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Formation of oribatid mite complex in remediated gravel quarry soil

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Utilization of sewage sludge is one of the measures for remediation of destroyed soils. Remediation of soils with sewage sludge requires preliminary investigations of soil formation intensity, accumulation of heavy metals in organic material and the ecological status of the soil. Based on observation of the structural changes of oribatid mite complexes, the present work analyses the pattern of biological processes taking place in the soil forming in a gravel quarry remediated with sewage sludge and the ecological status of the soil.

The obtained results have shown that sewage sludge stimulates faster succession of microarthropod complexes and contribute to their abundance. In the first year of remediation of the quarry with sewage sludge, the total microarthropod abundance is higher than that in the naturally regenerating soils, but the species composition is poorer. After three years of remediation, oribatid mites are dominant in the microarthropod community, but their complex is characterized by a small number of species and a low abundance of individuals. In the 16th–18th years of remediation, these indices markedly increase. After 18 years, only in the soil not fertilized with sewage sludge the composition of the species spectrum approached the spectrum of forest oribatid mite communities characterized by a polydominant structure with the eudominant euribiont species *Oppiella nova*.

Key words: gravel quarry, sewage sludge, heavy metals, soil, oribatid mites

INTRODUCTION

The area of damaged soils in Lithuania (exhausted gravel, sand, clay and peat quarries) accounts for more than 33 thou ha. The soils of abandoned sand and gravel quarries are poor and exposed to a permanent destructive impact of wind and water erosion adding to pollution of neighbouring water bodies and farm lands (Šleinys, 2001). In the course of time, soil organisms almost disappear in the exploited soil layers, the content of humus reduces to 0.5%, and the soil structure loses stability. Only in a few years, when the first plants appear (Petrovas, 1994), poor zoocoenoses start to develop. Therefore, it is important not only to speed up the rates of regeneration, but also to prevent damage to new soil areas. Remediation of damaged soil and soil formation require organic matter. Fertilization of exhausted quarries with sewage sludge increases the content of biogenic elements in their soils (Budavičienė, 1997) and favours soil formation processes (Багданавичене и др., 1990). Sewage sludge accumulated in urban waste water treatment equipments is a useful organic fertilizer. The use of sewage sludge for fertilization would solve two major problems: return to the soil the organic matter eliminated with yields of cultural plants and would utilize the urban organic wastes. However, an unconditional use of sewage for fertilization is limited by two factors: pollution with heavy metals and pathogenic microorganisms (Eitminavičiūtė, 1997). It is common knowledge that heavy metals inhibit disintegration of organic matter, reduce the vital activity of microorganisms and exert a toxic effect on invertebrate. However, research works fully evaluating the environmental implications of fertilization with sewage are deficient.

Soil zoocoenoses, microarthropods in particular, their complex structure and species composition are widely reported bioindicators of the regeneration degree of the productive soil layer (Bielska, 1995; Hutson, 1980) and the levels of pH, C/N and pollution with heavy metals (Doran, Safley, 1997; Straalen van, 1997). The ratios of microarthropod group abundance and species composition show the type of soil, its granulometric composition, moisture regime, etc. (Eitminavičiūtė, 2001). Remediation of soils with sewage sludge facilitates best the development of microarthropods (Eitminavičiūtė, 1997). Appearance and dominance of oribatid mites (Acari: *Oribatida*) in the microarthropod complex indicates the beginning of soil and humus formation. Analysis of *Oribatida* abundance dynamics and of the structure of their community helps to reveal the degree of soil stability and its formation trend.

The aim of the present research was to find the pattern of biological processes in soil remediated with sewage sludge and the ecological status of the forming soil based on observations of the structural changes in the complex of oribatid mites.

MATERIAL AND METHODS

The investigation material was collected in the exhausted Verkšionys gravel quarry of Trakai District. The quarry is situated on the third Neris River terrace at a distance of 300–400 m from the river. The quarry area is 12 ha. Experiments were performed in an area of 7 ha.

