STAATL. MUSEUM FÜR NATURKUNDE GÖRLITZ

Abh. Ber. Naturkundemus. Görlitz	Band 76 Heft 2	S. 157 – 172	2005

ISSN 0373-7586

Assessment of lumbricid species diversity on soil monitoring sites in Saxony-Anhalt

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Abstract

The soil biological status assessment of different land-use types is just at the beginning. This paper will contribute to an evaluation of soil monitoring sites. A matrix indicating the ecological requirements (pH-ranges, soil organic carbon, and soil humidity) of lumbricid species was developed that together with the population parameters enables easy determination of the lumbricid density at a site. Sixty-eight sites were included into this evaluation. Abundance, biomass and species diversity of lumbricids were evaluated. The goal of the project is to develop a habitat classification for Central Germany, which is a low precipitation area. Therefore, a matrix with ecological requirements of lumbricid species was developed.

Keywords: Biodiversity, lumbricid population, habitat classification, pH-ranges, soil organic carbon

Zusammenfassung

Bewertung der Artendiversität von Lumbriciden auf Bodendauerbeobachtungsflächen in Sachsen-Anhalt – Die bodenbiologische Zustandsbewertung unterschiedlich genutzter Flächen befindet sich erst im Anfang. In vorliegender Arbeit wird ein Beitrag für eine derartige Bewertung von Bodendauerbeobachtungsflächen geleistet. Es wurde eine Matrix mit ökologischen Ansprüchen (pH-Werte und C_{org}-Gehalt des Bodens, Bodenfeuchte) von Lumbricidenarten erstellt, die zusammen mit den Populationskennwerten eine einfache Bewertungsmöglichkeit des Lumbricidenvorkommens eines Standortes erlaubt. In die Bewertung wurden die Ergebnisse von 68 Flächen einbezogen. Ziel der Arbeit war es, eine Standortklassifikation für den mitteldeutschen Raum, der durch niedrige Niederschlagsmengen geprägt ist, zu erstellen.

1. Introduction

The monitoring of soil-monitoring sites contributes to survey the long-term changes in the soil status and function as defined by the German soil protection law (BBodSchG). Lumbricids have proved to be a particularly suitable indicator taxocoenosis (GRAEFE 1995). As objects of research they are important elements of the nutrient cycle in the soil and can be considered as indicator organisms standing for soil quality.

Using exclusively habitat criteria (e.g. climate, pH-value, water content, litter layer etc.) for the classification in order to maintain homogeneous habitat types, to which the animal communities are assigned, has already been attempted very early in the history of field ecology (BROCKMANN-JEROSCH & RÜBEL 1912). It is in general not clear how to survey an intact and an unbalanced ecosystem. Dealing with this assessment method needs a bioindication that enables to keep complete ecosystems under surveillance. By a definite actual-value idea for typical species communities, the foundations are laid for the evaluation of affected systems (LENNARTZ & ROSS-NICKOLL 1999). The assessment of soil-biological parameters is just at the beginning, though many soil-biological methods are recommended for application to soil-monitoring sites. This concerns, according to BECK et al. (2001), particularly the status assessment of sites under different land use (fields, grassland, forest). This project aimed at developing a habitat classification for Central Germany, a low-precipitation area (1). For this purpose a matrix with ecological requirements of lumbricid species was developed (2) helping to achieve an easy assessment of lumbricid parameters together with the population incidence at a site (3).

2. Materials and Methods

2.1. Monitoring sites

The abundance and the biomass were determined on 68 soil-monitoring sites differently used (Fields n = 2: of these S/C (silt/clay)-soil 22, sandy soil 6; grassland n = 15; forest n = 20: of these 14 deciduous/mixed forests, 6 coniferous forests; mine spoil n = 5 of these 2 fields, 3 forests). The age of mine spoil ranges from 10 to 30 years after recultivation.

The long-term soil research sites were selected according to the soil representation of Saxony-Anhalt. Four soil groups take about 75 % of the country area. There are alluvial soils (with 27.1 %), Chernozems (21.3 %), Brown Soil Podzols and Brown Podzolic Soils (15.9 %) and Luvisole and Albeluvisole (12.2 %) (STRING & WELLER 1997). The greatest portion of these soils have a silty/clay texture. Only on fields is the texture of soil important for occurrence of lumbricid species. Therefore, there was only a differentiation of soil texture on fields. The climate of Saxony-Anhalt is influenced by the Harz mountains. The dominating portion of monitoring sites are therefore low-precipitation areas with about 450 mm per year. The federal state of Saxony-Anhalt is characterised by a high anthropogenic input in the past, mainly produced by permanent emission of pollutants by industry, energy providers, municipal refuse, and traffic. Eight of the 68 studied soil-monitoring sites showed very high amounts of heavy metals (according to the German soil protection law- BBodSchG).

