# Earthworms (Lumbricidae) of an air-polluted area affected by ameliorative liming

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**ABSTRACT**: The study was aimed at the area of the Krušné hory Mts. with stands of substitute species, soils disturbed by long-term acidification and affected repeatedly by aerial ameliorative liming. Ten species of earthworms were recorded. The highest abundance was shown by earthworms of *Dendrobaena attemsi, Dendrobaena octaedra* and *Dendrobaena vejdovskyi*, which are considered to be acidotolerant being, however, monitored in the high and balanced abundance at pH 2.8–6.2. Ubiquitous species developed in soils of markedly lower pH, viz. *Lumbricus rubellus* (2.8–5.6), *Aporrectodea caliginosa* (3.1–5.5), and *Octolasion lacteum* (3.2–5.2). *Dendrobaena attemsi* responded positively to low saturation of the base-exchange complex, low C/N ratio and high content of phosphorus, and negatively to the high level of calcium. *D. octaedra* responded positively to the higher level of calcium and *D. vejdovskyi* to the higher content of potassium.

**Keywords**: forest ecosystem; Krušné hory Mts.; liming; Lumbricidae; soil chemistry

Ameliorative liming of stands of substitute species contributes to acceleration of the revitalization process of soils disturbed by long-term acidification. In the period 1978–1991 and 2000–2006, the area of 62 and 30 thousand ha, respectively, was limed (Kubelka et al. 1992; Šrámek et al. 2006) in the Krušné hory Mts., a number of stands being treated repeatedly. At the same time, broadleaved stands (*Betula pendula* Roth, *Sorbus aucuparia* L., *Alnus glutinosa* (L.) Gaertn., *Populus tremula* L.) (Ulbrichová, Podrázský 2002; Möllerová 2004) contribute to improvement of soil conditions in contrast to extensive monocultures of blue spruce.

In consequence of the development of soil chemistry and vegetation structure a new environment is continually created also for the soil fauna. In forest ecosystems with the reduced value of pH (< 4.5), acidotolerant species of earthworms *Dendrobaena octaedra* (Sav.) and *Dendrodrilus rubidus* (Sav.) predominate (Nordström, Rundgren 1974; Rundgren 1994). Positive responses of the community of earthworms to liming are known (Makeschin 1991; Ammer 1992). Pižl (2002a) reported that in natural and anthropogenic ecosystems of the northern temperate zone, the abundance of earthworms reached 30–400 individuals·m$^{-2}$. At monitoring the species diversity of the community of earthworms of coniferous stands in the Beskids and Krkonoše Mts., Pižl (1991) found only 4 or 5 species with the dominant proportion of epigeous species *D. octaedra* and *D. rubidus*. The species diversity of earthworms of monitored localities in the Krušné hory Mts. was higher than in the Krkonoše Mts. (Kula, Matoušek 2004). In addition to two less important species [*Lumbricus rubellus* (Hoffm.), *Aporrectodea caliginosa* (Sav.)], *D. octaedra* and *D. rubidus* predominate in podzol and degraded forest soils (Nordström, Rundgren 1973). Low pH values of soil are the limiting factor of the species richness

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of earthworm communities in coniferous forests. Existing studies from similar ecosystems prove the dominance of the acidotolerant species *D. octaedra* accompanied by *D. rubidus* and *L. rubellus* and in some cases also by *Aporrectodea rosea* (Sav.) and *A. caliginosa* (Abrahamsen 1972; Huhta et al. 1986). According to Pižl (2001, 2002b), the community of earthworms *D. attemsi, D. octaedra* and *Dendrobaena vejdovskyi* (Čern.) is characteristic of well-preserved mountain spruce ecosystems.

The aim of the paper is to characterize the coenosis of Lumbricidae in an area with long-term and repeated liming in relation to changing site conditions.