The remediation of the Verkšnionys gravel quarry with sewage sludge from the Vilnius city was assumed in 1989. In 1989–1995, thorough investigations of hydrochemical composition, soil fauna, sludge degradation, content of heavy metals and other parameters were carried out (Eitminavičiūtė, 1997; Navickienė, 1997; Bagdanavičienė, Budavičienė, 1997). Author of this article resumed the investigations of microarthropods in the sixteenth year of quarry remediation with sewage sludge, investigations lasted three years (2004–2006). The sampling material was taken in four stationary sites: 1) a quarry sector where sewage sludge (250 t/ha) was spread on the surface (variant I); 2) a quarry sector where sewage sludge (250 t/ha) was inserted into the soil (variant II); 3) quarry slope not fertilized (control sector); 4) pine forest (about 35 years old) growing by the edge of the quarry.

The following physical-chemical properties of soils in the quarry remediated with sewage sludge and in the neighbouring area were investigated: pH, moisture (%), temperature (t °C), and the concentration of heavy metals (mg/kg). The concentration of heavy metals in the soils was determined by the method of spectral analysis at SP UAB "Vilniaus vandenys" and calculated in mg/kg of dry mass. The species diversity of oribatid mites and formation trends of their complex were evaluated. Soil samples were taken five times in spring (May) and autumn (September) in each sector from the top soil layer with the aid of a cenometer (5 × 5 × 5 cm). A total of 120 soil samples were examined. Microarthropods were extracted from the soil with the modified Berlese–Tullgren light extractor using standard methods (Гиляров, Стриганова, 1987). Mature individuals were characterized to the species. Based on the analysis of collected material, the species composition of oribatid mites, d ($d = S-1/logN$) (Margalef, 1958) was determined and their abundance n (ind./m^2), and percentage ratio were calculated. Species abundance was determined according to H. Engelmann (Engelmann, 1978).

The standard analysis was performed using Microsoft Excel and STATISTICA 6.0 programs.

RESULTS AND DISCUSSION

The concentrations of heavy metals in the sewage sludge from the Vilnius city, used for quarry remediation, was close to the highest permissible values (HPV) for sludge: copper 489, nickel 218.5, zinc 439.75, and chromium 329.75 mg/kg of dry mass (Bagdanavičienė, Budavičienė, 1997).

Investigations in 2004–2006 showed that the concentration of heavy metals in the control soil (not fertilized with sewage sludge) was considerably lower than in the soil fertilized with sewage sludge. The highest concentration of heavy metals after 16–18 years of remediation was determined in variant I where sewage sludge was spread over a sand surface. It contained an especially high concentration of Zn: 505.33 mg/kg (Fig. 1).

Heavy metals in the soil are linked with organic and inorganic soil compounds and with humus (Kabala, Singh, 2001). The granulometric composition of soils, soil type and the content of organic matter are among the major factors predetermining the mobility of heavy metals. In a weakly acid environment where the biological activity of soils is higher, metal ions are mostly absorbed by living soil organisms and by mineral and organic particles (Тейт, 1991).

After 16–18 years of remediation with sewage sludge, the quarry soil was alkaline. In variant I, the average pH value was 7.7 and in variant II 7.8. In the control variant, the pH value

