UDC [595.142+595.4]: 591.52

COMPARISON OF EARTHWORMS (LUMBRICIDAE) AND ORIBATID MITE (ACARI, ORIBATIDA) COMMUNITIES IN NATURAL AND URBAN ECOSYSTEMS

M. Murvanidze[1], E. Kvavadze[2], L. Mumladze[3], T. Arabuli[4]

[1,2,4] *Entomology and Biocontrol Research Centre of Ilia State University,*
  Chavchavadze ave., 31, Tbilis, 0179 Georgia
 [3] *Institute of Ecology of Ilia State University, Cholokashvili ave., 3-5, Tbilisi, 0162 Georgia*
 e-mail: maka.murvanidze@iliauni.edu.ge

Comparison of Earthworm (Lumbricidae) and Oribatid Mite (Acari, Oribatida) Communities in Natural and Urban Ecosystems. Murvanidze M., Kvavadze E., Mumladze L., Arabuli T. — This study investigates earthworm and oribatid mite communities in urban, semi-natural and natural ecosystems of Tbilisi (Georgia). Ten species of earthworms and 100 species of oribatid mites were registered in 45 soil samples. Two species of oribatid mites, *Microzetes auxilaris* Grandjean, 1936 and *Multioppia laniseta* Moritz, 1966, are new for the Caucasian fauna. We hypothesized that species number and abundance of invertebrate animals tend to decrease from natural to urban ecosystems. The hypothesis was supported only partially. Number of species of oribatid mites and earthworms decreased together with increase of urbanization, whereas abundance showed no significant changes due to high density of stress tolerant and ubiquitous species in urban sites. Accordingly, species abundance is considered to have minor indicatory value. Our studies support ecological "time-hypothesis" in a way that older (natural) sites were presented with more diverse fauna than recent (urban) ones. Statistical analyses showed that studied ecosystems should be grouped in two rather than three categories: in urban and natural ones.

K e y w o r d s: earthworms, oribatid mites, urbanisation, ecological "time-hypothesis", Tbilisi.

Сравнение сообществ дождевых червей (Lumbricidae) и панцирных клещей (Acari, Oribatida) в природных и урбанизированных экосистемах. Мурванидзе М., Квавадзе Э., Мамладзе Л., Арабули Т. — В статье предоставлены результаты исследования сообществ дождевых червей и панцирных клещей в урбанизированных, полуприродных и природных экосистемах г. Тбилиси (Грузия). В 45 почвенных пробах были найдены 10 видов дождевых червей и 100 видов панцирных клещей. Два вида клещей − *Microzetes auxilaris* Grandjean, 1936 и *Multioppia laniseta* Moritz, 1966 являются новыми для фауны Кавказа. Мы предположили, что количество и плотность населения безпозвоночных должны уменьшаться от природных к урбанизированным экосистемам. Наша гипотеза подтвердилась частично. Количество видов дождевых червей и панцирных клещей сократилось с увеличением степени урбанизированности среды, тогда, как плотность населения существенно не менялась из-за высокой плотности отдельных убиквистовых и толерантных к стрессам видов. Соответственно считаем, что плотность населения не имеет большого индикационного значения. Наши результаты подтверждают экологическую «гипотезу времени» тем, что более старые (природные) участки были представлены более разнообразной фауной, чем более новые (урбанизированные). Статистический анализ показал, что изученные экосистемы должны быть сгруппированны по двум, а не по трем категориям: по природным и урбанизированным.

К л ю ч е в ы е с л о в а: дождевые черви, панцирные клещи, урбанизация, экологическая «гипотеза времени», Тбилиси.

Introduction

In an urban environment animals have to exist in extreme and unnatural conditions. Heightened temperature, soil and air pollution and impoverished plant cover are constantly affecting them (Klausnitzer, 1990). Different biotopes of cities often form a patchwork where similar plots are isolated from each other.

We investigated earthworm and oribatid mite fauna on different kind of ecosystems existing in Tbilisi (Georgia, Caucasus) and its surroundings. Not long ago, the outskirts of Tbilisi were covered with forests. Currently, more or less undisturbed ecosystem parts remain like islands. Urbanisation obviously causes a change in the species pattern in these types of habitats and minimizes the number of species in central urban regions. The most important regional factors are relative aridity, air pollution and habitat fragmentation, showing a similar increasing tendency from suburban to central regions of Tbilisi (Kajaia, 2008).

