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Application of Soil Oribatid Mites as Bioindicators in Impact Areas of the Gas Industry in the West Siberian Tundra

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Abstract: Atmospheric emissions from gas pre-treatment centers of the Gazprom Dobycha Yamburg LLC influenced the community of oribatid mites in southern tundra ecosystems. It was evidenced by changing the ratio of the ecological groups of the oribatid mites rather than its total abundance. The euedaphic oribatid mites prevailed essentially in the mites community of more contaminated biotopes located closer to the source of atmospheric pollution. In the conditions of decreasing pollution levels, the mites community structure was changed to predominance of litter-surface oribatid mites species, larger in size and typical for undisturbed natural communities. Level of pollution was evaluated on the basis of cumulative index of anthropogenic pollution load per unit of an ecosystem surface (I_{PLS}). It was found that the best characteristic of bioindication of pollution is the ratio of litter-topsoil oribatid mites to euedaphic ones ($R_{L/S}$). Very simple equation with significantly high determination coefficient was obtained to describe this dependence: $R_{L/S} = 4.84 - Ln(I_{PLS})$.

Keywords: Oribatid mites, bioindication, pollution, gas industry, tundra, West Siberia.

INTRODUCTION

One of the applicable approaches to assess the external impact on an ecosystem as a whole and its biogeochemical structure is to investigate the specific reactions of the individual biotic components – plant communities, animals, microorganisms, generally known as bioindicators. The main advantages of using these biological indices are their ability to evaluate the total influence of all the abiotic factors on an ecosystem as a whole and on the soil as the ecosystems' principal component. In some cases the values obtained from these biological indices allow the researcher to exclude the need to monitor the relevant chemical and physical parameters of the soil (Bashkin 2006, Klimentiev *at al.* 2006).

Animal species have a specific status among bioindicators. Animals have a number of features that distinguish them from other components of the biota. They have a higher level of structural and functional organization, have more complex morphology, physiology, more developed sense organs, complex behavior and are characterized by a greater diversity of species. Animal communities are also flexible in terms of species composition, abundance, routes and speed of migration. Thus, zoological parameters are more precise, more rapid and more variable to reflect disturbance of their environment.

Various taxonomic, functional and ecological aspects of animal groups can be used to indicate different processes in the environment. For assessing the anthropogenic impact on the soil component of ecosystems many authors recommended using soil invertebrates (Gilarov 1965, 1978, Stebaev 1968, Mordkovich 1977, 1982, Krivolutsky 1978, Krivolutsky *et al.* 1985, Krivolutsky 1994, Cortet *et al.* 1999; Enami *et al.* 1999, Lindberg *et al.* 2002, Mordkovich *et al.* 2003, Mordkovich *et al.* 2004; Mordkovich *et al.* 2006, Mordkovich *et al.* 2014). Among the most representative groups there is the taxonomic group of oribatid mites, which are characterized by such indicative parameters as simple sampling, high abundance, taxonomic and ecological variability, representing in practically all bioclimatic zones / belts and soil types. They are also able to survive in extreme conditions and rapidly react to environmental alterations.

Indicative possibilities of the oribatid mites reacting to the change of environmental conditions, including contamination by heavy metals and/or by atmospheric pollutants were frequently shown (Aleynikova 1976, Krivolutsky 1978, Andre *et al.* 1982; Norton & Sillman 1985, Seniczak *et al.* 1995, Steiner 1995; Stebaeva & Andrievskii 1997; Behan-Pelletier 1999; Zaitsev & van Straalen 2001, Balogh & Balogh 2002, Andrievskii 2003, Lindberg & Bengtsson 2005, Gulvik 2007, Gergocs & Hufnagel 2009, Ivan & Vasiliu 2009, Khalil *et al.* 2009).

Owing to the abovementioned features, oribatid mites have been selected for bioindication of impact of atmospheric pollutants produced by the gas industry in the studied area – West Siberian tundra. There are very few such investigations in the tundra ecosystems, carried out in the

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Fig. (1). One of gas pre-treatment centers at Tazovskiy peninsula on the territory of Gazprom Dobycha Yamburg LLC.