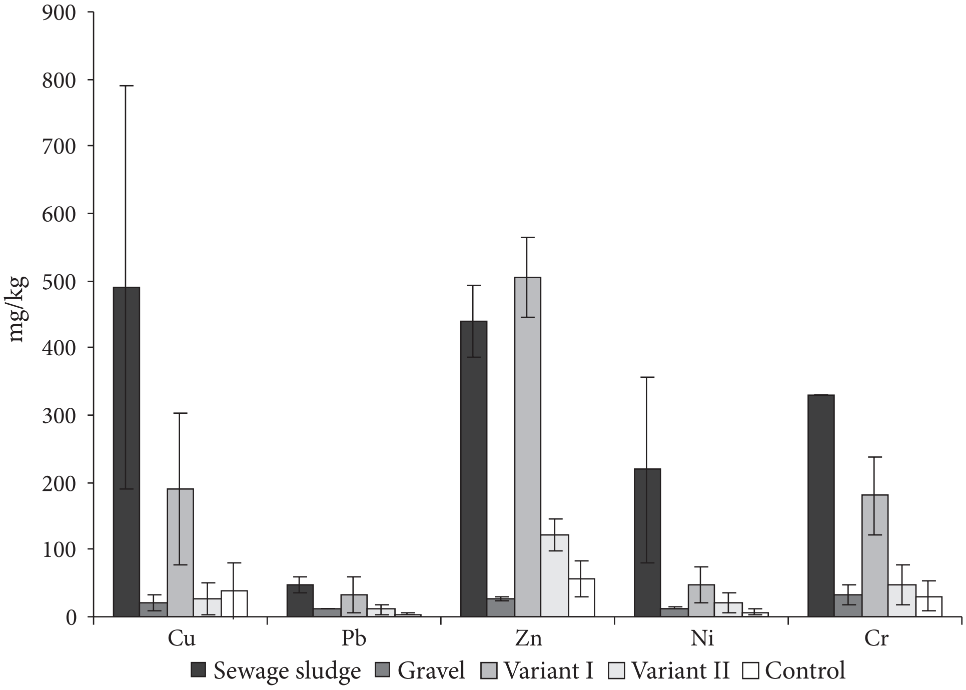

Fig. 1. Concentrations of heavy metals in the sewage sludge and in the of soil gravel quarry (average of 1989–1990) (Bagdanavičienė, Budavičienė, 1997) and in the forming soil (average of 2002–2004)

