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Earthworms (Lumbricidae) from a surface layer and wireworms (Elateridae) of forest stands in the anthropogenically-disturbed area of the Děčínská vrchovina Upland (Czech Republic)

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Abstract: Kula, E. Švarc, P. 2012: Earthworms (Lumbricidae) from a surface layer and wireworms (Elateridae) of forest stands in the anthropogenically-disturbed area of the Děčínská vrchovina Upland (Czech Republic). – *Beskydy,* 5 (1): 43–54

In the area negatively affected by air pollution in the past, the earthworm assemblages and the occurrence of wireworms (Elateridae) in forest ecosystems were evaluated in relation to site conditions. From soil samples taken in 38 stands (*Fagus, Betula, Alnus, Quercus, Pinus, Larix, Abies*) earthworms and wireworms were extracted by means of Tullgren funnels. Eudominant species (*Dendrobaena vejdovskyi, D. octaedra, D. illyrica*) are typical representatives of forest ecosystems of the Ore Mountains. Relationships were proved to a tree species creating a forest stand and the pH of Ah horizon. The area is characterized by the generally low diversity of earthworms particularly in young stands of beech and Norway spruce. Faunistically rich sites occurred only in a mixed stand (birch, mountain ash, larch) and in a blue spruce monoculture. Reduced abundance of earthworms in the organic matter of mounds was surprising. The type/form of soil preparation, forest weed cover and the age of trees did not affect significantly the earthworm assemblages. The abundance of wireworms was increased in pine and larch stands and reduced in alder and blue spruce stands. The increasing pH value negatively affected the abundance of wireworms.

Key words: earthworm, Lumbricidae, forest ecosystems, pH, Děčínská vrchovina highland

Introduction

Soil-forming processes in forest ecosystems are markedly affected by fauna including soil mites (Oribatida), springtails (Collembola), earthworms (Lumbricidae) and other invertebrates the effectiveness of which depends on site conditions [for example wireworms (Elateridae)].

Climatic effects and simultaneously occurring long-term air pollution impacts were the cause of the direct damage to spruce stands (Kubelka et al. 1992), which also initiated the degradation of soil processes in extensive above all mountain areas of the Czech Republic (Langkrammer, Lettl 1982, Lochman 1981, Hruška, Cienciala 2002). Air-pollution damages to forest stands culminated in the years of 1978–1985. In the area of the Ore Mountains, 36 thousand ha forest stands were deforested (Kubelka et al. 1992) with the consequential establishment of stands of substitute tree species (33 thousand ha) with the dominant proportion of blue spruce (*Picea pungens* Engelm.) and european birch (*Betula pendula* Roth) (Jirgle 1980, Smejkal et al. 1994, Kula 2011). The new tree species composition and in some areas the whole-area preparation of soil (including spreading upper horizons into mounds) variously affected existing unfavourable ecological conditions (Jirgle 1984, 1988, Kubelka et al. 1992, Šach 1995, Podrázský 1995, Podrázský, Remeš 2006, Vavříček et al. 2006) including revitalization liming (Podrázský et al. 2003, Šrámek et al. 2006, Kula 2009).

Communities of earthworms participate significantly on the mechanical decomposition of dead organic matter. Depending on the quality of forest litter, soil chemistry and the size of the population of earthworms but also accompanying organisms soil microstructure is created and forms of humus (Edwards, Bohlen 1996, Tomlin et al. 1995).

The majority of earthworm species is neutrophilous with the optimum soil reaction within the limits of pH 6–7. However, due to acidification, the abundance of earthworms is reduced (Wallvork 1976, Hagvar 1987, Persson et al. 1987). Rundgren (1994) mentions that in forest soils, generally two as many as four earthworm species occur but after the fall of pH, they change even to a single-species community. Soil acidification also significantly affects the growth and reproduction of earthworms (Bengtsson et al. 1986). Species diversity on degraded soils is also markedly affected (Nordström, Rundgren 1974, Enckell, Rundgren 1988). In the Ore Mountains, extraordinary tolerance was noted of *Dendrodrilus rubidus* Sav. (pH 2.7) (Pižl 2002). Some other studies come from air pollution areas of the CR (Pižl 1995, Kula, Matoušek 2004, Švarc, Kula 2011, Kula, Švarc 2011).