## MATERIAL AND METHODS

Based on the archival documentation on the aerial application of dolomitic limestone (2.5–3 t·ha$^{-1}$) in several hundreds of stands of substitute species in the area of Forest District Klášterec nad Ohří (Krušné hory Mts., Czech Republic) (1986–2002), 49 stands were selected (Kula 2010). This group represents the time and frequency of the repeated aerial liming applications and site conditions. The group of check stands includes unlimed sites at altitudes of 740–960 m a.s.l. and simultaneously localities with the single application of dolomitic limestone for the whole defined period, namely in 1986, 1990, 1995, 2000, 2002. In stands with two to four applications, liming was carried out at an interval of 5–6 years. The stands rank among the forest type groups (FTG) 6K, 7K and 6S. According to general characteristics, *Piceeto-Fagetum acidophilum* (6K) and *Piceeto-Fagetum mesotrophicum* (6S) are typical sites of locations at altitudes of 650–950 m a.s.l. with mean annual temperature 4.5–5.5°C, total annual precipitation 900–1,050 mm, growing season 115–130 days and natural species composition *Fagus sylvatica* L., *Abies alba* Mill. and *Picea abies* (L.) Karst. *Fageto-Piceetum acidophilum* (7K) is a typical site of upland locations of the Krušné hory Mts. (altitude 900–1,050 m) with mean annual temperature 4–4.5°C and total annual precipitation 1,050–1,200 mm, growing season 100–115 days and natural species composition *P. abies, F. sylvatica* and *A. alba* (Průša 2001).

At each of the localities, four soil pits (25 × 25 × 15 cm) (in total 392 samples) were always sampled in two aspects (spring – V/VI and late summer – IX) in the year 2007. Before the transport from field to laboratory conditions, soil samples were deposited for a short term in a snow cache at a temperature of 4°C. Half of the samples from each of the localities was placed immediately into Tullgren funnels (Novák et al. 1969; Tuf, Tvardík 2005) modified by Kula (2009). The temperature extraction proceeded for the period of three weeks when earthworms penetrated through the layer of drying up soil and fell into an intercepting vessel with 0.5% formaldehyde and subsequent preservation in 75% ethanol. The remaining samples had to be stored for a period of 21 days (from the spring sampling in a cooling box at 5°C, from the late summer sampling in a karst cavern at 5°C). Stable temperature and moisture limited the mortality of earthworms. Lumbricidae were identified by Dr. V. Pižl from the Institute of Soil Biology, Academy of Sciences of the CR (AV ČR) in České Budějovice using the key Pižl (2002a). Soil characteristics (exchangeable $pH_{KCl}$, total carbon and nitrogen, exchangeable soil sorption and degree of base saturation of the sorption complex and available nutrients P, Mg, K and Ca) were determined for monitored stands in the H and Ah horizons (see in detail Menšík, Kula 2011).

For statistical evaluation a single-factor analysis ANOVA was used and Tukey's test was used for the detection of differences between groups.

## RESULTS

### Testing the methodology of soil sample storage

It is recommended to transfer soil samples for the extraction of fauna into Tullgren funnels within 24 hours. The capacity of Tullgren funnels and the volume of soil samples taken by a single application required the three-week storage of spring samples in a large-capacity cooling device. Thus, the total abundance of adult earthworms decreased from 26 to 19 individuals·m$^{-2}$, of juvenile earthworms from 46 to 41 individuals·m$^{-2}$ and in *D. attemsi* (–4 individuals·m$^{-2}$) (Table 1). Differences in dominance became evident only in adults of *D. octaedra* (–6%) and *D. vejdovskyi* (+10%). In samples from the late summer sampling placed in the karst cavern, a marked decrease occurred in the total abundance only in juvenile stages (–28 individuals·m$^{-2}$), namely particularly in *D. attemsi* (–22 individuals·m$^{-2}$), *D. octaedra* (–3.5 individuals·m$^{-2}$) and *L. rubellus* (–2.5 individuals·m$^{-2}$).

Statistically insignificant effects of the storage of soil samples before extraction were proved on the amount of caught juvenile and adult earthworms on the spring and autumn date of sampling at the level of significance $\alpha = 0.05$.