We focused on soil organisms, which are particularly good subjects of study, as far modifications associated with urban infrastructure directly impact soil properties. City soils are more likely to be compacted, water-logged, and impervious to water flow and lacking of organic matter. The importance of soil animals as biological indicators is of great relevance to biological-geocenological and agricultural research and for the organization of environmental monitoring stations (Ghilarov, 1980). The value of an indicator organism depends on its life expectancy, life style and specific importance (Cortet et al., 1999).

The earthworms, as bioturbators, are convenient bioindicators where their abundance is rather high and the soil inhabiting communities of soil invertebrates are not disturbed by unregulated anthropogenic factors.

Microarthropods and in particular, oribatid mites are well known indicators of environmental quality (Parisi et al., 2005; Weigmann, Kratz, 1987; Kehl, Weigmann, 1992; Weigman, Jung, 1992). Their diversity is high, they occur in high numbers, they are easily sampled in all seasons, identification of adults is relatively easy and they represent a trophically heterogeneous group (Behan-Pelletier, 1999).

Our objectives were: i) to determine soil faunal complexes of earthworms and oribatid mites along a transect from natural ecosystems located in city outskirts via semi-natural and urban sites back to the natural forests; ii) to evaluate city ecosystems by means of indicator species groups; iii) to determine the pool of species that is tolerant to anthropogenic disturbances. We hypothesized that species number and abundance of invertebrate animals tend to decrease from natural to urban ecosystems.

Material and methods

Site description

Samples were collected in May 2008, on transect from natural old grows polydominant forests via semi-natural and urban sites back to the natural forest. Fifteen chosen sites belonged to three conditionally divided ecosystem types: natural, semi-natural and urban ecosystems. At each site three soil samples were taken with a distance of 2-3 km between sites. The ecological characteristic of studied sites is as follows:

N1. River Vere gorge. Natural polydominant broad-leaved forest. *Quercus iberica* Stev., *Carpinus orientalis* Mill., *C. caucasica* Grossh., *Cerasus silvestris* (Kirschl.) Garsault., *Cornus mas* L. Elevation 847 m. s. l; N 41.71766°; E 44.65474°.

SN1. River Vere gorge. Artificial pine forest. *Pinus eldarica* Medw., understorey represented by *Cerasus incana* (Pall.) Spach, *Paiurus spina-christi* Mil., *Lonicera* sp. , *Cotoneaster* sp., *Quercus iberica* Stev., *Rhamnus pallasii* F. et M., *Prunus spinosa* L., *Carpinus orientalis* Mill., *Jasminum.* Elevation 695 m. s. l; N 41.71722°; E 44.68119°.

SN2. River Vere gorge. Shrubs. *Paliurus spina-christi* Mil., *Cerasus incana* Pall.) Spach, *Cotoneaster* sp., *Festuca pratensis* Huds., *Andropogon ischaemum* L., *Asparagus, Papaver* sp. Elevation 640 m. s. l; N 41.71626°; E 44.68707°.

SN3. River Vere gorge. Artificial *Amygdalus* forest. Understorey with *Paliurus spina-christi* Mil., *Rhamnus pallasii* F. et M, *Juniperus rufescens* Link. Elevation 600 m. s. l; N 41.71989°; E 44.69276°.

N2. Nutsubidze plateau. Shrubs. *Paliurus spina-christi* Mil., *Rhamnus pallasii* F. et M., *Juniperus rufescens* Link, *Asparagus officinalis* L., *Cotoneaster racemiflora* (Desf.) C. Koch., *Cerasus incana* (Pall.) Spach. Elevation 600 m. s. l.; N 41.43654°; E 44.42844°.

N3. Nutsubidze plateau. *Paliurus spina-christi* Mil. shrubs. Elevation 594 m. s. l.; N 414.3633°; E 44.42875°.

U1. Former Transcaucasian Military Unit. *Pinus eldarica* Medw., *Agropynum repens* (L.) P. B., *Androgon ischaemum* L. Elevation 455 m. s. l.; N 41.71743°; E 44.74539°.

U2. Square on the Chavchavadze ave. Forb meadow on artificial soil. Elevation 470 m. s. l.; N 41.42645°; E 44.45708°.

N4. Riv. Vere gorge. Derivat of Flood-plane forest. *Populus hybrida* M.B, *P. gracilis* Grossh., *Salix fragilis* L., *Ulmus suberoza, Tmarix meyeri, Hyppaphae rhamniodes, Hedera helix* L. N 41.425032°; E 44.461182°.

U3. Hero's square. Forb meadow on artificial soil. Elevation 408 m. s. l.; N 41.42709°; E 44.46930°.

U4. Chodrishvili str. *Andropogon ischaemum* L., *Paliurus spina-christi* Mill. Elevation 533 m. s. l.; N 41.7304°; E 44.821°.