Larvae of Elateridae (wireworms) are also the significant component of forest soils where they participate in decomposition (Nielsen 1974, 1975, Schauermann 1986). In the soil of forest stands of the Kienhaida Nature Reserve (Ore Mountains) and adjacent anthropogenically disturbed stands, 24 species of wireworms (larvae) of Elateridae were noted with the eudominant position of a carnivorous saprophagous *Athous subfuscus* (O. F. Műll.) (71.09 %) and a carnivorous *Dalopius marginatus* (L.) (14.53 %) (Kula, Švarc 2010).

The aim of the paper is to evaluate the community of Lumbricidae and the occurrence of larvae of Elateridae in forest stands of the air-pollution area of the Děčínská vrchovina Upland in relation to site conditions (tree species, undergrowth, soil preparation, pH).

Methods

Soil samples to determine earthworms and larvae of Elateridae were cut out with a spade as a compact block 25×25 cm to a depth of 10–15 cm. From each of the stands always four samples were obtained, namely in the spring (May, 2011) and late summer aspects (September, 2011) 20 m apart situated to a central line beginning generally at the tree height from the stand margin. At localities with mounds, sampling was carried out in the space between mounds and simultaneously on mounds created originally from the piled up organic material. Each of the samples (304) was separately placed into a PE bag and transported at the latest within 72 hours into laboratory conditions. For extraction, Tullgren funnels (Novák 1969) made-over by Tuf and Tvardík (2005) and adapted by Kula (2009) with exposure time 21 days was used. 0.5 % formaldehyde served as a killing medium followed by the subsequent preservation of caught earthworms and wireworms in 75 % ethanol. At the same time, soil samples were taken to determine active soil reaction (pH/H_2O) and potential exchange soil reaction (pH/KCl) at each of the localities. In the laboratory, soil pH was measured using a pH meter with a combined glass and calomel electrode (filling: mercurous chloride) (ISO/DIS 1992).

Juvenile and adult individuals of Lumbricidae were determined by Ing. Petr Švarc in cooperation with RNDr. Václav Pižl, CSc. from the Institute of Soil Biology, Academy of Science of the Czech Republic, České Budějovice. Larvae of Elateridae were not determined according to species with respect to demandingness and existing findings from the Ore Mountains on the eudominant occurrence of *A. subfuscus* (87.23 %) in birch stands among 22 species of larvae (Kula, Švarc 2010, Kula 2009).

The method of Tullgren funnels made possible to determine abundance (pcs.m^{-2}), dominance in the earthworm assemblages and structural characters of the community of Lumbricidae (diversity, equitability) for each of the localities (Losos et al. 1984).

A statistical evaluation was carried out at a level of the type of soil preparation and the level of particular tree species. Numbers of samples were associated at a locality for both sampling terms (Tab. 1).

Results were processed using the STATISTICA 8 (StatSoft 2007) program. To evaluate the database, non-parametric ANOVA (Kruskal-Wallis test) was used. Significance was tested at a level of $\alpha = 0.05$ (Meloun et al. 2005). The effect of different site conditions on the population of earthworms was tested using the Canoco for Windows 4.5 (TerBraak, Šmilauer 2002) program. To depict diagrams we used the CanoDraw for Windows program. The statistical significance of particular variables was tested by a Monte-Carlo permutation test (999 permutations).

Description of the area of examination

The studied area of the Děčínská vrchovina Upland (Forest Range Tisá, Celnice, Forest District Děčín) occurs largely on a plateau of

Tab. 1: Characteristics of stands (Forest District Sněžník, Forest Range Tisá).