European part of Russia; most studies concerned oil pollution (Melekhina 2007), and severe contamination by heavy metals and fluorine from nonferrous-metals industry (Evdokimova *et al.* 2005, Zenkova *et al.* 2011). Similar studies on the impact of very serious sulfur and heavy metal pollution on the density and diversity of oribatid mites were carried out around the big Norilsk Nickel mining and smelting complex located in the forest-tundra of Middle Siberia (Bezkorovaynaya 2014). The influences of air pollution owing to the emissions of the gas industry in the conditions of Siberian tundra on the populations of oribatid mites are unknown.

MATERIALS AND METHODS

The influence of atmospheric pollutants on the oribatid mites communities was studied on the impact area of Gazprom Dobycha Yamburg LLC. This company is situated on the north of West Siberian Plain on Tazovskiy peninsula in the bioclimatic subzone of the southern tundra. Visible disturbances of the territory of Gazprom Dobycha Yamburg LLC are very local and limited to small areas nearby very few settlements, industrial units, roads and pipelines. Disturbance of these areas is obviously connected with mechanical damage of the soil surface. But it is limited to a very few dozen meters from these constructions.

We supposed that the most important reason for ecosystem disturbance is contamination due to the pollutants emitted into atmosphere. This can cover a much bigger area compared to mechanical damages of the soil surface. The main sources of pollutants are several gas pre-treatment centers (GPCs) situated at various distances from each other. GPC is a complex of processing equipment and auxiliary systems for collecting and processing of natural gas and gas condensate (Fig. **1**).

The following air pollutants from GPC come in the form of gases and aerosols and solid particles /dust: CO, NO_x, CH_4, methanol, vapors of benzene, diesel fuel and oil, Mn compounds, fluorides, CrO_x, SO_2 and sulfurous acid, aceton, xylol, toluene, mixture of aromatic hydrocarbons and some others. In spite of the big list of contaminators, their influence on environment is much less pronounced compared to the nonferrous-metals industry, for example, which often forms technogenic deserts around its centers. Our investigations of vegetation cover, plant biodiversity and some general soil properties did not allow us to recognize influence of contamination (Bashkin *et al.* 2012). Therefore we can obviously consider contamination from GPCs as a soft one.

We were working in the area between eight GPCs but mostly round GPC #2 because it is the oldest one on the territory of the company with 25 years of operation and it is characterized by maximum amounts of emitted pollutants. To evaluate relatively low influence of emitted pollutants we used new criteria: cumulative index of anthropogenic pollution load per unit of an ecosystem surface (I_{PLS}). The index is calculated from two coefficients, which reflect the dependence of the amount of deposited atmospheric contaminants per surface unit from (1) wind velocity and wind direction and (2) proximity to source of pollution. The cumulative index (expressed as a percentage) is calculated by multiplying the coefficients. In case if a studied object is under the influence of more than one source of man-made pollution, individual indices are calculated separately for each source, and then summed (Bashkin *et al.* 2012).

Biotopes for sampling of soil oribatid mites were mainly chosen on the basis of different remoteness from the source of pollution in north-west and south-east directions and similarity of plant community and soil properties as close as it was possible to find (Table **1**).

For the analysis of oribatid mites in the studied area sampling was carried out in replicates of seven by the conventional method (Methods… 1975). The period of sampling was in August 2011. The samples were taken from the surface soil layers up to 5 cm depth together with plant residues and lichen layer (predominant places of oribatid habitants) using the standard cylinder sampler of 123 cm^3 volume. The orbatid mites were then extracted from the soil samples by Berlese-Tullgren's standard method of thermo-eclection using eclector devices of 40 wt electric lamp light into small glass vials containing fixing liquid (70% C_2H_5OH). From

Table 1. Characteristics of biotopes at sampling points.

Characteristics Items	Sampling Point / Biotope				
	# 1	# 2	# 3	# 4	# 5
Distance from GPC, m	0	0	750	5 000	17 000
Direction from GPC	SE	NW	SE	NW	NW
Index of pollution load (I_{PLS})	93	85	75	13	0.2
Plant community	dwarf shrub-lichen tundra				
Soil type[@]	Histic Reductaquic Cryosols (Loamic)	Turbic Cryosols (Albic, Arenic)	Histic Cryosols (Loamic)	Spodic Histic Cryosols (Loamic)	Histic Cryosols (Loamic)
Topsoil horizon(s) appropriate to 0-5 cm soil layer	T1	O and AO	T	T1	T1
Soil chemical properties:					
Losses of ignition, %	66.6	31.9	90.0	87.9	76.5
Total C, %	34.2	15.3	42.2	41.0	36.8
Total N, %	0.510	0.415	0.935	0.872	0.720
Total P, %	0.047	0.031	0.057	0.050	0.048
C / N ratio	67.1	36.8	45.1	47.0	51.1