Table 1. Effects of the storage of soil samples on the mortality of earthworms

| | | Abundance (individuals·m$^{-2}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Aspect | spring | | | | late summer | | | |
| | Stadium | adult | | juvenile | | adult | | juvenile | |
| | Sample series | I. | II. | I. | II. | I. | II. | I. | II. |
| Species | *Aporrectodea caliginosa* | 0.98 | 0.16 | 0.98 | 0.98 | 0.49 | 0.16 | 0.49 | 0.33 |
| | *Aporrectodea rosea* | 0.33 | 0.00 | 4.41 | 0.82 | 0.00 | 0.00 | 0.16 | 0.00 |
| | *Dendrobaena attemsi* | 13.55 | 9.47 | 23.84 | 19.92 | 2.94 | 7.02 | 42.94 | 21.06 |
| | *Dendrobaena illyrica* | 0.16 | 0.65 | 1.14 | 1.14 | 0.00 | 0.00 | 1.96 | 0.49 |
| | *Dendrobaena octaedra* | 3.59 | 1.47 | 7.02 | 7.02 | 3.27 | 2.61 | 12.41 | 8.82 |
| | *Dendrobaena vejdovskyi* | 6.37 | 6.69 | 5.06 | 5.88 | 1.47 | 0.16 | 3.27 | 2.94 |
| | *Dendrodrilus rubidus* | 0.33 | 0.33 | 1.31 | 2.78 | 0.98 | 0.49 | 0.16 | 1.80 |
| | *Lumbricus castaneus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 | 0.00 |
| | *Lumbricus rubellus* | 0.33 | 0.33 | 1.80 | 2.12 | 0.82 | 0.98 | 4.08 | 1.63 |
| | *Octolasium lacteum* | 0.49 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.33 | 0.98 |
| | Total (individuals·m$^{-2}$) | 26.12 | 19.27 | 45.71 | 40.82 | 10.12 | 11.76 | 65.80 | 38.04 |
| | *N*-samples | 194 | 174 | 194 | 174 | 150 | 156 | 150 | 156 |

I. – soil samples extracted immediately on tullgrens, II. – soil samples were storaged for a period of 21 days before extraction on tullgrens (see methods)

**Fauna of the family Lumbricidae**

In the monitored area, 1,578 individuals were noted and surprisingly high diversity of ten species of earthworms was determined. It concerns the generally distributed and abundant epigeous species (*D. octaedra, D. rubidus, L. rubellus*) in the area of the CR. Further, the species *D. attemsi* was found to live in preserved broadleaved stands and spruce forests of virgin type as well as *D. vejdovskyi* and some endogenic species *A. caliginosa*, *A. rosea* and *Octolasion lacteum* (Sav.). *D. attemsi* occurred in a eudominant position both in the adult (48.2%) and juvenile (53.8%) stage. Dominant species of the genus *Dendrobaena* are also important, particularly *D. octaedra* (16% and 21.4%) and *D. vejdovskyi* (23.1% and 9.3%). Other seven species equally account for 12.6% of adult and 15.5% of juvenile individuals in the total community of caught earthworms. Only one adult individual of *Lumbricus castaneus* (Sav.) was noted. If we use the abundance of earthworms in monitored groups of forest stands regardless of the time and repetition of liming to characterize the limed area, we can draw the general conclusion that the abundance of juvenile earthworms was 2.8 times higher in FTG 6K and 3 times higher in FTG 7K and 6S than that of adult earthworms (Table 2). The aggregate abundance gradually decreases from FTG 6S (72 individuals·m$^{-2}$) through FTG 6K (66.5 individuals·m$^{-2}$) to the stands of FTG 7K at the highest elevations (58 individuals·m$^{-2}$) (Table 2). The

Table 2. The abundance (individuals·m$^{-2}$) of Lumbricidae in forest type groups (FTG) affected by liming in stands of substitute species (FD Klášterec)