Tree species	N	Age	Samples (TS)	Species composition	Soil preparation	Forest weed (%)	pH (H_20)	pH (KCl)
***Pinus sylvestris* L.**	6	29	8	100	site of mound	80	3.7	3.5
		38	8	100	site of mound	90	3.7	3.2
		32	8	100	without	30	3.7	3.1
		85	8	100	without	70	3.4	2.8
		87	8	100	without	100	3.6	2.9
		42	8	100	without	70	3.5	2.9
***Larix decidua* Mill.**	4	35	8	100	site of mound	80	3.7	2.9
		31	8	100	site of mound	10	4	3.3
		27	8	100	without	70	3.6	3
		32	8	100	without	30	3.7	2.9
***Picea pungens* Engelm.**	2	32	8	100	site of mound	50	5.6	5.2
		30	8	100	site of mound	70	4.1	3.4
***Picea abies* (L.) Karst.**	4	117	8	100	without	100	3.8	2.9
		35	16	100	without	0	3.7	3
		83	8	100	without	70	3.7	3.1
***Betula pendula* Roth**	6	35	8	100	mound	80	3.4	2.9
		31	8	100	mound	100	3.5	3.1
		31	16	100	site of mound	100	3.7	3.4
		32	16	100	without	70	3.9	3.3
***Fagus sylvatica* L.**	6	47	8	100	site of mound	0	3.9	3.1
		28	8	100	site of mound	0	5.9	5.5
		36	8	100	without	0	3.8	3.1
		51	8	100	without	0	5.8	5.3
		187	8	100	without	10	3.8	3.1
		153	8	100	without	50	3.7	3.2
***Quercus rubra* L.**	6	25	8	100	site of mound	100	5.7	5.3
		26	8	100	site of mound	90	3.8	3.3
		25	8	100	mound	100	4.3	3.5
		26	8	100	mound	100	3.5	3.2
		32	8	100	without	40	3.9	3.2
		45	8	100	without	90	5.6	5.1
***Alnus glutinosa* L.**	2	32	8	100	without	100	3.8	3.4
		62	8	100	without	100	3.7	3.1
Betula, Larix, Sorbus	2	31	16	40, 45, 15	without	100	3.7	3.1

an altitude of 450–700 m. It is characterized by harsh mountain climate of a mean annual temperature 6–7 °C, total annual precipitation 700–800 mm, growing season 110–120 days and mean daily temperature exceeding 15 °C. In 2011, a mean annual temperature reached 7.6 °C and annual total precipitation 786.5 mm.

Forest percentage reaches 85 % whereas protective forests of extremely unfavourable sites on rocky blocks of the Děčínský Sněžník and Tiské walls occupy 423 ha. Forests affected by air pollution with different methods of management (the Děčínská vysočina Upland plateau) occupy 7741 ha. Acid sites participate in 81.3% and an extreme zones 7.1 %. High precipitation and flat terrain are the cause of the occurrence of gleyed and waterlogged sites (9.2%). More favourable conditions occur at lower locations (altitude < 400 m) (9.7%).

It refers to an air pollution area, which is stressed for a long time by air pollution with the predominance of SO_2 mean annual (1969–1987) concentrations of which exceeded 60 μg.m^{-3}. According to monitoring stations occurring within 15 km, the period of 1988–1993 was characterized by the moderate reduction of air pollution load. However, absolute daily maxima exceeded 600 μg.m^{-3} SO_2, e.g. on Sněžník in 1993, values 783 μg.m^{-3} SO_2 and 188 μg.m^{-3} NO_x were determined. The air pollution monitoring of the ČHMÚ (Czech Hydrometeorological Institute) in Ústí n. L. measured at the Sněžník location showed that there were the fall of air pollution to 44.1–22.4–12.4 μg.m^{-3} SO_2 in 1995–1998–2001.

The monitoring was realized in 38 check stands, which were mutually connected one another and created the network of localities of an area of about 15 km^2. Particular stands differed in their species composition, age and forest weed infestation, and soil preparation before reforestation (Tab. 1).

Results

In the area of the Děčín Sněžník, some 328 earthworms of seven species were caught by the method of Tellgren funnels (124 individuals in the spring and 204 individuals in the late summer aspect). Juvenile stages predominated.