SN4. Tbilisi Reservoir, the secondary meadow; *Paliurus spina-christi* Mill., *Rhamnus pallasii* F. et M., *Spartum* sp. Elevation 550 m. s. l.; N 41.739°; E 44.847°.

SN5. Makhata Mountain. *Andropogon ischaemum* L., *Stipa* sp., *Cotinus coggygria* Scop., *Rhamnus pallasii* F. et M, *Thelycrania australis* (C.A.M.) K. San. N 41.72244°; E 44.82312°.

U5. Former Norio Military Unit. Site is applied with sawage sludge. Vegetation is presented by *Agropyrum repens* (L.) P. B. Elevation 673 m. s. l.; N 41.718°; E 44.962°.

N5. Norio broad-lived forest. *Quercus iberica* Stev., *Carpinus orientalis* Mill., *C. caucasica* Grossh., *Acer* sp., *Cornus mas* L., *Corylus avellana* L. Elevation 673 m. s. l.; N 41.8202°; E 44.964°.

N − natural site; SN − semi-natural site; U − urban site.

Sampling and extraction technique

For the earthworms each soil sample was 50 x 50 x 50 cm. Earthworms were collected by hand and preserved in 80% ethanol, then studied and identified under the stereomicroscope. For oribatid mites each sample comprised 10 cm³ soil, from which mites were extracted by Berlese-Tulgren apparatus. Specimens were preserved in 70% ethanol and after clearing were studied in lactic acid in an open hollow-ground microscope slide. For identification the keys of Kvavadze (1999), Ghilarov & Krivolutsky (1975) and Weigmann (2006) were used. Only adult earthworms and oribatid mites were identified and counted.

Statistical analysis

Statistical analysis was done using SPSS v13 for Windows (SPSS Inc., Chicago, Illinois). Hierarchical cluster analyses, based on a Bray-Curtis similarity matrix of presence-absence data were used to compare the species communities for the mites and earthworms along the studied transect. Species richness and abundance were compared among sites using one-way analyses of variance and Tukey's HSD post hoc tests.

Correlation analysis was used to compare patterns in mites and earthworms. All correlation coefficients were calculated using Spearman's rank correlation, acknowledging the fact that some data showed nonlinearity.

Shannon index of diversity was calculated for each site.

Abundance of the earthworms and oribatid mites was calculated as number of individuals per square meter.

Results

Faunal composition and abundance

Ten species of earthworms and 100 species of oribatid mites were registered in 45 soil samples. Two species of oribatid mites, *Microzetes auxilaris* Grandjean, 1936 and *Multioppia laniseta* Moritz, 1966, are new for the Caucasian fauna.

Natural and semi-natural sites are characterized by presence of forest and open woodland species, such as the earthworm species *Dendrobaena kurashvilii, D. pentheri, D. surbiensis* and *Omodeoia biblica* and the oribatid mite species *Platynothrus peltifer* (C. L. Koch, 1839), *Aleurodamaeus setosus* (Berlese, 1883), *Eremobelba geographica* Berlese, 1908,
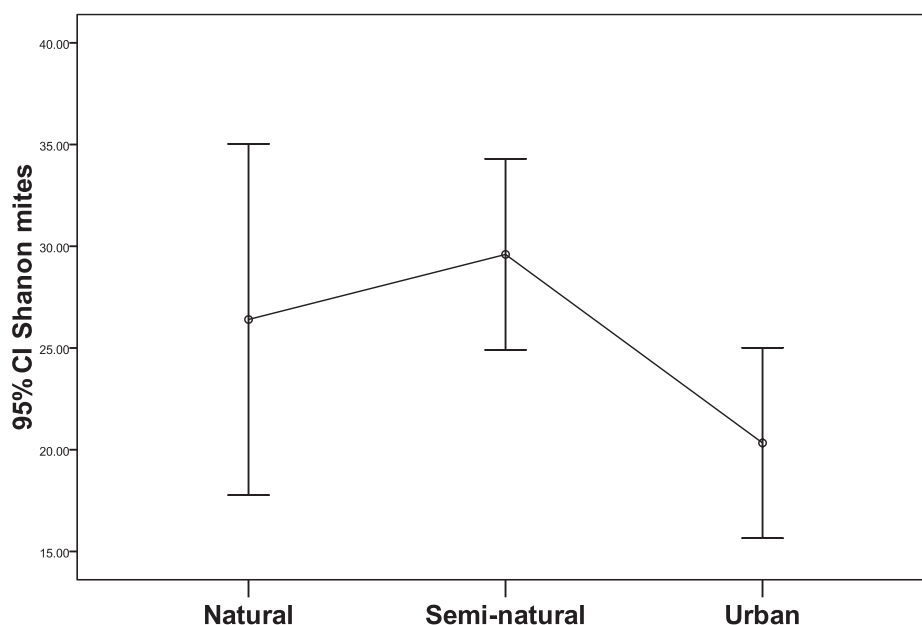

Fig. 1. Shannon index of diversity of oribatid mites changes across the Natural–Semi-natural–Urban gradient. (Error bars show 95% of confidence level).