| Species | 6S | 6K | 7K | FD | (%) |
|---|---|---|---|---|---|
| *Aporrectodea caliginosa* | | 1.52 | 0.43 | 0.65 | 0.99 |
| *Aporrectodea rosea* | | 0.18 | 4.57 | 0.06 | 0.09 |
| *Dendrobaena attemsi* | 59 | 38.00 | 25.14 | 33.86 | 51.60 |
| *Dendrobaena illyrica* | | 1.76 | 0.71 | 8.97 | 13.67 |
| *Dendrobaena octaedra* | 4 | 10.48 | 15.14 | 5.07 | 7.72 |
| *Dendrobaena vejdovskyi* | 5 | 8.67 | 6.71 | 9.60 | 14.64 |
| *Dendrodrilus rubidus* | 1 | 2.00 | 2.29 | 3.24 | 4.94 |
| *Lumbricus castaneus* | | 0.06 | | 1.45 | 2.21 |
| *Lumbricus rubellus* | 2 | 3.39 | 2.29 | 1.89 | 2.89 |
| *Octolasium lacteum* | 1 | 0.48 | 1.00 | 0.83 | 1.26 |
| Total (individuals·m$^{-2}$) | 72 | 66.55 | 58.29 | 65.61 | 100 |
| *N*-samples | 24 | 470 | 180 | 674 | |

FD – forest district, 6S, 6K, 7K (see chapter Methods and description of the area of research) species spectrum of FTG 6K and 7K is identical, however, fundamental differences consist in the higher profiling of *D. attemsi* (59 individuals·m$^{-2}$) and fall in 6K (38 individuals·m$^{-2}$) and 7K (25 individuals·m$^{-2}$). On the other hand, abundance in FTG 7K increases and culminates in *D. octaedra* (15.1 individuals·m$^{-2}$) and *A. rosea* (4.6 individuals·m$^{-2}$). The altitudinal gradient, which was not sufficiently marked (740–960 m), did not become evident in the abundance of earthworms by a fundamental deviation. At localities of lower altitudes > 850 m, the abundance of earthworms was 66 individuals·m$^{-2}$, in stands > 850 m 77 individuals·m$^{-2}$.

Under conditions defined by the number of repeated ameliorative liming measures and site preparation, ten categories were created within 49 sampling stands (Table 3). Through the abundance of earthworms (32–79 individuals·m$^{-2}$), particular sites are differentiated in such a way that the lowest abundance occurred at unlimed localities (with the "excavator" preparation) and on afforested former non-forest land (fields, meadows). The highest population density of earthworms (72–79 individuals·m$^{-2}$) was found not only in stands limed 2–3 times but also at an unlimed site and without site preparation or at a limed site with the applied "bulldozer" preparation (Table 3). At other sites, profiling by abundance was not evident although it referred to conditions of localities with liming and their differentiated preparation.

From the aspect of the frequency of occurrence and dominance in the monitored area, species of the genus *Dendrobaena* can be ranked among generally distributed. *D. octaedra* was a decisive component of the coenosis. It occurred in all assessed site categories (6.4–52%) with the definite preference of intensively limed and afforested former agricultural land. In spite of rather marked deviations in dominance, *D. attemsi* shows moderate occurrence at limed sites (35–41%) and relatively low occurrence on areas characterized by repeated liming. Other species show general distribution but low dominance (*A. caliginosa, D. illyrica, L. rubelus*) and only sporadic occurrence (*L. castaneus, O. lacteum, A. rosea*).

## Soil chemistry and coenoses of earthworms (Lumbricidae)

In monitored stands, $pH_{KCl}$ was determined, viz. 2.84–6.15. The coenosis of earthworms was

Table 3. The abundance of species of the family Lumbricidae at sites affected by liming and site preparation (individuals·m$^{-2}$) (Forest District Klášterec)