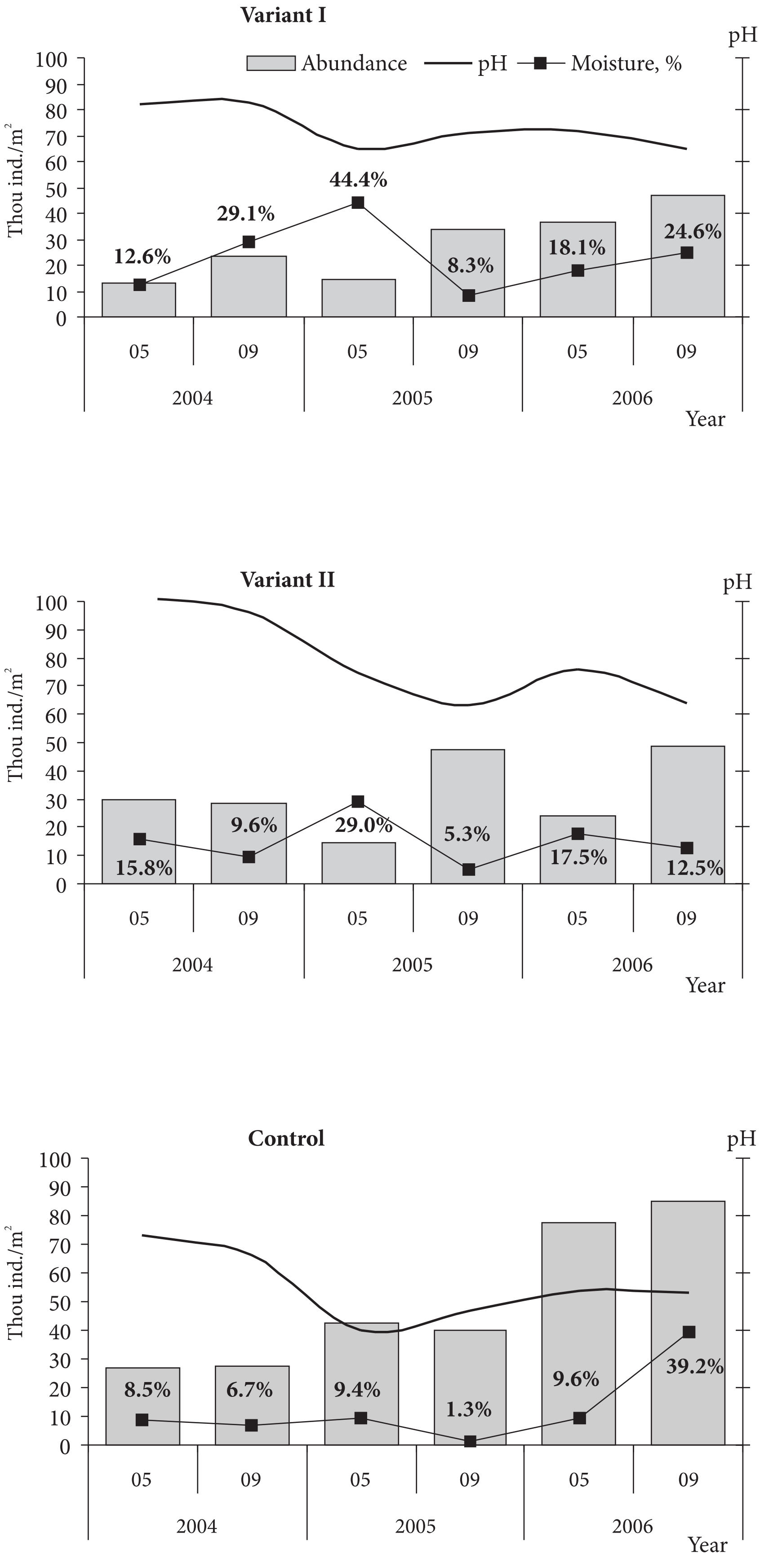

Fig. 2. Dependence of the abundance (thou ind/m^2) of oribatid mites on the moisture regime (%) and pH of the soil of remediated quarry in 2004–2006 (the 16th–18th years of remediation)

was slightly lower. Our results showed that when the pH value was lower, the abundance of oribatid mites increase (Fig. 2). Soil moisture regime varied within different years. According to Jucevica and Malecis (2005), structural changes of the community might be influenced by the changed moisture regime in the substratum. Yet we did not observe any interdependence of moisture regime and abundance dynamics of oribatid mites. Mites are likely to be more dependent on food supply than on water content.

Under conditions of natural regeneration of soil in exhausted quarries, humus and species diversity of zoocoenoses develop very slowly because organic matter appears only at the end of the vegetation period of a poor plant community. During the remediation of destroyed soils with organic matter (sewage sludge), the appearance and dominance of oribatid mites in the microarthropod complex show the beginning of soil and humus formation.

At the beginning of the experiment in 1989, the control variant (sand) of the Verkšionys quarry contained no oribatid mites. Oribatid mites in this part of the quarry appeared only five months after the beginning of remediation. In the first four years, the oribatid complex was poor in species composition and abundance. The total abundance of oribatid mites in the control variant reached 1.26 thou ind/m^2, whereas in the fifth–seventh years it ranged from 14.0 to 16.26 thou ind/m^2. In the first seven years of remediation, nine species of oribatid mites were found in this variant (Navickienė, 1997). In the 16th–18th years of remediation, the average total abundance of oribatid mites in the unfertilized part of the quarry was 49.8 thou ind/m^2 (Fig. 2). A total of 33 species of oribatid mites was found (Table). An especially high abundance of oribatid mites (81.3 thou ind/m^2) was recorded in the 18th year of remediation.

Oribatid mites are indicators of clean, naturally forming soil. Therefore right after fertilization with sewage sludge they occur in a very low abundance. Their abundance increased in the third year of remediation when the

Table. **Species diversity and abundance of oribatid mites in the Verkšionys gravel quarry remediated with sewage sludge in 2004–2006**

Species	2004								2005								2006							
	05	09	05	09	05	09	05	09	05	09	05	09	05	09	05	09	05	09	05	09	05	09	05	09
	Variant I		Variant II		Control		Forest		Variant I		Variant II		Control		Forest		Variant I		Variant II		Control		Forest	
	Thou ind/m²																							
Adoristes poppei (Oudemans, 1906)								0.2																
Achipteria coleoptrata (Linnaeus, 1758)																						0.1		
Brachychthonius sp.		0.5	0.1	2.2	2.9	0.7	0.8	0.9	0.3	0.5	0.7	2.6	1.5	3.4	0.3	0.4	3.6	2.5		2.3	11.5	5.4	1.4	0.4
Brachychthonius sp. *a*					0.5																			
Carabodes sp.																					0.1			
Ceratozetes sp.							0.1	0.1							0.2	0.1			1.9					
Chamobates pusillus (Berlese, 1895)							2.1	1.6																
Chamobates schützii (Oudemans, 1902)														0.1										
Chamobates sp.															1.2	1.2	0.2			0.1	1.8	2.9	1.8	5.2
Diapterobates numerosus (Sellnick, 1924)																							0.1	0.1
Diapterobates oblongus (C. L. Koch, 1879)																							0.2	
Dissorhina ornata (Oudemans, 1900)						0.2															8.2	5.8		
Epidamaeus sp.																					0.5	0.5	0.1	
Eupelops duplex (Berlese, 1916)								0.1																
Eupelops occultus (C. L. Koch, 1836)							0.1					0.4		0.1								0.1		
Eupelops sp.									0.4	0.3														0.3
Euzetes sp.											0.1													
Galumna sp.		1.0	0.7	1.6	0.1	0.7	0.1	0.1			0.1	0.6	0.1	0.7	0.1		0.4	0.3		0.2	1.0	2.2	0.2	0.5
Latilamellobates incisellus (Kramer, 1897)		0.1																0.1						
Lauroppia fallax (Paoli, 1908)																					0.3			
Lauroppia maritima (Willmann, 1929)																							0.5	
Lauroppia neerlandica (Oudemans, 1900)																								0.1