Рис. 1. Индекс Шеннона по изменению разнообразия панцирных клещей в природных, полуприродных и урбанистических экосистемах (планки погрешности демонстрируют 95% степень достоверности).
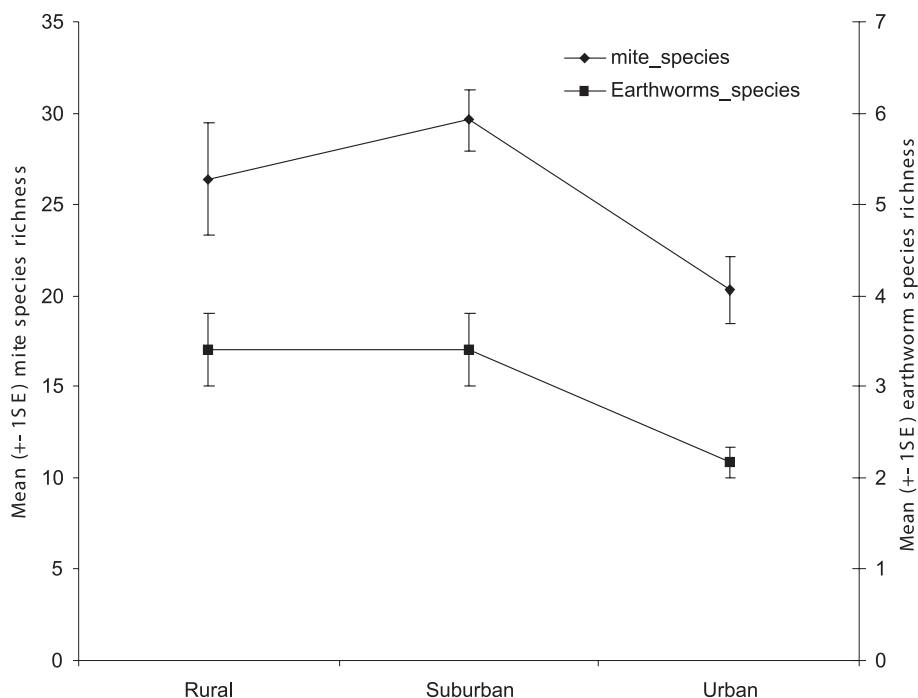
Fig. 2. Indexes of abundances of earthworms and oribatid mites along the studied transect (N — Natural sites; SN — Semi-natural sites; U — Urban sites).

Рис. 2. Индекс распространения дождевых червей и панцирных клещей в исследуемых экосистемах (N — природные экосистемы; SN — полуприродные экосистемы; U — урбанистические экосистемы).

Cultroribula confinis Berlese, 1908, *Carabodes willmanni* Bernini, 1975, *Berniniella sigma* (Strenzke, 1951), *Spinozetes inexpectatus* Piffl, 1966, *Passalozetes africanus* Grandjean, 1932, *Oribatella colchica* Krivolutsky, 1974 and *Tectoribates ornatus* (Schuster, 1958).

In urban ecosystems prevailed wide distributed species, like *Allolobophora yassiensis, A. trapezoides, Eisenia fetida, E. rosea, Dendrobaena veneta, Tectocepheus velatus velatus* (Michael, 1880), *T. velatus sarekensis* Trдgardh, 1910, *Oppiella fallax* (Paoli, 1908), *Ramusella clavipectinata* (Michael, 1885), *R. insculpta* (Paoli, 1908), *Minunthozetes pseudofusiger* (Schweizer, 1922), *Punctoribates punctum* (C. L. Koch, 1839) and *Oribatula tibialis* (Nicolet, 1855). Number of species of earthworms and oribatid mites in natural and semi-natural sites was higher than in urban areas. As it was to be expected, Number of species of both, earthworms and oribatid mites correlated with the Shannon index of diversity. Average values of the Shannon index for oribatid mites and earthworms both decreased with increasing of anthropogenic pressure, however statistically significant differences were observed only between the Shannon index of oribatid mites in Semi-natural and Urban sites (fig. 1).