| Localities | | *Aporrectodea caliginosa* | *Aporrectodea rosea* | *Dendrobaena attemsi* | *Dendrobaena illyrica* | *Dendrobaena octaedra* | *Dendrobaena vejdovskyi* | *Dendrodrilus rubidus* | *Lumbricus castaneus* | *Lumbricus rubellus* | *Octolasium lacteum* | Individuals·m$^{-2}$ | *N*-species | *N*-samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | without liming and site preparation | 0.5 | | 52.5 | 1.5 | 8.5 | 8.5 | | | 1.0 | | 72.5 | 6 | 69 |
| B | without liming and with the "excavator" preparation of a site | 2.0 | | | 6.0 | 22.0 | | | | 2.0 | | 32 | 4 | 13 |
| C | once limed without site preparation | 2.0 | | 34.5 | 1.8 | 14.0 | 9.5 | 0.7 | 0.2 | 2.7 | 0.8 | 66.2 | 9 | 169 |
| D | once limed with the "excavator" preparation of a site | 0.2 | 0.5 | 37.3 | 1.3 | 8.7 | 11.6 | 0.5 | | 1.8 | 0.7 | 62.7 | 9 | 132 |
| E | once limed with the "bulldozer" preparation of a site | | 21.3 | 8.7 | | 10.7 | 4.7 | 4.7 | | 6.0 | 2.0 | 58 | 7 | 38 |
| F | 2–3 times limed without site preparation | 2.4 | | 41.2 | 1.6 | 6.4 | 4.0 | | | 3.2 | 0.8 | 59.6 | 7 | 77 |
| G | 2–3 times limed with the "excavator" preparation of a site | | | 19.2 | 1.6 | 10.4 | 8.4 | 10.8 | | 7.6 | | 58 | 6 | 65 |
| H | 2–3 times limed with the "bulldozer" preparation of a site | 1.0 | | 60.0 | 0.7 | 8.7 | 4.3 | 1.0 | | 3.0 | 0.3 | 79 | 8 | 88 |
| CH | without liming on agricultural land (field, meadow) | 8.0 | | | | 26.0 | | 4.0 | | | 2.0 | 40 | 4 | 11 |
| I | 2–3 times limed on agricultural land (field, meadow) | | | 2.0 | | 52.0 | 12.0 | 8.0 | | | | 74 | 4 | 12 |

represented in the humus layer in the entire pH range. At sites with low pH (< 3.5), the abundance was 61 individuals·m$^{-2}$, at moderate pH (3.5–4.5) 74 individuals·m$^{-2}$ and in stands with high pH values (4.5–6.15) 68 individuals·m$^{-2}$. The response of the majority of determined species of earthworms was not substantially profiled as documented by the balanced abundance of *D. attemsi* (38.6–33.1–36.3 individuals·m$^{-2}$) and *D. vejdovskyi* (8.7–7.9–6.3 individuals·m$^{-2}$). A partial shift according to abundance was indicated towards higher pH in *D. octaedra* (Table 4).

The high level of the sorption capacity of soil (T) was dominant. Because comparative categories are missing, it is not possible to evaluate the forming coenosis of earthworms from the aspect of this parameter. Only *D. vejdovskyi* showed a higher value of dominance at the medium value of maximum sorption capacity (Table 4). The base saturation of sorption complex (V) occurred in a very wide range in monitored stands from markedly unsaturated to saturated (1–92%). The proportion of saturated sites (2) in the assessed group was not representative and this fact could account for the high proportion of the occurrence of *D. octaedra.* On the other hand, the balanced proportion of some species of earthworms is clearly documented (*D. octaedra* 10.2–7 individuals·m$^{-2}$, *D. vejdovskyi* 9.1 to 5.3 individuals·m$^{-2}$, *L. rubellus* 2.5–4 individuals·m$^{-2}$) in soil characterized by markedly saturated or even slightly saturated sorption complex. *D. attemsi* is profiled by its abundance (48.5 individuals·m$^{-2}$) at slight saturation of the sorption complex (Table 4).

The C/N ratio can be affected by nitrogen mineralization after liming. The ratio showed less favourable values which did not fundamentally profile the earthworm coenosis in the area although higher abundance of *D. attemsi* was determined at a low C/N ratio (Table 4). The content of nutrient elements (P, Mg, Ca, K) was determined in all monitored stands. In soils with the high content of phosphorus, *D. attemsi* showed the highest abundance. This species responded to the higher content of potassium in the same way whereas the high level of calcium resulted in the fall of its abundance. As for other species, *D. octaedra* responded positively to the higher level of calcium and *D. vejdovskyi* to the higher content of potassium (Table 5).