Eudominant species included *Dendrobaena vejdovskyi* (Čer.) (38.39%), *Dendrobaena octaedra* (30.60%) and *Dendrobaena illyrica* (Cog.) (23.81%). Particular species differed in their dominance between the spring and late summer aspects. *D. illyrica* decreased its proportion from 31.6% to 18.8% while at *D. vejdovskyi*, the proportion increased progressively through dominance from 31.4% to 42.9%. Remaining species were classified as receding (*D. rubidus, Lumbricus rubellus* Hoffm., *Lumbricus terrestris* L. and *Aporrectodea rosea* Sav.) (Tab. 2). The average abundance of earthworms in the area reached 22.09 pcs.m^{-2} (spring aspect 17.22 pcs.m^{-2}, late summer aspect 26.96 pcs.m^{-2}).

The studied area of the Děčínská vrchovina Upland is characterized by the very low diversity of earthworms (H´ 1.06). The species-poorest sites have been created by well-preserved old stands, which survived the period of air pollution impact. It refers to beech stands with a single-species assemblage and spruce sites with 2–3 species of earthworms. On the contrary, monocultures of blue spruce and a mixed stand of birch, larch and mountain ash appear to be richer from the aspect of fauna (Tab. 2). Effects of tree species on the abundance Lumbricidae were statistically significant [H(8, N=152)=38.91197, p=0.0000]. Using the test of a multiple comparison we found out a significant difference between a mixed stand (birch, larch, mountain ash) and monocultures of beech, oak and Norway spruce.

This finding results also from the comparison of average abundances of earthworms (birch, larch, mountain ash 53 pcs.m^{-2}, beech 5.67 pcs.m^{-2}, oak, spruce 10 pcs.m^{-2}).

No significant differences were found in the amount of surface earthworms on areas between particular mounds and in mounds of concentrated organic soil; on mounds and sites without the soil surface treatment [H(2, N=152)=5.513800, p=0.0635].

CCA – canonical correspondence analysis proved the significant effect of a tree species on the abundance of earthworms (p=0.0010). On the basis of the epigeic earthworm population similarity four groups of sites were differentiated. The first group of stands (spruce, birch and mixtures of birch, larch and mountain ash) is characterized by *D. octaedra* and *D. illyrica*. The second group is created by stands of larch and pine, which are increasingly preferred by *D. vejdovskyi*. Stands of beech and alder and partly also stands of blue spruce are very similar. These localities are increasingly colonized by receding species *L. rubellus* and *D. rubidus*. Red oak stands are the quite different type of sites. They are unambiguously preferred by *A. rosea* (Fig. 1).

Statistically significant effects are proved by soil pH (p=0.0010), which reached a value of 3.4–5.9 pH/H_2O and 2.8–5.5 pH/KCl. Species *A. rosea, L. rubellus, L. terrestris* and *D. rubidus* respond positively to changed pH (Fig. 2). Other species are not significantly affected by changed pH values.

Types/forms of soil preparation (p=0.1060), tree age (p=0.8320) and the degree of the locality weed infestation (p=0.4780) did not show significant effects on earthworm populations.

The abundance of wireworms (12–214 pcs.m^{-2}) was differentiated among stands. The effect of tree species on the abundance of wireworm larvae was statistically significant [H(8, N=152)=2.4378, p=0.01679]. Using the test of a multiple comparison we found significant differences between pine and larch stands as against stands of alder and blue spruce. In other stands, the profiling did not appear. Wireworms tended rather to localities with lower pH values and responded differently than Lumbricidae (Fig. 3).

Tab. 2: Earthworm assemblages depending on the stand tree species (Sněžník, Forest District Děčín).