Note. [@] according to WRB soil classification (IUSS Working Group WRB 2014).

these vials the oribatid mites were studied under a microscope using preparation needles, placed on the microscope slides into liquid of For-Berlese. These were put into a drying oven for at least seven days at temperature 45°C to gain the stable preparations. The oribatid mites were observed under a microscope with 200-500x-magnification to establish their species. The oribatid mite abundance was calculated by the number of species and individuals per m^2.

Statistical analyses were performed with the software package Snedecor v.5.0 (Sorokin 2014). Statistical significance was determined at $p \leq 0.05$.

RESULTS AND DISCUSSION

The ecological status of living organisms is usually evaluated by such quantitative parameters as diversity of species and their abundance (Chernov 1991). These parameters for the studied biotopes are represented in Table **2**. Only 13 species of oribatid mites were detected on the studied area. This number of species is very close to that reported for oribatid mites communities in typical tundra of Taimyr peninsula in Central Siberia: from 12 to 13 (Anan'eva *et al.* 1973).

For one particular biotope within the studied area, richness in species almost does not change and varied from five to seven species (Table **2**). This might be explained due to single sampling in the restricted area of habitats.

The total abundances of oribatid mites gives paradoxical picture at the first sight: in general they are higher in the three biotopes situated closer to the GPC (sampling points #1, #2 and #3) and lower at the sites, which are further from the source of pollution (points #4 and #5) (Table **2**). That is, if we proceed from the total abundances of oribatid mites, the impact of air pollutants from GPC can be described as not depressing, as one could expect, but as stimulating.

For explanation of this seeming stimulating effect of air pollutants on the total abundance of the oribatid mites, the distribution of certain species in the biotopes situated at different distances from GPC needs to be scrutinized. Such species as *Tectocepheus velatus, Moritzoppia praestans, M. microdentata and Oppiella nova* were predominant nearby to the source of the pollution (sampling points #1 and #2). The last three species are distinguished by high productivity allowing them to have two and more generations during one season. They are of mainly small size: about and less than 0.2 mm, which allow them to penetrate into deeper soil layers through soil pores preventing themselves from unfavorable environmental conditions (Krivolutsky 1994). Such peculiarities allow them more easily than the others, much larger species, to adapt to any alterations of environment. The species *Tectocepheus velatus* is somewhat larger than the three species mentioned above (its size is about 0.3 mm) and is well known as widespread euritopic cosmopolitan species. It is very plastic ecologically and tolerant to extreme environmental conditions of different nature. Because of these characteristics *T. velatus* in this case is associated with the three species described previously. The indicated peculiarities allow us to unite these four species (listed in the Table **2** under numbers from 1 to 4) into one ecological group

Table 2. The distribution of oribatid mites at the sampling points with different vicinities of gas pre-treatment centers, averaged (for seven replicates) abundance, individuals per m^2.

Oribatid Mites' Species	Sampling Point / Biotope				
	# 1	# 2	# 3	# 4	# 5
Number of discovered species	7	7	5	5	7
All individuals	10986	20057	9600	2200	4400
(1)*Moritzoppia praestans* (Gordeeva & Grishina 1991)	4929	4457	0	0	0
(2) *Oppiella nova* (Oudemans 1902)	2057	6000	0	0	0
(3) *Tectocepheus velatus* (Michael 1880)	1986	6000	6000	600	600
(4) *Moritzoppia microdentata* (Gordeeva & Grishina 1991)	814	200	0	0	0
(5) *Nothrus palustris* (C.L. Koch 1839)	400	0	0	0	0
(6) *Cultroribula bicultrata* (Berlese 1905)	200	200	1000	0	1000
(7) *Liacarus xylaria* (Schrank 1803)	0	2200	0	0	0
(8) *Trichoribates novus* (Sellnick 1928)	600	1000	1800	0	600
(9) *Tectoribates ornatus* (Schuster, 1958)	0	0	600	0	0
(10) *Scheloribates laevigatus* (C.L. Koch 1835)	0	0	200	200	200
(11) *Punctoribates minimus* (Shaldybina 1969)	0	0	0	600	800
(12) *Camisia horrida* (Hermann 1804)	0	0	0	200	200
(13) *Trhypochthonius cladonicola* (Willmann 1919)	0	0	0	600	1000
Individuals of the Group 'S'	9786	16657	6000	600	600
Individuals of the Group 'L'	1200	3400	3600	1600	3800

(called further as the Group 'S'). They differ from other oribatid mites (listed in the Table **2** under numbers from 5 to 13) which can be combined into other ecological group (called further as the Group 'L'). The oribatid mites of the last group are predominantly larger in size species (0.7 – 1.0 mm).