## DISCUSSION

The time-shifted extraction of earthworms from soil samples of spring sampling did not affect the results of determined abundance. In the late-summer aspect, the fall of juvenile species is partly related to their continual development in the course of storage. The fall of the amount of individuals of *D. attemsi* after three weeks can be related to its bionomics. Švarc and Kula (2010) did not confirm (using the method of Tullgren funnels) the occurrence of this species in the late summer aspect in samples not affected by storage. During the second half of the 20$^{th}$ century, the stability of spruce stands was disturbed due to acidification in the Krušné hory Mts. These stands

Table 4. The dominance of species of the family Lumbricidae in the humus layer depending on pH, T, V, C/N (FD Klášterec)

| Species | pH/KCl | | | T | | V | | | | C:N | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | < 3.5 | 3.5–4.5 | > 4.5 | 125–250 | > 250 | 0–30 | 30–50 | 50–80 | 80–100 | 0–15 | 15–25 |
| *Aporrectodea caliginosa* | 1.46 | 1.94 | 0.49 | 5.41 | 1.42 | 1.22 | 4.49 | 0.00 | 1.89 | 0.79 | 1.63 |
| *Aporrectodea rosea* | 0.12 | 6.59 | 0.00 | 0.00 | 2.36 | 3.04 | 0.00 | 0.00 | 0.00 | 0.00 | 2.72 |
| *Dendrobaena attemsi* | 63.30 | 44.96 | 53.69 | 45.95 | 56.24 | 56.77 | 55.62 | 70.80 | 1.89 | 65.61 | 54.00 |
| *Dendrobaena illyrica* | 2.07 | 1.74 | 3.94 | 2.70 | 2.23 | 2.17 | 2.25 | 1.46 | 5.66 | 4.35 | 1.78 |
| *Dendrobaena octaedra* | 12.64 | 20.54 | 24.14 | 13.51 | 16.72 | 15.02 | 16.29 | 10.22 | 69.81 | 16.60 | 16.83 |
| *Dendrobaena vejdovskyi* | 14.34 | 10.66 | 9.36 | 21.62 | 12.27 | 13.37 | 8.99 | 10.22 | 11.32 | 8.30 | 13.27 |
| *Dendrodrilus rubidus* | 1.46 | 5.43 | 3.94 | 0.00 | 3.24 | 2.95 | 4.49 | 1.46 | 7.55 | 1.58 | 3.41 |
| *Lumbricus castaneus* | 0.12 | 0.00 | 0.00 | 0.00 | 0.07 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 |
| *Lumbricus rubellus* | 3.89 | 6.59 | 3.45 | 10.81 | 4.52 | 4.60 | 6.74 | 3.65 | 1.89 | 2.37 | 5.20 |
| *Octolasium lacteum* | 0.61 | 1.55 | 0.99 | 0.00 | 0.94 | 0.78 | 1.12 | 2.19 | 0.00 | 0.40 | 1.09 |
| *N*-samples | 335 | 225 | 92 | 15 | 625 | 465 | 88 | 62 | 25 | 107 | 545 |

T – soil exchangeable sorption, V – degree of the sorption complex saturation by basic cations

Table 5. The proportion of species of the family Lumbricidae in the humus layer depending on the content of nutrient elements (P, Mg, Ca, K) (Forest District Klášterec)

| Species | P | | Mg | | | Ca | | K | |
|---|---|---|---|---|---|---|---|---|---|
| | < 10 | 10–30 | < 150 | 150–400 | > 400 | 150–500 | > 500 | < 200 | 200–400 |
| *Aporrectodea caliginosa* | 1.63 | 0.00 | 1.57 | 1.23 | 1.75 | 1.71 | 1.31 | 1.69 | 0.00 |
| *Aporrectodea rosea* | 2.49 | 0.00 | 0.00 | 0.53 | 7.98 | 0.00 | 4.16 | 2.58 | 0.00 |
| *Dendrobaena attemsi* | 56.22 | 52.59 | 68.47 | 46.38 | 51.37 | 69.76 | 44.35 | 54.53 | 66.12 |
| *Dendrobaena illyrica* | 2.20 | 2.22 | 2.09 | 3.17 | 1.00 | 1.85 | 2.50 | 2.35 | 1.09 |
| *Dendrobaena octaedra* | 15.85 | 26.67 | 12.02 | 20.99 | 17.71 | 10.98 | 21.64 | 17.29 | 13.11 |
| *Dendrobaena vejdovskyi* | 12.58 | 11.11 | 11.85 | 15.17 | 9.48 | 10.13 | 14.39 | 11.92 | 16.39 |
| *Dendrodrilus rubidus* | 2.91 | 5.19 | 0.52 | 5.64 | 3.24 | 0.71 | 5.11 | 3.46 | 0.55 |
| *Lumbricus castaneus* | 0.07 | 0.00 | 0.17 | 0.00 | 0.00 | 0.14 | 0.00 | 0.07 | 0.00 |
| *Lumbricus rubellus* | 5.05 | 1.48 | 3.14 | 5.47 | 5.99 | 4.14 | 5.23 | 5.15 | 1.64 |
| *Octolasium lacteum* | 1.00 | 0.74 | 0.17 | 1.41 | 1.50 | 0.57 | 1.31 | 0.96 | 1.09 |
| *N*-samples | 605 | 47 | 214 | 264 | 174 | 287 | 365 | 597 | 55 |