	Tullgren funnels												
		Aspect		Tree species									
Species	**Canoco**	**Spring**	**Late summer**	***Fagus***	***Pinus***	***Betula***	***Betula, Larix, Sorbus***	***Quercus***	***Larix***	***Alnus***	***Picea***	***Picea pungens***	**Dominance in study area**
***Aporrectodea rosea* (Savigny)**	A_ros	4	2					20					1.01
***Dendrobaena illyrica* (Cognetti)**	D_ill	40	41	11.76	36.36	26.76	37.74	13.33	24.32	6.06	45.00	11.76	23.81
***Dendrobaena octaedra* (Savigny)**	D_oct	38	68	17.65	12.12	57.75	33.96	13.33	29.73	21.21	50.00	23.53	30.60
***Dendrobaena vejdovskyi* (Černosvitov)**	D_vej	35	85	64.71	51.52	14.08	22.64	46.67	45.95	69.70	5.00	44.12	38.39
***Dendrodrilus rubidus* (Eisen)**	D_rub	4	3	5.88		1.41				3.03		11.76	2.85
***Lumbricus rubellus* (Hoffmeister)**	L_rub		4				1.89					8.82	2.01
***Lumbricus terrestris* (Linnaeus)**	L_ter	3	1				3.77	6.67					1.34
N - individuals		124	204	17	33	71	53	30	37	33	20	34	Total 328
Abundance in study area (ks.m^{-2})				5.67	11.00	23.67	53.00	10.00	18.50	33.00	10.00	34.00	Average 22.1
Index diversity				1.01	0.97	1.01	1.27	1.07	1.06	0.86	0.86	1.42	Average 1.06

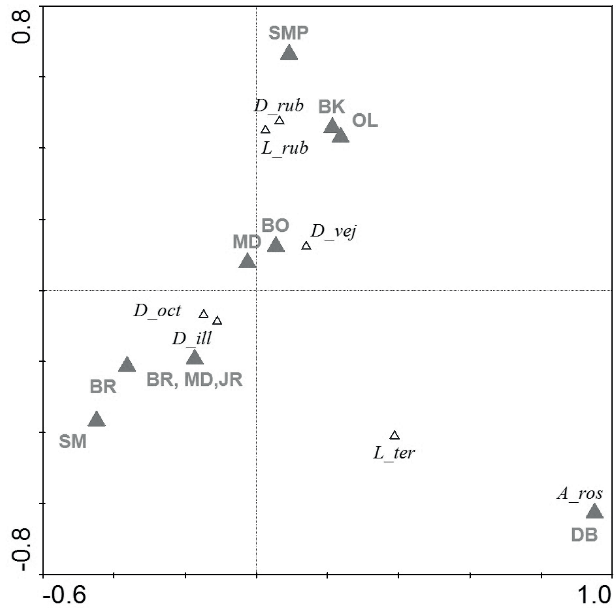

Fig. 1: Ordination diagram of canonical correspondence analysis (CCA) expressing effects of a tree species on the abundance of earthworms (see tab. 2 – column Canoco; SMP – P. pungens, BK – F. sylvatica, OL – Alnus, BO – P. sylvestris, MD – L. decidua, BR – B. pendula, JR – Sorbus, SM – P. abies, DB – Quercus).

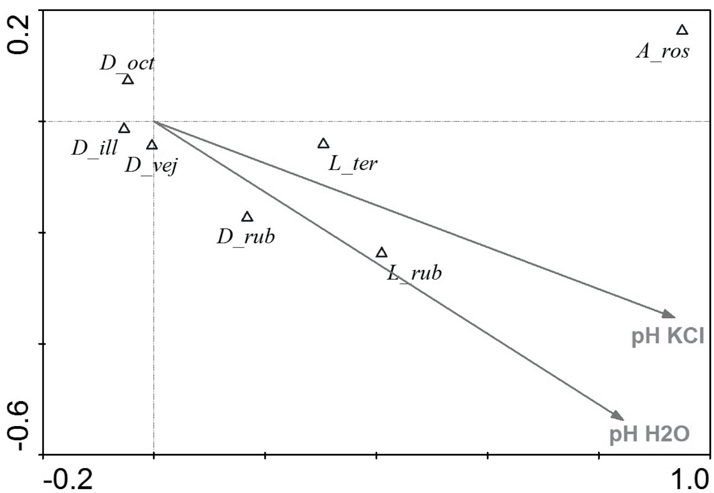

Fig. 2: Ordination diagram of canonical correspondence analysis (CCA) expressing effects of the soil pH on the abundance of earthworms (see tab. 2 – Canoco).