Table (continued)

Liebstadia humerata Sellnick, 1928								0.1																
Liebstadia similis (Michael, 1888)		0.1								2.0	0.1	11.0	0.4	0.6			4.4	3.1		0.2	0.1	2.7		
Medioppia obsoleta (Paoli, 1908)	0.1						0.4	17.6														1.0		
Metabelba pulverulenta (C. L. Koch, 1839)																						0.1		
Metabelba sp.					0.3	0.5	0.2	0.3					0.3	0.4	0.2	0.3		0.1			0.8	0.2	0.1	0.2
Micreremus brevipes (Michael, 1888)							0.1	0.2																
Microppia minus (Paoli, 1908)							0.9	3.5							2.0	0.2					0.9		1.4	4.0
Moritzoppia unicarinata (Paoli, 1908)																						0.1	2.4	
Nothrus silvestris Nicolet, 1855							0.3	1.7								0.2							0.5	
Oppia sp.															1.5	0.1								
Oppiella nova (Oudemans, 1902)	0.8	0.4		3.8	3.3	4.4	19.1	30.6	0.6	0.4	3.2	0.5	13.0	2.2	25.3	14.5	3.2	1.9	1.6	1.8	20.0	19.1	23.2	8.9
Oppiella splendens (C. L. Koch, 1841)																					0.1			
Oribatula tibialis (Nicolet, 1855)		0.6			0.4	0.7	0.2	0.7		0.9			0.7	1.9		0.7		6.7	0.3	3.5	2.2	3.5	0.8	
Oribotritia loricata (Rathke, 1799)	0.3	0.1				0.2					0.1						0.1	0.2	0.1	0.6	0.7	1.4		
Parachipteria punctata (Nicolet, 1855)																						0.1		
Peloptulus phaenotus (C. L. Koch, 1844)						0.3				0.2		0.1	0.2				0.2	0.3		0.1		0.2		
Phthiracarus borealis (Trägardh, 1910)		0.3		0.1																			0.7	
Phthiracarus sp.							0.5	0.4																0.7
Heminothrus peltifer (C. L. Koch, 1839)								0.2															0.1	1.5
Podoribates gratus (Sellnick, 1921)	0.1				0.1	0.1						0.1	0.1						0.3	0.2		0.2		

Table (continued)

Quadroppia quadricarinata (Michael, 1885)		1.7		3.2	1.4	0.2	1.9	2.0			0.3	2.3	1.9	2.5	1.7	0.7	0.4	1.1	0.3	4.1	2.9	4.0	0.7	3.0
Scheloribates laevigatus (C. L. Koch, 1836)													0.1	1.5										
Scheloribates latipes (C. L. Koch, 1844)	0.2	0.1				0.8				0.4						0.7		1.7			0.7	0.2		0.1
Scutovertex minutus (C. L. Koch, 1836)	0.4	0.4	0.7	0.1	0.8	0.7			0.1		0.8		0.6	0.1					0.2	0.2	0.2			
Sphaerozetes tricuspidatus Willmann, 1923								0.1																
Suctobelba sp.	0.4	1.0	0.1	2.0	0.9	3.6	6.1	2.0	1.7	2.3	0.1	1.9	6.0	3.0	5.0	2.4			1.6	1.4	5.2	1.8	6.3	4.1
Suctobelbella sp.	0.9		0.3		0.3		1.1	18.5	0.7		1.3		4.2	0.5	0.7	0.5	1.7	2.8			0.2	0.1	0.8	2.0
Tectocepheus velatus (Michael, 1880)	2.8	9.3	8.4	4.1	5.1	6.0	1.6	16.0	7.4	17.0	3.1	8.3	5.2	4.1	0.8	1.6	11.0	8.3	7.6	13.0	4.5	11.6	5.1	0.4
Trichoribates novus (Sellnick, 1928)				0.1									0.2											
Trichoribates trimaculatus (C. L. Koch, 1836)										0.1							0.1						0.1	
Trhypochthoniellus badius (Berlese, 1905)							0.1								0.2									
Xenillus tegeocranus (Hermann, 1804)														0.1							0.2			
Σ	6	15.6	10.3	17.2	16.1	19.1	35.7	96.9	11.2	24.0	9.9	27.3	34.6	21.2	39.2	23.6	25.7	29.1	13.9	27.9	62.1	63.3	46.5	31.5
Number of species	10	13	6	9	12	14	18	21	7	10	11	10	15	15	13	14	11	13	9	13	21	23	20	16