2.2. Lumbricids

The monitoring was done in 8 – 10 sample areas (sector: 0.125 m^2) each of each permanent plot outside the core area (50 x 50 m). The lumbricids were collected by hand from the organic layer and expelled by formaldehyde solution (0.2 %) from the mineral soil (DIN ISO-rules 11268-3). The lumbricid density can rather completely be estimated by a combination of collecting by hand and expelling under consideration of the diapause. In the fields the lumbricids were surveyed by digging down to a depth of 30 cm and subsequent application of formaldehyde. Identification keys according to GRAFF (1953) and SIMS & GERARD (1985) were used. Heavy metals were measured in soil samples (four replications per monitoring site) according to DIN 38414-7, pH-ranges (according to VDLUFA-instructions), and C_{org}-content (according DIN ISO-rules 10694).

Variance analysis with the Tukey test and correlation analysis (Pearson) with the statistic program SPSS 10.0 for Windows were applied for the statistical interpretation.

3. Results and Discussion

3.1 Soil chemical parameters

The results show a strong to very strong acidic soil reaction at the forest sites. Three of them even have pH-values below 3. Significant differences could not be seen with regard to the pH-values and C_{org}-content between different land-use types. The highest heavy metal contents were assumed on alluvial sites. Therefore, contaminated sites were especially considered for lumbricid occurrence (Tab. 1, Tab. 3). The findings indicate so far that the contamination is strongly linked with the soil properties which, on the other hand, depended on the sedimentation conditions and consequently on the terrain. Due to the micro-site variability of soil-inhabiting species, there should be no cause for concern, if partly high pollutant concentrations were found in flood areas on some sites (ANACKER et al. 2003).

Tab. 1 Soil chemical parameters of 68 soil monitoring sites in different land use

Land use type	n	pH ($CaCl_2$)	C_{org} SOC (%)	Heavy metal content mg/kg DS soil (results with * are higher than limits for heavy metals for soil texture silt/clay according to the soil protection law in Germany)					
				Cd	Zn	Pb	Ni	Cr	Cu
Field, total	28	6.3	1.66	0.3	63.0	28.4	15.3	21.3	19.8
Field (S/C)	22	6.6	1.85	0.3	71.1	30.3	18.1	23.7	23.2
Field (S)	6	5.4	0.94	0.2	33.2	21.6	5.0	12.5	7.3
Grassland, total	15	5.9	5.96	1.4*	198.3*	79.6*	20.3	38.8	39.7
Grassl. without alluv.	10	6.0	6.36	0.4	54.7	42.1	13.5	26.6	16.1
Alluvial grassland[1)]	5	5.7	4.80	3.4*	456.7*	147.2*	32.4	60.9*	82.2*
Forest, total	20	3.9	4.72	1.4*	156.4*	117.1*	17.7	24.4	31.6
Dec. for., total	14	4.4	4.76	1.9*	212.8*	141.2*	23.7	32.1	40.7*
Dec. for., without alluv.	10	4.0	4.30	0.3	55.6	70.8*	11.2	12.8	11.2
Alluvial forest[1)]	4	5.4	5.80	6.0*	605.7*	317.2*	55.2*	80.1*	114.4*
Coniferous for.	6	3.0	4.64	0.1	24.7	60.9	3.8	6.5	10.3
Mine spoil	5	6.7	1.17	0.1	31.6	10.0	15.2	17.3	8.1

[1)] Habitats with very high heavy metal contents, mainly Cd, Zn, Pb, and Cu

3.2. Occurence of lumbricids

This summarising paper is based on the bulky data material from 68 soil monitoring sites. It is arranged according to the average occurrence dependent on the cultivation. Detailed data with respect to the habitats of soil monitoring sites can be taken from GUTTECK (1997) and TISCHER (2003).

15 species from seven genera were monitored altogether. The most frequent species were *Lumbricus terrestris* (Linnaeus 1758) (41 times), *Aporrectodea caliginosa* (Savigny 1826) (39 times), *Aporrectodea rosea* (Savigny 1826) (37 times), *Allolobophara chlorotica* (Savigny 1826) (17 times), *Lumbricus rubellus* (Hoffmeister 1843) (18 times), and *Dendrobaena octaedra* (Savigny 1826) (18 times). The following pH-ranges and individual weights for the various species on the soil monitoring sites can be determined in the habitats (Tab. 2).