Unlike the species number, the abundance of earthworms and oribatid mites showed no significant difference between natural, semi-natural and urban sites. For certain species abundance was even higher in urban ecosystems than in natural ones (fig. 2). From oribatid mites *Tectocepheus sarekensis, T. velatus, Oppiella fallax, Ramusella clavipectinata, Punctoribates punctum* and *Oribatula tibialis* showed high dominance and were constantly found in all studied sites.

Hierarchical cluster analyses

Hierarchical cluster analyses showed that earthworms and oribatid mites inhabiting natural ecosystems grouped separately from those living in soils of urban sites, with ori-

batid mites showing the pattern more clearly. Mites living in forest ecosystems (N1, N5) were separated from those inhabiting shrub sites (N2, N3, SN2). Animals living in semi-natural ecosystems grouped together with natural ecosystem inhabiting animals. Earthworms and oribatid mites of soils of flood-plain forest (N4) grouped together with animals living in soils of urban sites (fig. 3, 4).
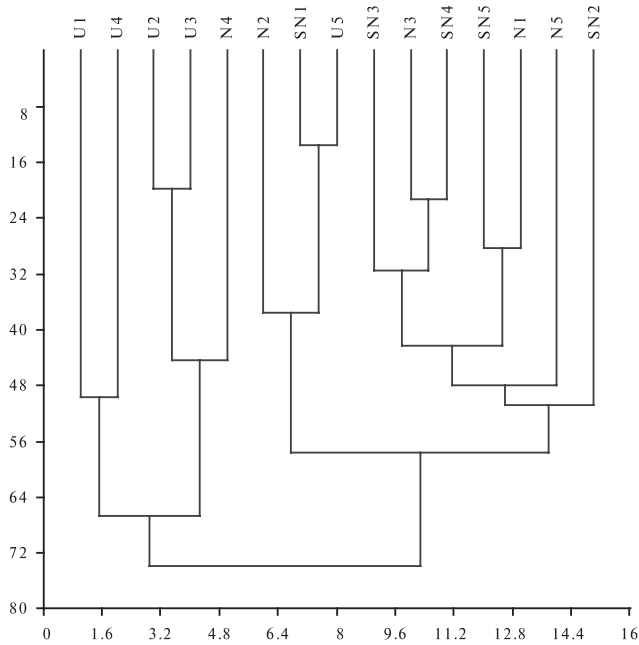
Fig. 3. Hierarchical cluster analyses of earthworms along the studied transect.
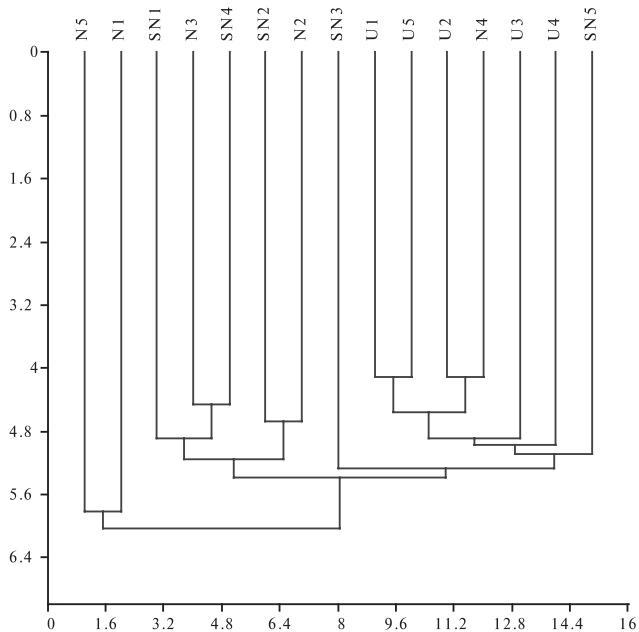Рис. 3. Иерархический кластерный анализ дождевых червей в исследуемых экосистемах.

Fig. 4. Hierarchical cluster analyses of oribatid mites along the studied transect.
Рис. 4. Иерархический кластерный анализ панцирных клещей в исследуемых экосистемах.