content of nitrogen and easily disintegrating organics reduced in the substratum. In the fourth year of remediation, the abundance or oribatid mites in variant I, where sewage sludge was spread over the surface, reached 1.2–10.4 thou ind/m^2 and in variant II, where sewage sludge was inserted into the soil, 0.6–112.0 thou ind/m^2 (Navickienė, 1997). This shows that the oribatid mite complex developed at highest rates in the soil with inserted sewage sludge. The increasing abundance of oribatid mites shows that inserted sewage sludge accelerates mineralization of organic matter, and soil formation processes start earlier. In the first six years of experiment, nine species of oribatid mites were found in variant I and 7 in variant II (Navickienė, 1997).

In the 16th–18th years of the experiment, the abundance of oribatid mites in variant I (sewage sludge spread over the surface) ranged from 18.55 to 41.7 thou ind/m^2 (Fig. 2). A total of 21 species of oribatid mites was found: 16 in 2004, 12 in 2005 and 15 in 2006. In variant II (sewage sludge inserted in the soil), the average abundance of oribatid mites ranged from 19.9 to 36.55 thou ind/m^2. A total of 19 species was found: 10 in 2004, 14 in 2005 and 14 in 2006 (Table). Thus, even in the 16th–18th years of remediation with sewage sludge, the species diversity and abundance of oribatid mites were higher in variant II (sewage sludge inserted in the soil).

Analysis of oribatid mites in the adjoining forest soil showed that their average abundance reached 62.8 thou ind/m^2. Thirty five species of oribatid mites were defined in this biotope (Table).

In 1989–1995, the index of species diversity of oribatid mites (d) in the fertilized part of the quarry was lower than in the control variant. Only in the fifth year of experiment, this index in the fertilized part of the quarry approached the value typical of naturally forming soil complex (Navickienė, 1997). In all variants, a clear trend of increasing species diversity was observed in the 18th year of remediation (Fig. 3). In the control variant, the species diversity index was highest and approached the one of the forest biotope.

A comparison of long-term (from the beginning through 18 years of remediation), formation of oribatid mite complex showed that their species composition in fertilized and unfertilized soils was different.

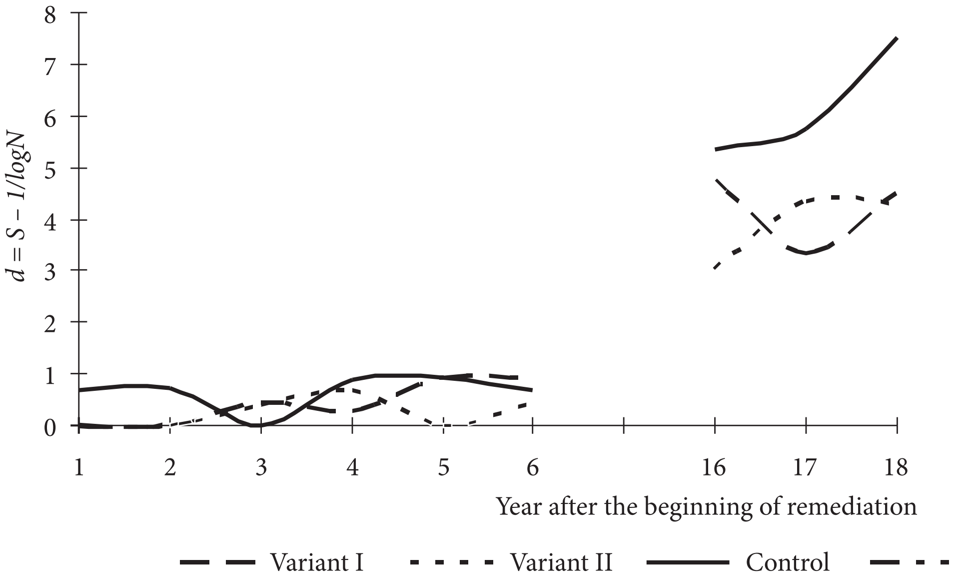

Fig. 3. Species diversity (d) dynamics in the complex of oribatid mites of the remediated quarry

