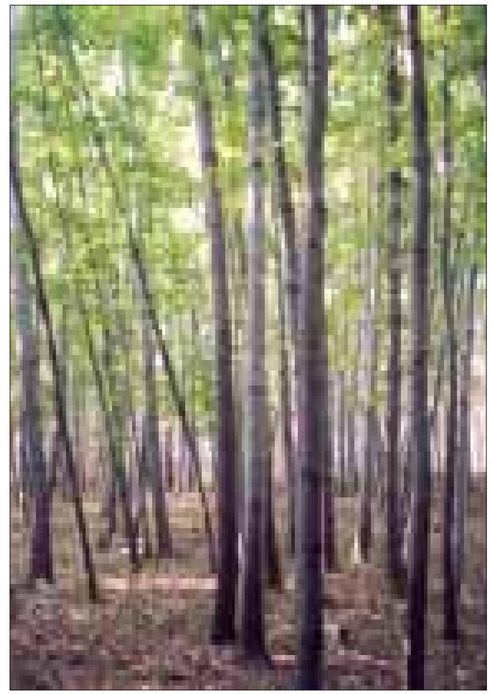
	U1	U2	U3	U4	S1	S2	S4	R1	R2	R3	R4
Sanicula europaea L.	+					+		+			
Silene alba (Mill.)							+				
Sonchus asper (L.)	+										
Stachys germanica L.					+						
Stachys recta L.					+						
Stellaria holostea L.						+	+	+	+		
Stellaria media (L.)	+										
Stellaria nemorum L.							+				
Symphytum 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.									+		

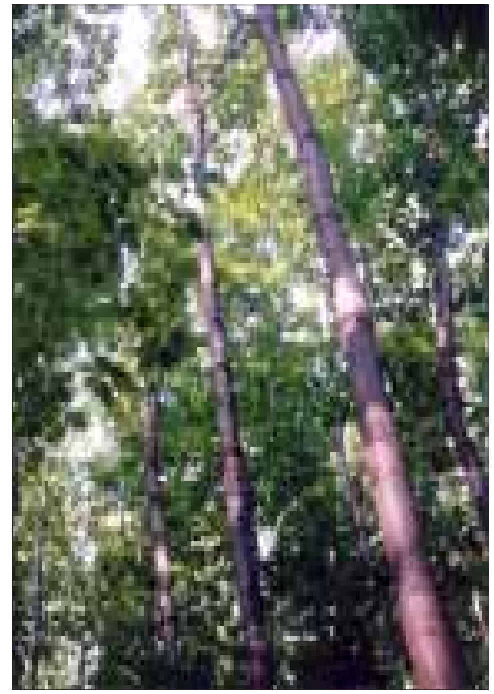
Appendix II A. Appearance of the Sofia GLOBENET sites (gradient 1) – Knyaz Borissovata Gradina (U1).





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).