Three life form categories are usually considered for soil invertebrates: epedaphic (dwellers of litter surface and soil surface), hemiedaphic (dwellers of litter depth and the most top soil layer) and euedaphic (dwellers of relatively deeper layers of soil) (Hopkin 1997, Eisenbeis 2006). In our studies the oribatid mites of the Group 'L' correspond both epedaphic and hemiedaphic life forms and can be shortly named as litter-topsoil oribatid mites. The mites of the Group 'S' correspond euedaphic life form enabling to move within the soil pore system and therefore can inhabit the lower soil layers. In general the oribatid mites of the Group 'S' are characterized by easier adaptation to any environmental changes, even extreme ones, than larger in size species of the Group 'L', which are more characteristic for undisturbed ecosystems.

Oribatid mites of the Group 'S" with rather high abundance colonize soil even nearby the GPC where the pollutants emission concentrations are obviously maximal. At the points #1 and #2 the species of the Group 'S' represent 83-89% of the oribatid mites community. The oribatid mites of the Group 'L' presented other 11-17% of oribatid mites community nearby the GPC. At the points #1 and #2 the larger-sized species are represented by *Nothrus palustris*, *Cultroribula bicultrata*, *Liacarus xylaria*, and *Trichoribates novus*.

Under less contaminated conditions (sampling point #3, which is about 750m apart from GPC) the proportion of small species to large litter-soil surface species is changing with decreasing abundance of the Group 'S' species (up to 63%) and increasing one of the Group 'L' species (up to 37%). From the Group 'S' species, *Moritzoppia praestans*, *M. microdentata* and *Oppiella nova* fully disappeared. They were substituted, still in relatively low quantities, by the larger in size species *Tectoribates ornatus* and *Scheloribates laevigatus*, which are more characteristic for the communities of undisturbed ecosystems as we mentioned above. Abundance