disintegrated and stands of substitute species were established. The forest area was characterized by heavy weed infestation and fundamental quality changes in the soil environment (Slodičák et al. 2008). Acidification of forest soils results in the fall of abundance, total biomass and species diversity of earthworms (Abrahamsen 1972; Nordström, Rundgren 1974; Kreutzer 1995). The survey of the Krušné hory Mts. area is missing and only partial data are available from the air-pollution period (Houšková 1991; Pižl 2002a; Kula, Matoušek 2004). These studies show that nine species and two subspecies of earthworms have been determined in the Krušné hory Mts. so far. *L. castaneus* is a newly determined species in this area. *D. attemsi* is a commonly distributed species in the air-polluted area. According to Pižl (2002a), it is a eudominant species of preserved mountain spruce forests and was noted only at several localities in the CR. It is of interest that on limed areas (Litvínov Forest District), the species occurred in a minority position whereas *D. illyrica* (11.1 individuals·$m^{-2}$), *D. octaedra* (20.6 individuals·$m^{-2}$) and *D. rubidus* (9.5 individuals·$m^{-2}$) (method of Tullgren funnels) (Kula 2009) were ranked among eudominant species. Thus, the hypothesis of a positive response of *O. lacteum* to liming formulated by Ammer (1992) has not been proved.

The species diversity and abundance of earthworms can be affected by site conditions related to the site preparation before the stand establishment and subsequently by the species composition. Švarc and Kula (2010) reported the abundance of earthworms from unlimed sites with the differentiated extent of anthropogenic damage to sites. In stands affected by liming, this factor did not become evident as dominant and, therefore the soil chemistry was monitored and its effects on the coenosis of earthworms. Limed stands with different variants of site preparation are characterised by the highest diversity and abundance (Table 4).