Tab. 2 Distribution of the most frequent lumbricid species according to pH-ranges, C_{org}- and clay contents (mean value with standard deviation)

Species	Individual-weight in g	pH-value	C_{org}-cont. (%)	Clay-cont. (%)	Number of occurence
Epigeic: *Dendrobaena octaedra*	0.11 ± 0.04	3.77 ± 0.88	4.66 ± 2.17	14.1 ± 8.0	18
Dendrodrilus rubida	0.09 ± 0.03	4.65 ± 1.13	5.91 ± 3.83	16.3 ± 7.5	12
Eiseniella tetraedra (Michaelsen, 1900)	0.05 ± 0.01	6.01 ± 0.80	6.39 ± 1.64	20.1 ± 6.6	4
Lumbricus castaneus	0.13 ± 0.05	5.56 ± 0.98	5.11 ± 1.89	17.5 ± 5.9	12
Lumbricus rubellus	0.50 ± 0.22	4.73 ± 1.31	5.61 ± 3.35	20.7 ± 15.1	18
Endogeic: *Allolobophora chlorotica*	0.32 ± 0.16	6.35 ± 0.79	3.00 ± 2.04	22.4 ± 13.1	17
Aporrectodea caliginosa	0.45 ± 0.14	6.14 ± 0.75	3.31 ± 3.16	18.9 ± 11.2	39
Aporrectodea nocturna *	1.02 ± 0.23	5.82 ± 0.69	3.04 ± 2.53	13.8 ± 9.9	9
Aporrectodea limicola (Michaelsen, 1890)	0.12 ± 0.02	4.99 ± 0.05	4.68 ± 0.52	23.9 ± 4.6	2
Aporrectodea rosea	0.24 ± 0.08	6.27 ± 0.76	3.42 ± 3.03	21.1 ± 9.9	37
Octolasion cyaneum	1.15 ± 0.44	6.45 ± 0.75	3.19 ± 2.26	20.8 ± 5.0	15
Octolasion tyrtaeum	0.71 ± 0.20	5.78 ± 0.68	5.69 ± 4.31	17.5 ± 7.0	10
Anecic: *Aporrectodea longa longa* (Ude, 1885)	0.97 ± 0.15	6.04 ± 0.67	3.35 ± 2.27	19.5 ± 10.2	11
Lumbricus terrestris	2.96 ± 0.65	6.17 ± 0.85	3.40 ± 3.08	19.8 ± 10.6	41

* One of the four phenotypes of *Aporrectodea caliginosa* according to SIMS & GERARD (1985)

Apart from the listed species, also *Eisenia fetida* (Savigny 1826) is present as an accompanying species in one field. The individual weight of the single species is, with one exception, independent of the pH-value. *L. rubellus* exhibits with increasing pH-values a decrease in the individual weight ($r^2 = 0.64^*$, $p < 0.05$, Pearson, $n = 15$). The determinative factors for the individual weights are rather the food situation, the humidity in the areas, the nutritional competition with other species living in the soil, and the age of the animals (EDWARDS 1983). Similar evidence can also be given for the dominance of the species. A striking pH-dependence occurs here only with *D. octaedra* ($r^2 = 0.57^*$) and *L. rubellus* ($r^2 = 0.43^*$). With increasing pH-values a proportional decrease in the dominance of both species was determined. The other endogeic and anecic species exhibit a high variability in their dominance proportion on several soil monitoring sites at pH-values higher than 5. The area conditions (pH-value, humus content, soil humidity, clay content), the kind of cultivation, and the nutritional situation (also the competition with other species) are determining factors for the occurrence of the various species. The data in Tab. 2 provide the basis for developing the matrix of the ecological requirements (Tab. 5).

The highest individual numbers as well as the biomass were found in the grassland. With respect to the biomass, the following order of the land use types can be established: grassland > field (sandy soil) > deciduous/mixed forest > mine spoil > field (S/C-soils) > coniferous forest (Fig. 1).