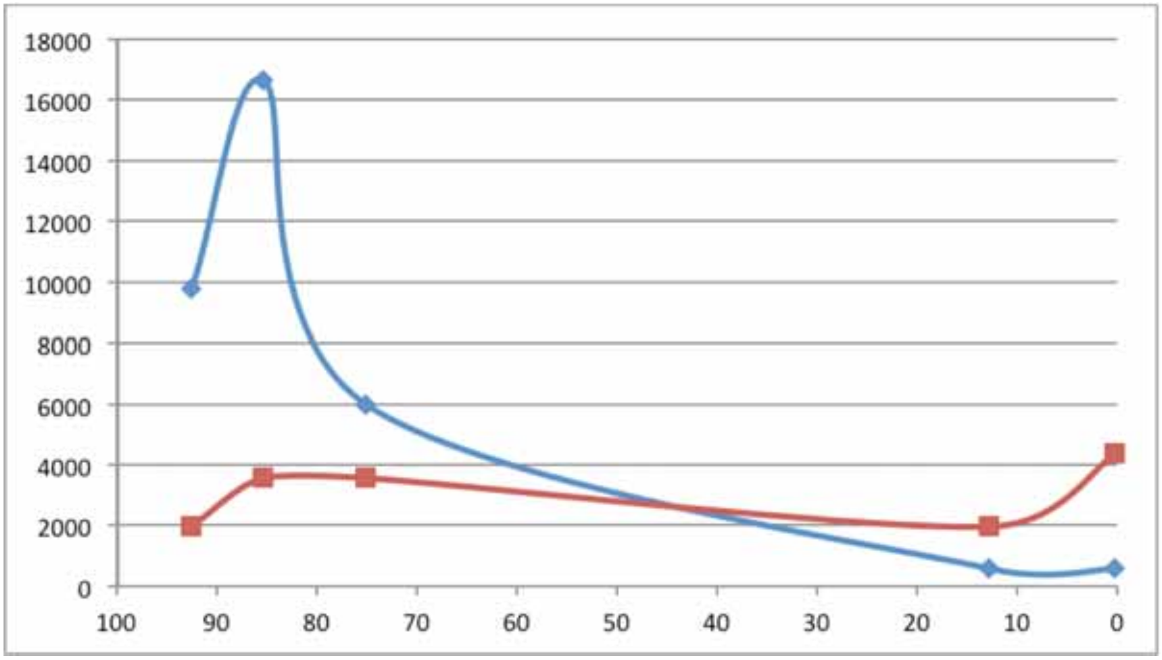

Fig. (2). Abundance (averaged for seven replicates) of the ecological groups of oribatid mites (individuals per m^2 of soil area) (ordinate axis) depending on the pollution index I_{PLS} (abscissa axis).

Notes. Blue row – the Group 'S' of the oribatid mites, brown row – the Group 'L' of the oribatid mites.

of *Trichoribates novus* and *Cultroribula bicultrata* was increased 3-5 times at the point #3 as compared to the points #1 and #2.

At more remote distance from GPC (around 5000 m, point #4) the situation was essentially changed. Abundance of *Tectocepheus velatus* decreased sharply there as compared to the point #3 whereas three other species of the Group 'S' (*Moritzoppia praestans, M. microdentata, O. nova)* were absent as well at the distances 750 m and 5000 m far from GPC. Instead of these larger litter-topsoil species, which are characteristic for natural undisturbed communities, new oribatid mites were detected at the point #4: *Punctoribates minimus*, *Camisia horrida* and *Trhypochthonius cadonicola*. The proportion of the small-sized species of the Group 'S' and larger litter-topsoil ones of the Group 'L' became 27% to 73%, getting close to that, which is typical for the communities of oribatid mites under natural uncontaminated environment. It allows us to conclude that at the distance of 5000 m from the GPC the contaminating influence on oribatid mite taxocene is obviously weakened. However, this influence is, apparently, not entirely gone.

The given tendency for changing the oribatid mites community is enforced for the point #5 placed at more than 17 km from the pollution source. In this biotope the proportion of species abundance of the Group 'S' to the Group 'L' becomes 14% to 86%, respectively, that is completely opposite to the biotopes at the points #1 and #2. The data, which characterize this point, can be considered as the background ones in the studied series of the ecosystems – under the rather small atmospheric pollution. Abundance of all discovered species of the oribatid mites at this point (4400 individuals per m^2) is close to that reported for typical tundra of Western Taimyr peninsula (from 2000 in the most cases up to 4500) (Anan'eva *et al.* 1973).

In order to prove statistically influence of anthropogenic pollution on oribatid mites density we tried to find a correlation between the total (for all species) oribatid mites abundance and pollution load level expressed as cumulative index of anthropogenic pollution load per unit of an ecosystem surface (I_{PLS}). Both linear and non-liner regression analyses did not reveal statistically significant coefficients of regression and determination for dependence of total oribatid mites abundance on I_{PLS}.

Comparison of the abundance of the selected ecological groups of the oribatid mites ('S' and 'L') with the pollution index demonstrated a more apparent picture. For the sequence of points from #2 to #5, the clear tendency is obvious for decreasing the Group 'S' oribatid mites density (28-tolds) as the distance from GPC is increasing (Fig. **2**). Abundance of the Group 'L' oribatid mites decreased twice from point #2 to #4 but increased again at the point #5. We should also note that the increase in the oribatid mites density of both the Groups from the sampling point #1 to #2 is probably related to a high pollutants load level (I_{PLS} = 93 units) at the first point that is unfavorable even for oribatid mites species, which are rather well adapted to polluted habitats.

A clearer picture was revealed if we calculate the ratios of densities of the two considered Groups. The ratio of oribatid mites abundances of the Group 'S' to the Group 'L' ($R_{S/L}$) was gradually decreasing from 8.15 to 0.16 along with decreasing the index I_{PLS} from 93 to 0.2 (Fig. **3**). This dependence was satisfactory described by the equation:

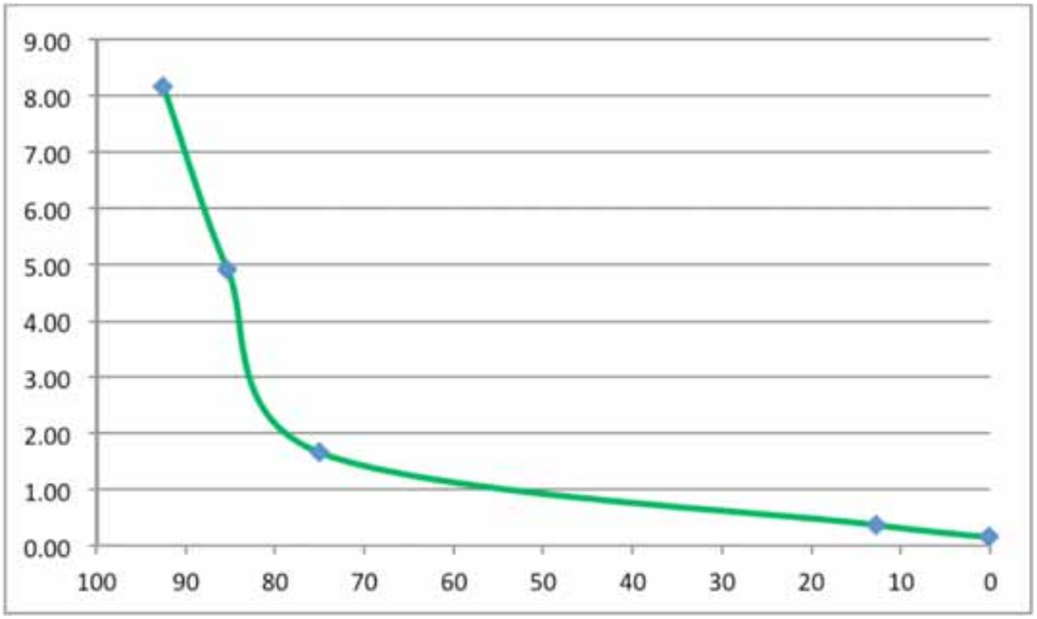

Fig. (3). Ratio of the oribatid mites Group 'S' to the Group 'L' (ordinate axis) depending on the pollution index I_{PLS} (abscissa axis).

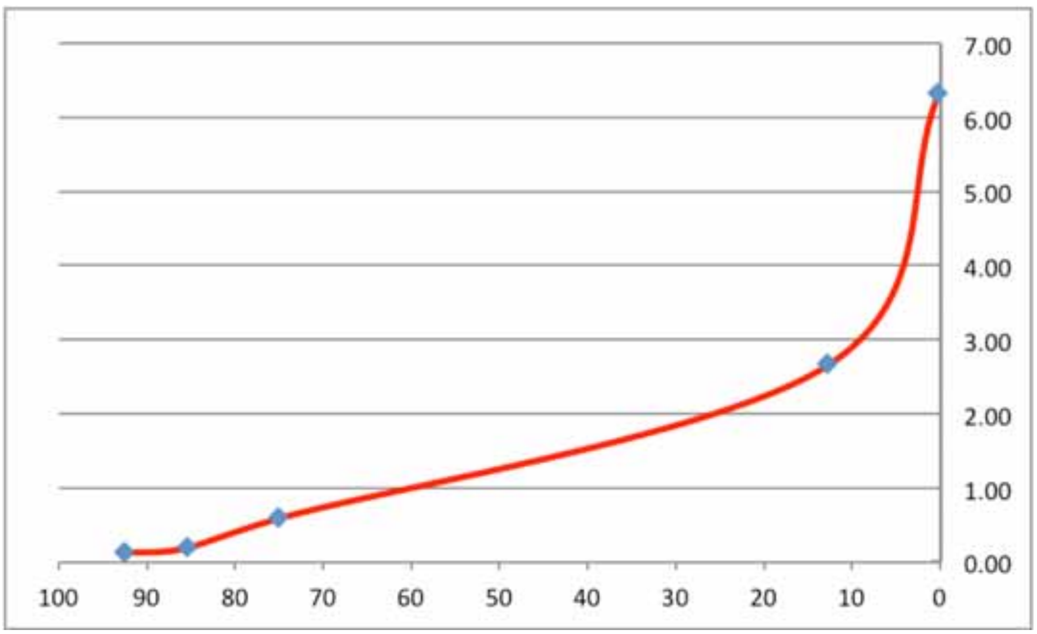

Fig. (4). Ratio of the oribatid mites Group 'L' to the Group 'S' (ordinate axis) depending on the pollution index I_{PLS} (abscissa axis).