Principal Component analyses

Two components were extracted from the PCA. The first component explained 47% of total variation and correlated with species number and biodiversity indices for both earthworms and mites (table 1). The second component explains 25% of the total variation among the sites. PCA showed that ecosystems existing in such an urban area as Tbilisi should be grouped in two types, natural and urban, rather than three (fig. 5). Like the cluster analyses, comparison of principal components showed flood-plain forest (N4) to be grouped together with urban sites. The first principal component, which well separated the Natural and Urban sites, had high loadings of species number and Shannon biodiversity index for both earthworms and mites. This means that natural sites have higher species number and biodiversity index compared to urban sites, but organism abundance does not seem to be different (table 1).
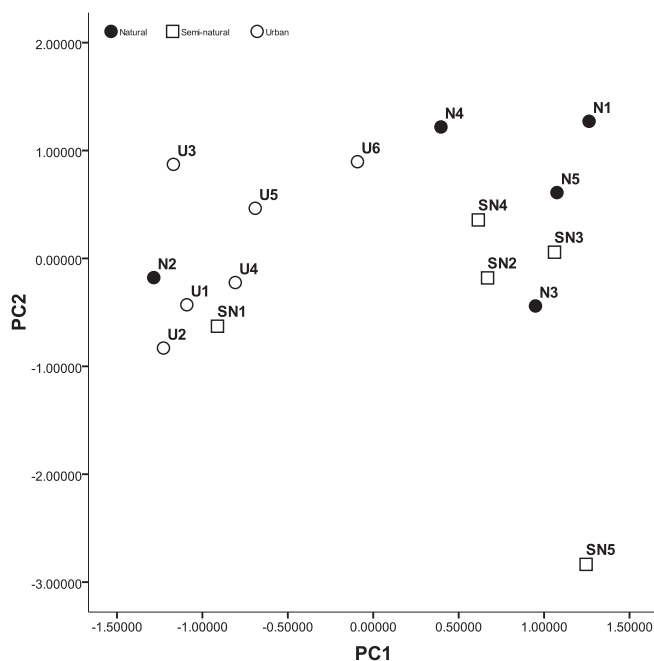

Fig. 5. Component scores of the first two principal components from the PCA. These results show that studied ecosystems are separated in two groups — natural and urban. Semi-natural ecosystems are not well separated and show high similarity to natural ones.

Рис. 5. Оценка показателей первых двух принципиальных компонентов из АГК. Эти результаты показывают, что исследованные экосистемы разделяются на две группы — природные и урбанистические. Полуприродные экосистемы не выделяются отчетливо и показывают высокое сходство с природными.

T a b l e 1. Component matrix for earthworms and oribatid mites
Таблица 1. Матрица компонентов для дождевых червей и панцирных клещей

Categories	Component	
	1	2
earthworm_species	0.886	0.409
mite_species	0.859	-0.220
Shannon_mites	0.713	-0.585
Shannon_earthworms	0.890	0.388
Earthworms_abundance	-0.160	0.716
mite_abundance	0.026	0.515

Conclusions

Our results suggest that there are two strongly different ecosystem types in Tbilisi and its surroundings: natural and urban ones. Semi-natural ecosystems are not well separated and show high similarity to natural ones. These types of ecosystems, vegetated mainly by shrubs, are remnants of the former natural forests, remaining after long-time logging in Tbilisi and its environs.

In urban sites the widely distributed *Allolobophora yasiensis, A. trapezoides* and *Dendrobaena veneta* dominated the earthworm fauna. Of the oribatid mite species like *Sphaerochthonius splendidus* (Berlese, 1904)*, Eniochthonius minutissimus* (Berlese, 1903)*, Hypochthonius luteus* Oudemans, 1917 and *Spinozetes inexpectatus* Piffl, 1966*,* were mostly affected by anthropogenic disturbances. Their densities in urban sites were minor.

Species of genus *Epilohmannia* were found on almost all study sites, but with minor quantities.

Species of Poronota were constantly found in studied area, but usually with low abundance. However, the species of genera *Punctoribates and Minunthosetes* increased their quantity in urban sites. These genera are usually disturbance resistant and are often found in urban and agricultural systems with high density (Maraun, Scheu, 2000; Maraun et al., 2003; Scheu, Schulz, 1996) which presumable is due to high fecundity and fast development during recolonisation of disturbed habitats (Maraun, Scheu, 2000).

Tectocepheus species usually tolerate with disturbances. They are known to be able to recover quickly from disturbances and to tolerate harsh environmental conditions (Maraun, Scheu, 2000; Maraun et al., 2003; Skubala, 1995). However in urban soils of Berlin *Tectocepheus velatus velatus* is absent and *T. velatus sarekensis* is frequent to find. High PH and calcium level in urban soils are considered as reason of such distribution (Weigmann, 1995).

The present Oppiidae species were also less affected with anthropogenic disturbances. They are known to be able to occupy a wide range of ecological niches and colonize a wide spectrum of ecosystems (Stefaniak & Seniczak, 1981). *Oppiella fallax*, the most abundant species in the studied fauna, is denser in soils of natural ecosystems compared to urban ones.