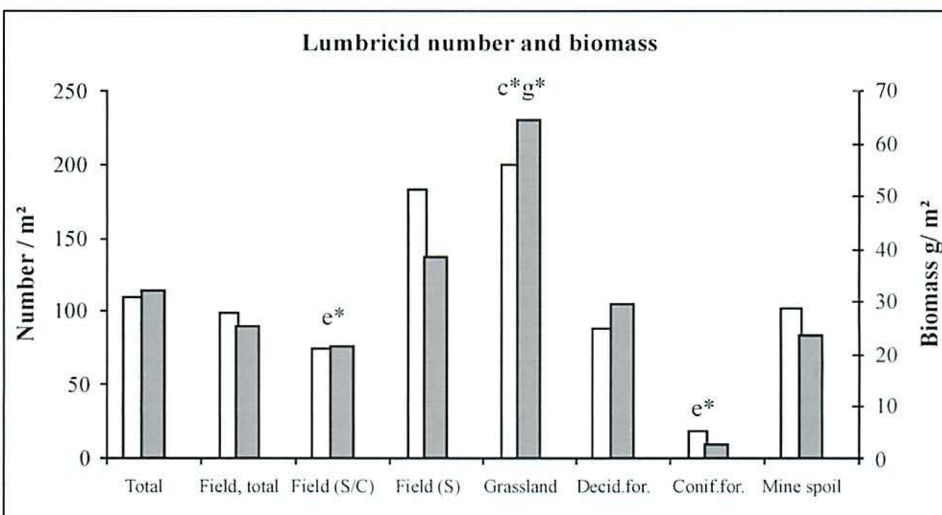

Fig. 1 Lumbricid number and biomass in different types of land use (significance in the Tukey test, * $p < 0.05$, number and biomass)

The highest species diversity (SHANNON 1948) is achieved in grassland with 1.26 on the average followed by forest and field habitats and the mine spoil as well (Fig. 2). In the fields with continuously changing conditions by cultivation and other agricultural practices, the largest range of variation of the diversity index can be seen. Five coniferous forest habitats with pH-values < 4 exhibit the most unfavourable soil conditions caused mainly by low pH-values. The index is under these circumstances nearly zero and often only the species *D. octaedra* has been found.

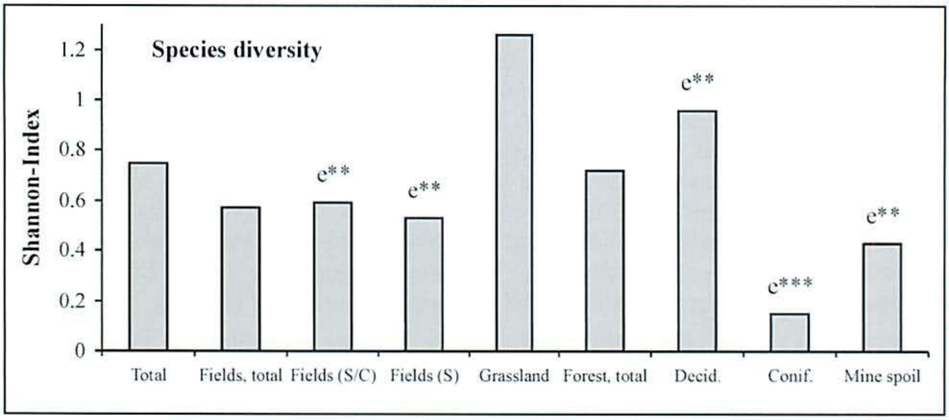

Fig. 2 Species diversity in different types of land use (significance in the Tukey test, $^{**}p < 0.01$, $^{***}p < 0.001$)

Tab. 3 Survey of the average portion of the ecological groups in different land use types (incidence in per cent, number per m^2 and biomass in g/m^2)

Land use type	n	adult (%)	Epigeic Species			Endogeic Species			Anecic Species		
			Per-cent	Num-ber	Bio-mass	Per-cent	Num-ber	Bio-mass	Per-cent	Num-ber	Bio-mass
Field, total	28	36.8	0	0	0	82.6	29	11.0	17.4	2	6.3
Field (S/C)	22	39.8	0	0	0	80.8	27	9.7	19.2	3	6.9
Field (S)	6	25.6	0	0	0	86.7	34	17.6	13.3	2	4.2
Grassland, total	15	22.4	14.7	8	1.3	61.6	33	13.0	23.7	9	23.7
Grassl. without all.	10	21.8	10	5	1.2	66.2	32	14.0	23.8	8	21.5
Alluvial grassland*	5	23.0	24.5	12	1.4	54.2	34	14.0	21.3	10	25.5
Forest, total	20	42.1	78.3	13	3.5	17.1	9	2.8	4.6	2	7.7
Dec. for. total	14	40.6	69.0	15	4.4	24.5	13	4.0	6.5	3	11.0
Dec. for. without all.	10	46.7	77.2	13	4.1	18.4	10	2.7	4.4	1	1.9
Alluvial forest*	4	25.4	48.6	20	5.1	39.7	21	7.1	11.7	9	33.9
Coniferous For.	6	45.5	100	10	1.6	0	0	0	0	0	0
Mine spoil	5	17.3	0	0	0	85.6	15	8.3	14.4	2	3.9