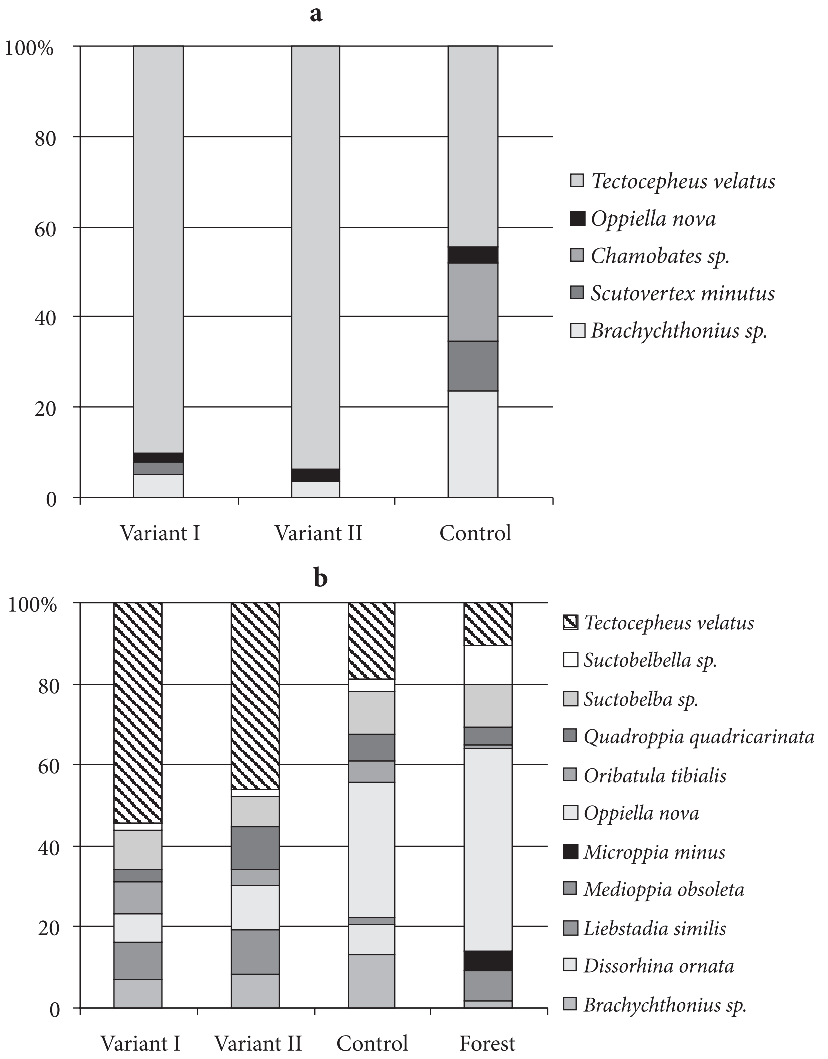

Fig. 4. Distribution of nucleate species of oribatid mites in the community in 1989–1995 (*a* – the 1st-6th year after the beginning of remediation) (Navickienė, 1997), and in 2004–2006 (*b* – the 16th–18th year after the beginning of remediation) (eudominants 40–100%; dominants 12.5–39.9%, subdominants 4–12.4%)

In the first year of experiment in the fertilized soils, the oribatid complex was of monodynamic character: the euribiont species *Tectocepheus velatus* was eudominant (Fig. 4a).

The number of species increased in the 5th–6th years of the experiment. Along with the absolutely eudominant *Tectocepheus velatus* there appeared a complex of rarer species: *Brachychthonius* sp., *Oppia* sp., *Sheloribates laevigatus*, etc. (Navickienė, 1997). In the 16th–18th years of remediation, a single species (*Tectocepheus velatus*) was eudominant in variants I and II (50.3 and 42.0%, respectively) (Fig. 4b).