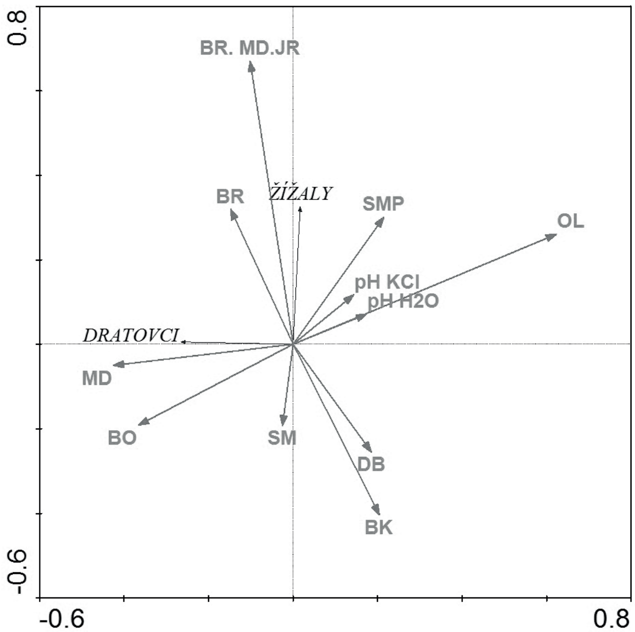

Fig. 3: Ordination diagram of redundancy analysis (RDA) expressing effects of a tree species and the soil pH on the community of earthworms and wireworms (see tab. 2 – column Canoco; SMP – P. pungens, BK – F. sylvatica, OL – Alnus, BO – P. sylvestris, MD – L. decidua, BR – B. pendula, JR – Sorbus, SM – P. abies, DB – Quercus; Dratovci – Elateridae – wireworms, Žížaly – Lumbricidae).

Discussion

Lumbricidae

Earthworm assemblages of mountain forest ecosystems in air-polluted areas belong to relatively poor ones (Pižl 1991a, 1991b, Kula 2009, Švarc, Kula 2011). The studied region of the Děčínský Sněžník is one of the poorest areas within the Labské pískovce /Elbe sandstones/ CHKO (Protected Landscape Area) and the Děčínská vrchovina Upland (Pižl 1997). Generally, in forest types of the Děčínská vrchovina Upland, the occurrence of *D. octaedra, D. rubidus* and *L. rubellus* (Pižl, 2002) was expected. Through the high proportion of *D. vejdovskyi* and *D. attemsi*, the profiling of the community of earthworms tends to typical earthworm assemblages in the Ore Mountains (Kula, Švarc 2011). These earthworms colonize acid forest soils and undergo their whole life cycle in forest litter (Pižl 2002). The diversity of earthworms and the size of their populations in these soils are determined above all by pH and the availability of food (Pižl 1998). Moreover, a deep-digging *L. terrestris* was noted as well as endogenous *A. rosea*, which requires higher soil quality thereby its proportion was limited to two localities of higher pH (5.1–5.3).

Damage to stands and subsequent reforestation using substitute tree species resulted in the higher species diversity of earthworms. This finding corresponds with results of Pižl (1998) and positive changes in the availability of energy sources, fast development of the herb layer and accumulation of organic matter better available for earthworms. The abundance of earthworms markedly increased from zero values determined in the original 150-year beech stand up to 54 pcs.m^{-2} at a locality with the stand mixture of birch, larch and mountain ash. Pižl (1995) mentions, that the density of earthworms is markedly increased at localities with the higher degree of damage. The cause of the fact consisted in the change of the food quality. At little-damaged localities, the food consisted of hardly digestible spruce needle litter. In open stands, more favourable organic matter is created for earthworms due to the growth of forest weed. Also Švarc and Kula (2011) corroborate the significant effect of undergrowth on earthworm populations. In the studied area, effects of the locality weed infestation on the abundance of earthworms were not proved.