* Habitats with very high heavy metal contents, mainly Cd, Zn, Pb, and Cu

Profound differences between biotope types were found concerning the distribution of ecological groups. The endogeic species (*A. caliginosa, A. rosea, A. chlorotica, O. cyaneum*) dominate in field and grassland habitats. The anecic species (*L. terrestis, A. longa*), however, appear mostly in grassland. Epigeic species are exclusively found in addition to the other two life forms in grassland and the forest habitats. Only epigeic species were collected under coniferous trees. In highly contaminated areas (alluvial forest) (Tab.1) the proportion of anecic animals with 12 % of the individuals was slightly higher than in deciduous forest with 4 % (Tab. 3). The influence of pH-ranges is assumed higher as the pollution effect by heavy metals.

Dominating species in the fields are *L. terrestris, A. caliginosa,* and *A. rosea* (Fig. 3).

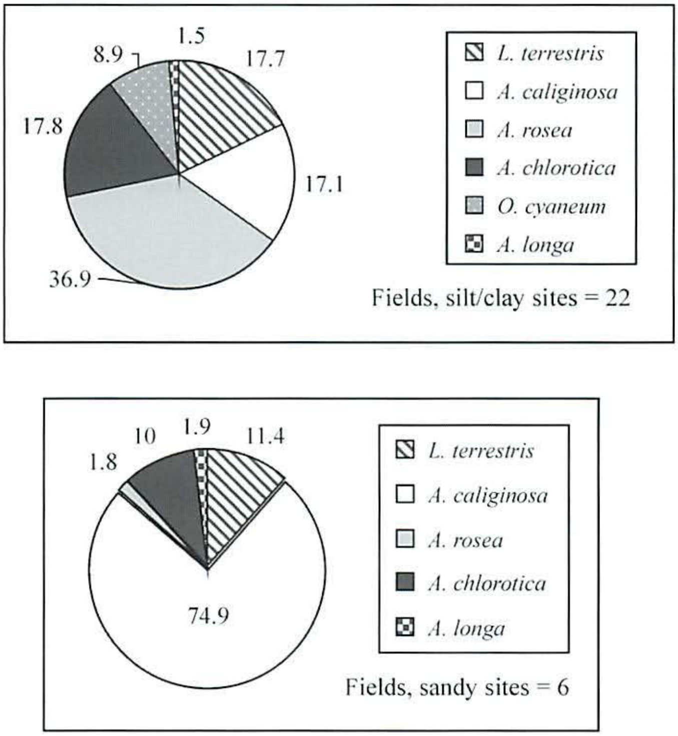

Fig. 3 Average species dominance (in per cent) in the fields

Considering the species range at the six sandy soil sites, the dominance of *A. caliginosa* (75 %) is striking. *Octolasion cyaneum* (Savigny 1826) was not present at all. *Aporrectodea nocturna* (Evans 1946), the deep-digging phenotype of *A. caliginosa*, was found with the exception of 4 sites mainly in sandy soil. *A. nocturna* is listed in Tab. 2 as a separate species. It belongs, according to Sims & Gerard (1985), to one of the four phenotypes of *A. caliginosa*.

The most frequent species in the grassland was *A. caliginosa* with a dominance of 37 % on the average, followed by *Lumbricus terrestris* with 21 %, *A. rosea* 14 %, *Lumbricus castaneus* (Savigny 1826) 10 %, *A. chlorotica* 6 %, and *O. cyaneum* 5 %.

The three species *A. caliginosa* (77 %, 5 times), *L. terrestris* (14 %, 3 times), and *A. rosea* (8%, 2 times) prevail in the 5 mine-spoil habitats that were differently used. After afforestation of mine-spoil soils with deciduous trees, DUNGER & WANNER (2001) found after 4 years *A. caliginosa*, after eight additionally *A. rosea* and *Octolasion tyrtaeum tyrtaeum* (Savigny 1826) and *L. rubellus* after ten years. Apparently, *A. caliginosa* was the best in resisting the dry conditions and the nutrition shortage in early times. With entering the pre-forest state, *L. rubellus* and *L. terrestris* prevail. A depleted lumbricid fauna consisting merely of *D. octaedra* and *A. caliginosa* developed in case of plantation with coniferous trees (DUNGER 1969).