$$R_{S/L} = 0.180 * \mathrm{Exp}(0.0375 * I_{PLS}) \quad (1)$$

with a significant determination coefficient (R^2) equal to 0.55. Another more complicated regression function gave a higher R^2 (0.83):

$$R_{S/L} = 0.228 * \mathrm{Exp}(0.000406 * (I_{PLS})^2) \quad (2)$$

But if we calculate the inverse ratio of the oribatid mites densities, that is the Group 'L' to the Group 'S' ($R_{L/S}$), the dependence between oribatid mites abundance and pollution (Fig. **4**) was surprisingly described by simple equation with very high R^2 (0.99) and very simple second regression coefficient equal to -1:

$$R_{L/S} = 4.84 - \mathrm{Ln}(I_{PLS}) \quad (3)$$

The probability values for the first and the second regression coefficients (determined from the t-statistic) in the equation (3) were more significant (0.0002 and 0.0004, respectively) as compare to the equation (1) (0.0131 and 0.0047, respectively) and equation (2) (0.0113 and 0.0033, respectively).

The pair (Pearson) correlation analysis did not reveal any significant correlation between soil properties (represented in the Table **1**) and densities of all species of the oribatid mites, both selected groups as well as $R_{L/S}$ and $R_{L/S}$ ratios. Therefore, we suppose that the obtained change of oribatid mite abundance along the series of the sampling points is much less connected with soil properties but much more with pollution level. We consider that these both ratios ($R_{L/S}$ and $R_{L/S}$) reflect indeed the dependence of ecological structure of oribatid mites' community on the level of anthropogenic pollution load.

Thus, the higher pollution level really causes enlargement of the one ecological group (euedaphic oribatid mites, i.e. the group 'S') and inhibition of another group (litter-topsoil mites, i.e. the Group 'L'). Such phenomenon of abundance increasing (sometimes even so significant as in tens or hundreds of times) for some animal species under severe disturbance of natural ecosystems (i.e. technogenic ones) along with disappearance of many other species was shown earlier but predominantly for insects (Bey-Bienko 1964). We suppose that the reasonable explanation of this phenomenon could be the following. An anthropogenic impact depress life activity of the oribatid mites species, which are more sensitive to a disturbance, and therefore the less sensitive oribatid mites get advantage in the competition. Similar suggestion was also made by S. Hagvar (1988) upon studying abundance of oribatid mites in Scandinavian forest soils affected by acid rains and lime application. In general, similar data for the oribatid mites are not numerous at all and these are related to ecosystems of more southern regions than we sampled. In particular, it was shown under summer drought at the border of grasslands and boreal forests in Canada (Newton 2013) as well as under anthropogenic pollution in the big city surrounding in the forest-steppe zone of West Siberia (Andrievskii & Syso 2012). A phenomenon of increasing abundance of one of species of oribatid mites (*Tectocepheus velatus*) under influence of atmospheric pollutants were obtained in forest soils of Norway (Hagvar 1984). But these authors had not attempted to describe mathematically the alteration of oribatid mites abundance as a function of pollution level.

CONCLUSION

The atmospheric emissions from gas industry plants influenced the community of oribatid mites in tundra ecosystems. It was evidenced by changing the ratio of the ecological groups of the oribatid mites rather than its total abundance. The number of the discovered species of mites was almost the same in a specific biotope (five to seven species), although set of species was changed. The total abundance of the oribatid mites (all individuals per square meter) was increased in higher contaminated biotopes, located closer to the source of the atmospheric pollution. In such biotopes euedaphic oribatid mites gave higher contribution to the oribatid mites community (up to 89% of all mites individuals). They differ from another ecological group (litter-topsoil mites) by smaller size and better adaptation to the environmental stresses, including soil contamination. In the conditions of decreasing pollution levels, the mites community structure was changed to predominance of litter-surface oribatid mites species, larger in size and typical for undisturbed natural communities.

Level of pollution was evaluated on the basis of cumulative index of anthropogenic pollution load per unit of an ecosystem surface (I_{PLS}). It was found that the best characteristic of bioindication of pollution is ratio of litter-topsoil oribatid mites to euedaphic ones ($R_{L/S}$). Very simple equation with high significant determination coefficient was obtained to describe this dependence: $R_{L/S} = 4.84 - \text{Ln}(I_{PLS})$.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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