Lower abundance of earthworms in young beech and spruce stands could be caused by the increased closure of stands with the slow decomposition of primary organic matter and cold microclimate (Wittich 1963) and reduced production of humus (Tomlin et al., 1995). The highest abundances are shown by sites of the stand mixture of birch with larch and mountain ash, alder, blue spruce and birch monocultures.

Outplanting suitable tree species can increase pH values of upper soil horizons, to improve forms of humus and availability of nutrients (Huhta, 1979, Heitz, 1998, Brandtberg et al. 2000, Hagen-Thorn et al. 2004). In broadleaved stands, forest litter shows favourable reclamation effects (Kulhavý et al., 2008). Generally, litter of broadleaved species is more available for earthworms than needle litter (Wittich, 1943, Muys, Lust, 1992), which increases the process of acidification (Kooijman et al., 2000). Nevertheless, facts mentioned above, do not explain the atypical position of earthworms in blue spruce stands.

Effects of pH were corroborated on earthworm populations according to findings of many authors (Satchell 1955, Laverack 1961, Abrahamsen 1972, Nordström, Rundgren 1974, Hagvar 1987, Persson et al. 1987 etc.). At lower pH values, also other soil fauna can be inhibited in the food intake and decomposition of organic material (Swift et al. 1979). Findings of Švarc and Kula (2011) on the positive effect of mounds from organic material at higher locations of the Ore Mountains on the abundance of earthworms were not proved under conditions of the Děčínská vrchovina Upland.

Elateridae - wireworms

Wolters (1989) ranks *Athous subfuscus* among humiphagous representatives with non-specific food behaviour and without dependence on soil conditions. In mixed pine stands, the author mentions relatively low abundance (38 pcs.m^{-2}) of larvae of Elateridae while in the Děčínská vrchovina Upland, pine reached an abundance of 28–128 pcs.m^{-2} in monitored weed-infested pine stands and in larch stands as many as 214 pcs.m^{-2}. In contrast to the increased abundance in stands of the Děčínská vrchovina Upland, Kula and Švarc (2010) determined relatively low abundance of wireworms in mounds (24 pcs.m^{-2}) as well as in inter-mound parts of stands in stands of the Kienhaida NR (Ore Mountains). According to Theenhaus and Schaefer (1995), larvae of *A. subfuscus* recede from clear-cut areas after felling beech stands and do not respond to liming. Wireworms represent the group of soil fauna, which reflects an undistinguished negative impact to the amount of population density particularly at higher application doses of dolomitic limestone and higher pH values (Kula 2009). Based on the abundance determined in forest stands, wireworms prefer lower pH, which corresponds to findings of Kula (2009) on the decline of abundance and diversity of larvae of Elateridae with increasing pH (pH < 3.5–4.5/15 species, pH > 4.5/8 species).

Conclusion

In the area negatively affected by air pollution in the past, the earthworm assemblages and the occurrence of Elateridae were evaluated in forest ecosystems in relation to site conditions. From soil samples taken in 38 stands (*Fagus, Betula, Alnus, Quercus, Pinus, Larix, Abies*), earthworms and wireworms were extracted by means of Tullgren funnels. Eudominant species (*Dendrobaena vejdovskyi, D. octaedra, D. illyrica*) are typical representatives of forest ecosystems of the Ore Mountains. Relationships were demonstrated to a tree species creating a forest stand and to the pH value of Ah horizon. The area is characterized by generally low diversity of earthworms particularly in young stands of beech and Norway spruce. Faunistically rich sites were represented only by a mixed stand (birch, mountain ash, larch) and the blue spruce monoculture. The reduced abundance of earthworms in the organic matter of mounds was surprising. Forms of the preparation/treatment of soil, forest weed cover and the age of trees did not significantly affect the earthworm assemblages. The abundance of wireworms was increased in pine and larch stands and reduced in stands of alder and blue spruce. Increasing pH negatively affected the abundance pf wireworms.

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