There is a negative relationship between soil acidity and the earthworm community organization (Abrahamsen 1971; Nordström, Rundgren 1974), population parameters and their activity, growth and reproduction (Bengtsson et al. 1986). Generally, it is possible to state that the number of species is low at naturally low soil pH. At these sites, the total fertility of earthworms is negatively affected. In the course of acidification the abundance of earthworms is decreased (Persson et al. 1987) while the species diversity gradually decreases in degraded soils (Nordström, Rundgren 1974; Enckell, Rundgren 1988). Acidification in coniferous stands affects at first the species requiring the high quality of soil (*A. caliginosa*) and the indigenous communities of 2–4 species of earthworms can even transform in one-species communities of earthworms (Rundgren 1994). The determination of pH for some species of the earthworm coenosis showed that data of Pižl et al. (2004) from the air-polluted area of the Krušné hory Mts. did not cover the whole range of pH which was tolerated by particular species. Although the majority of earthworms is considered to be neutrophilous (pH 6–7), there are species which are tolerant to heavily acid (pH 3.5) or alkaline (pH > 8) soils. In soils of the Krušné hory Mts. heavily damaged by acid rains, Pižl et al. (2004) determined the exceptional occurrence of *D. rubidus* in soil with pH 2.7. We monitored earthworms of *D. octaedra*, *D. attemsi* and *D. vejdovskyi* regarded as acidotolerant (pH 3.7–4.7) in high abundance and balanced proportion at pH 2.8–6.15. Ubiquitous species tolerating pH 4.7–7 were found in soils of lower pH, for example *L. rubellus* (2.8–5.6), *A. caliginosa* (3.1–5.5) and *O. lacteum* (3.2–5.2). In the monitored area, *A. caliginosa* represents the minority part of the earthworm coenosis. *D. rubidus* and *L. rubellus* are also relatively little abundant. In the air-polluted and for a long time affected area of the western Krušné hory Mts., populations of *D. attemsi, D. vejdovskyi* and *D. octaedra* are much more important according to our investigations. It is difficult to prove if the spectrum of ten species is the reflection of resistance of the whole coenosis or a positive response to long-term ameliorative liming. Under conditions of Litvínov Forest District, the exceptional increase of *D. rubidus* became evident on limed areas shortly after application particularly at higher application inputs of dolomitic limestone (Kula 2009). The forced transformation of spruce management to stands of substitute species with a dominant proportion of broadleaves, increase of forest weed and increased moisture could contribute to the better survival of the earthworm population. Comparisons of stands according to a dominant tree species show that in the area of Klášterec Forest District, deviations in the abundance of earthworms did not occur in stands with the predominance of conifers (68 individuals·m$^{-2}$) and broadleaves (74 individuals·m$^{-2}$). According to Makeschin and Ammer (1993), acidification induces the fall of colonization by earthworms and total extinction of *L. rubellus* and *D. rubidus.* In the 3$^{rd}$ year after liming, abundance culminates (400–500 individuals·m$^{-2}$) and subsequently in the 5$^{th}$ year, it falls to 200–250 individuals·m$^{-2}$. The species structure is usually shifted in favour of *L. rubellus* and earthworms in the mineral soil. This fact results from the reduction of soil acidity and the more favourable relation of bases as well as improved food conditions (Makeschin, Ammer 1993). At none of the monitored localities did we note such population density due to short-term (Kula 2009) or long-term effects of liming in the eastern Krušné hory Mts. The content of nutrient elements changes differentially due to the applied dolomitic limestone, namely calcium and magnesium generally increase and phosphorus and potassium decrease (Kula 2009). In the humus layer of stands affected by ameliorative liming, calcium occurred in optimum and with higher content.

At the balanced catch of earthworms (abundance 63.7 and 67.3 individuals·m$^{-2}$), the abundance of *D. attemsi* was clearly higher at the optimum level of calcium (44.5 and 29.8 individuals·m$^{-2}$) whereas in *D. octaedra*, an opposite ratio became evident and a higher proportion of individuals was determined in stands with the higher content of Ca in abundance (7 and 14.6 individuals·m$^{-2}$) (Table 5). As for magnesium, there were localities characterized by Mg deficiency up to its surplus while the coenoses of earthworms responded positively to the lower content of Mg (82 individuals·m$^{-2}$). Nevertheless, at the optimum and increased level, the species abundance was lower (60–67 individuals·m$^{-2}$). *A. rosea*, which occurs rarely, was noted particularly under conditions at the high level of Mg. *D. attemsi* responded, however, by higher abundance at the decreased content of Mg (56.1 and 27.7–34.3 individuals·m$^{-2}$). The content of phosphorus at a low and moderate level was not a differentiation factor of abundance of the earthworm coenosis (65.4 and 67.5 individuals·m$^{-2}$). At the higher content of phosphorus, the increase of abundance becomes evident in *D. octaedra* (Table 5). In contrast to calcium, the content of phosphorus and magnesium increases in the body of earthworms (van Rhee 1977).

## CONCLUSION

In the western part of the Krušné hory Mts., the occurrence of ten species of earthworms was determined. Surprisingly, a eudominant position was shown by *D. attemsi* reported as the eudominant representative of preserved mountain spruce stands. The fall of the earthworm abundance with the altitudinal vegetation zone was affected by the response of *D. attemsi* in FTG 7K. The site characteristics defined by the intensity of liming, wide spectrum of soil treatment before reforestation, missing data on the original composition and proportion of earthworms do not make it possible to analyse unambiguously differences in the actual abundance of earthworms. Thus, the soil chemistry is a decisive criterion for the development of acidotolerant and ubiquitous earthworms when it was stated that they can occupy soils with the broader range of pH. The species *D. attemsi* responded positively to the moderate saturation of base-exchange complex, low C/N ratio, high content of phosphorus and reduced content of calcium.

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