There are number of works reporting that earthworms and oribatid mites cannot coexist in high diversity and abundance of both. Earthworms, as bioturbators destroy oribatid mite habitat by consuming litter and mixing it with inorganic material (Maraun et al., 1999; Maraun et al., 2003; Maraun et al., 2008; Maraun, Scheu, 2000; McLean, Parkinson, 1998).

We did not see the expected negative correlation between earthworms and oribatid mites; in most cases neither abundance nor species diversity of these two taxa showed any correlation at all. However, there was one exception in site U5 (Russian former military base in Norio). Here abundance of earthworms was unusually high (328 ind/m^2), whereas abundance of oribatid mites remained low (5190 ind/m^2) (fig. 2). We explain this fact with negative effect of earthworm presence. This site is constantly polluted with sewage sludge, which increases soil humidity and adds organic matter to soil, thereby creating especially favourable conditions for earthworms. It is known that sites treated by sewage sludge show the presence of higher number of microarthropods and especially high number of earthworms. (Parisi et al., 2005).

In the conclusion we can postulate that i) soil faunal complexes of earthworms and oribatid mites on transect from natural ecosystems via semi-natural and urban sites back to the natural forests were determined; ii) indicator species groups of oribatid mites showed that city ecosystems should be divided in two rather than three categories: in natural and urban ones; iii) species like *Allolobophora yassiensis, A. trapezoides, Eisenia fetida, E. rosea, Dendrobaena veneta, Tectocepheus velatus, T. sarekensis, Oppiella fallax, Ramusella*

clavipectinata, R. insculpta, Minunthozetes pseudofusiger, Punctoribates punctum and *Oribatula tibialis* can be considered them as tolerant to anthropogenic disturbances.

Our results are relevant to ecological "time-hypotheses" (Pianka, 1988) in a way that oribatid mite diversity was higher in older (natural) habitats compared to comparably new (anthropogenic modified) ones. This statement is supported by research of Scheu and Schulz (1999) who found oribatid mites species number increasing from an arable field to beech forest. Huhta and Niemi showed lower diversity and density of oribatid mites in planted birch strands compared to the natural forests (Huhta & Niemi, 2003). Number of researches supports this statement. Removal of organic matter from forest soil induced decrease of the abundance and species richness of oribatid mites in sub-boreal spruce bio-geoclimatic zone of British Columbia (Battigelli et al., 2004).

High number of species is not always accompanied with corresponding high abundance. In most urban sites high abundance was caused by high dominance of several dominant species like *Tectocepheus velatus, T. sarekensis, Oppiella fallax, Ramusella clavipectinata, R. insculpta, Minunthozetes pseudofusiger* and *Punctoribates punctum*. Researches provided in Burgos province of Spain in steppe habitats from agricultural to natural sites showed that most abundant species were of cosmopolite or holarctic distribution (Arryo et al., 2005). Maraun et al., (2003) consider species of *Punctoribates* and *Minunthozetes* as increasing their number following disturbance.

The provided investigation supports our presented hypotheses in a way that species number of earthworms and oribatid mites decrease from city outskirts to the centre, whereas abundance seems to be not or less influenced by group of abiotic and biotic factors existing in the city centre. The latter is due to high abundance of wide distributed and dominant species. As a result, total abundance of worms or oribatid mites has no indicatory meaning in an evaluation of ecosystem types. By contrast, species number and diversity have good indicatory value and may be used in various studies on soil features.

Arroyo J., Inturrondobeitia J. C., Rad C., Gonzalez-Carcedo S. Oribatid mite (Acari) community structure in steppic habitats of Burgos Province, central northern Spain // J. of natural history. — 2005. — **39,** 39. — P. 3453−3470.

Battigelli J. P., Spence J. R., Langor D. W., Berch Sh. M. Short-term impact of forest soil compaction and organic matter removal on soil mesofauna density and oribatid mite diversity // Canadian J. of Forest Research. — 2004. — 34. — P. 1136−1149.

Behan-Pelletier V. Oribatid mite biodiversity in agroecosystems: role for bioindication // Agriculture, Ecosystems and Environment. — 1999. — 74. — P. 411−423.

Cortet J., Gomot-De Vauflery A., Poisot-Balaguer et al. The use of invertebrate fauna in monitoring pollutant effects // European J. of Soil Biology. — 1999. — **35** (3). — P. 115−134.

Erdmann G., Floren A., Linsenmair K. E., Scheu S., Maraun M. Little effect of forest age on oribatid mites on the bark of trees // Pedobiologia. — 2006. — 50. — P. 433−441.

Ghilarov M. S. Bodenwirbellose als Indikatoren des Bodenhaushaltes und seine Änderungen unter anthropogenen Einflüssen // Bioindikation. 4. Kongr Tag Univ Halr Wittenberg. Ed. H. Mühlerg.— 1980. — P. 3−9.