In the control variant and in the forest soil, the distribution of oribatid species was slightly different. In the first year of ex-

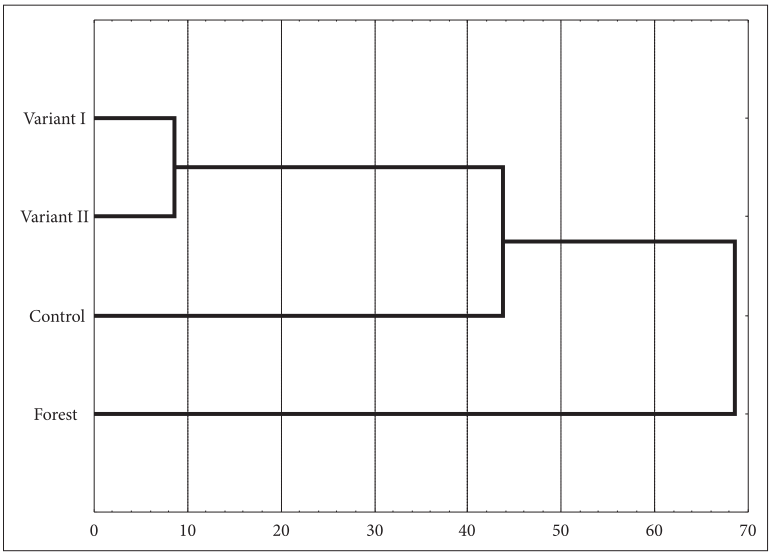

Fig. 5. Similarity cluster of the communities of oribatid mites in Verkšionys gravel quarry sites (2004–2006)

periment, euribiont species proliferated in the control variant: *Oppiella nova*, *Scutovertex minutus* (Navickienė, 1997). In the 16th–18th years of remediation, there appeared no eudominant but a few dominant (*Oppiella nova*, *Tectocepheus velatus*) and sub-dominant species. *Oppiella nova* was eudominant in the forest soil, accounting for 44.5%. A comparison of species spectrum showed that in the percentage of species the control variant was closest to the community of oribatid mites typical of forest soil (Fig. 4). This was also proved by cluster analysis according to species abundance (Fig. 5).

CONCLUSIONS

Soil regeneration is a long and slow process which depends on the environmental conditions. In the first year of soil remediation with sewage sludge, the total abundance of microarthropods is higher than in the naturally forming soils, but the species diversity is poorer. The highest rate of oribatid complex formation was characteristic of the part of the quarry where sewage sludge was inserted into the soil (variant II). However, despite fertilization with sewage sludge which increases microarthropod abundance, after 18 years of remediation the species composition and the index of dominance of the complexes of oribatid mites in the unfertilized soil approached the complexes of oribatid mites characteristic of natural forest ecosystems.

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ORIBATIDINIŲ ERKIŲ KOMPLEKSO FORMAVIMASIS REKULTIVUOTO ŽVYRO KARJERO DIRVOŽEMYJE

Santrauka

Viena priemonių sunaikintiems dirvožemiams rekultivuoti yra miestų nuotekų dumblo panaudojimas. Rekultivuojant dirvožemius nuotekų dumblu svarbu išaiškinti dirvožemio formavimosi proceso intensyvumą, sunkiųjų metalų akumuliaciją organinėse medžiagose ir dirvožemio ekologinę būklę. Darbe tiriamas rekultivuoto nuotekų dumblu žvyro karjero besiformuojančio dirvožemio biologinių procesų kryptingumas ir jo ekologinė būklė stebint oribatidinių erkių komplekso struktūros pokyčius.

Tyrimo rezultatai parodė, kad nuotekų dumblas skatina greitesnę mikroartropodų kompleksų formavimosi sukcesiją ir didina jų gausumą. Rekultivuojant karjerą nuotekų dumblu pirmaisiais metais bendras mikroartropodų gausumas yra didesnis nei natūraliai atsistatančiuose dirvožemiuose, tačiau rūšinė įvairovė skurdesnė. Mikroartropodų bendrijoje po trejų metų nuo dumblo užvežimo vyrauja oribatidinės erkės. Iš pradžių oribatidų kompleksui būdingas nedidelis rūšių skaičius ir individų gausumas, 16–18 rekultivacijos metais šie rodikliai ryškiai padidėja. Rūšinio spektro sudėtis per 18 metų tik netręštame dumblu variante priartėjo prie miško oribatidinių erkių bendrijų, kurioms būdinga polidominantinė struktūra su eudominuojančia euribiontine rūšimi *Oppiella nova*.

Raktažodžiai: žvyro karjeras, nuotekų dumblas, sunkieji metalai, dirvožemis, oribatidinės erkės