Ghilarov M. S., Krivolutski D. A. Identification keys of soil inhabiting mites. Sarcoptiformes. — Moscow : Nauka, 1975. — 490 p. — Russian : *Гиляров М. С., Криволуцкий Д. А.* Почвенные клещи и их роль в почвообразовании и в почвенных ценозах // Определитель обитающих в почве клещей. Sarcoptiformes.

Huhta V., Niemi R. Communities of soil mites (Acarina) in planted birch strandes compared with natural forests in Central Finland // Canadian J. of Forest Researches. — 2003. — **33.** — P. 171−180.

Kajaia G. Ecological Principles of Environment Protection.— Tbilisi : TSU, 2008. — Georgian.

Kehl Ch., Weigmann G. Die Hornmilbenzonosen (Acari, Oribatida) an Apfelbаьmen im Stadtgebiet von Berlin als Bioindikatoren fuer Luftqualitat. // Zool. Beitr. — 1992 — **34,** 2. — S. 261−171.

Klausnitser B. The Ecology of City Fauna. — Moscow : Mir, 1990. — 248 p. — Russian : *Клауснитцер Б.* Экология городской фауны.

Kvavadze Er. Earthworms of the Caucasus (*Lumbricidae*) (Systematic, Faunistic, Zoogeography, Ecology, Phylogeny) : Doctoral Thesis. — Tbilisi, 1999. — 313 p. — Georgian.

Maraun M., Alphei, J., Bonkowski et al. Middens of the earthworm *Lumbricus terrestris* are important microhabitats for micro- and mesofauna in forest soil // Pedobiologia. — 1999. — **43.** — P. 276−287.

Maraun M., Scheu, St. The structure of oribatid mite communities (Acari, Oribatida): patterns, mechanisms and implications for future research. // Ecography. — 2000. — **23**. — P. 374−383.

Maraun M., Salamon J. A., Schneider K. et al. Oribatid mite and collembolan diversity, density and community structure in a moder beech forest (*Fagus silvatica*): effects of mechanical perturbances // Soil Biology and Biochemistry. — 2003. — **35.** — P. 1387−1394.

Maraun M., Illig, J., Sandmann, D., Krashevska et al. Soil fauna // Gradients in a tropical mauntain Ecosystem of Ecuador. Ecological Studies. — Berlin ; Heidelberg : Springer-Verlag, 2008. — P. 181−192.

McLean M. A., Parkison, D. Impacts of the epigeic earthworm *Dendrobaena octaedra* on oribatid mite community diversity and microarthropod abundances in pine forest floor: a mesocosm study // Applied Soil Ecology. —1998. — **7.** — P. 125−136.

Parisi V., Menta Ch., Gardi C. et al. Microarthropod communities as a tool to assess soil quality and biodiversity: a new approach in Italy // Agriculture, Ecosystems and Environment. — 2005. — **105**. — P. 323−333.

Pianka E. R. Evolutionary Ecology. Fourth ed. — New York : Harper & Row, 1988. — 468 p.

Scheu S., Schulz, E. Secondary succession, soil formation and development of a diverse community of oribatids and sapropagous soil macro-invertebrates // Biodiversity Conservation. — 1996. — **5. —** P. 235−250.

Skubala P. Moss mites (Acarina, Oribatida) on industrial dumps of different age // Pedobiologia. — 1995. — **39**. — P. 170−184.

Stefaniak O., Seniczak, S. The effect of fungal diet on the development of *Oppia nitens* (Acari, Oribatei) and on the microflora of its alimentary tract // Pedobiologia. — 1981. — **21**. — P. 202−210.

Weigmann G. Zur Bedeutung von Hemerobie und Habitatstruktur fuer Hornmilben (Acari, Oribatida) in Stadtparks und Ruderalflachen // Schr.- R. f. Vegetationskde., Sukopp-Festschrifft. — 1995. — **H. 27**. — S. 223−230.

Weigmann G. Hornmilben (Oribatida) // Die Tierwelt Deutschlands. — Keltern : Goecke & Evers, 2006. — Bd 76. — 520 S.

Weigmann G., Jung, E. Die Hornmilben (Acari, Oribatida) an Strassenbaumen in Stadtzonen unterschiedlicher Luftbelastung in Berlin // Zool. Beitr. — 1992. — **34**, H. 2. — P. 273−287.

Weigmann G., Kratz, W. Oribatid mites in urban zones of West Berlin // Biol Fertil Soils. — 1987. — P. 81−84.