The acidophilic species *D. octaedra*, *Dendrodrilus rubida rubida* (Gerard 1964), and *L. rubellus* dominate in the forest habitats. *L. terrestris, A. rosea, A. caliginosa,* and *O. tyrtaeum* are present in the soil at pH-values higher than 4.5. *D. octaedra* and *L. rubellus*, as acidotolerant species, are found at pH-values 3 (*D. octaedra*) and between 4 and 6 (*D. rubida* and *L. rubellus*), respectively. Three of the alluvial forest habitats are with 7 to 10 species the forest areas with the largest number of species.

3.3. Assessment of the lumbricid occurrence

Considering the ways of land use, the assessment is carried out by the help of a five-step classification (Tab. 4). Own data were combined with results from the literature. BAUCHHENSS (1997) found similar population data in Bavaria (Germany). He monitored on soil monitoring sites of fields (n = 94) 45 organisms per m² and 29 g biomass, in grassland (n = 22) 188 organisms and 134 g/m² biomass.

Tab. 4 Classification according to the occurrence dependent on the land use type (A = number/m², B = biomass g/m²)

Class		Field	Grassland	Decid. Forest	Conif. Forest
1	A	< 30	< 50	< 30	< 10
very low	B	< 5	< 25	< 5	< 2
2	A	30 – 50	51 – 100	31 – 50	10 – 20
low	B	5 – 15	25 – 50	5 – 15	2 – 4
3	A	51 – 100	101 – 150	51 – 100	21 – 30
middle	B	15 – 30	50 – 80	15 – 30	4 – 8
4	A	101 – 150	151 – 200	101 – 150	31 – 50
high	B	30 – 60	80 – 110	30 – 50	8 – 12
5	A	> 150	> 200	> 150	> 50
very high	B	> 60	> 110	> 50	> 12

Class 3 corresponds to about the mean values of several ways of land use. Class 1 and 2 have a very low or low occurrence of lumbricids. The fields among the soil monitoring sites, that are assigned to class 1 of abundance or biomass, are those with a high cultivation intensity. The mine spoils were classified according to their exploitation.

The species were classified according to the ecological requirements of the lumbricids taking into account the pH-values, the humus contents, and the soil humidity. The biological habitat classification of the lumbricids is done in a multistage process whereby special attention was paid to accomplish the method chosen. The classification was made according to RÖMBKE (1997) with tripartite scales of values for the factors soil humidity (H), pH-value (P), and humus-C_{org}-content (C). Each factor was encoded by a letter and each class by a number. A species can either be characterised by one or by multiple combinations. The scales of values for the soil humidity were compiled from bibliographical references (see RÖMBKE 1997):

H0: dry habitat,

H1: medium soil humidity,

H2: high soil humidity.

The data from own investigations were analysed to group the preferred pH-ranges of the species. For this reason the mean value for each species was calculated taking the standard error of each site into account where the species occurred. The pH-ranges were defined from these data as follows (see Tab. 2):

P0 pH-value < 3.5 – 4.5

P1 pH-value 4.6 – 6.5

P2 pH-value > 6.5

In a similar way the C_{org}-contents were classified:

C0 < 1.0 – 2.3 %

C1 2.4 – 4.0 %

C2 > 4.0 %

From Tab. 5 the ecological distribution of the lumbricid species from the matrix can be inferred.

Apart from the 3 parameters mentioned above, the soil type and the exploitation were still included in the assessment of the ecological requirements. The soil types were also classified by a tripartite scale of values (sand, loam/silt, clay), they become, however, not directly integrated into the classification like the former parameters. Thus there are some reasonable differences in the habitat classification made by the soil types from Tab. 5: the species *A. caliginosa, A. rosea, A. longa, A. chlorotica* are present in fields (sand and clay), in loam/silt soils the same species and *O. cyaneum*.

Further exceptions must be taken into account for some species contingent on the exploitation. *O. tyrtaeum* is present only in grassland and forest habitats, not in fields, and *A. longa* was not found in forests.

Tab. 5 Matrix of the ecological requirements of the lumbricid species

Species	Soil humidity	pH-value	C_{org}	Code
Aporrectodea caliginosa	H0H1H2	P1P2	C0C1C2	H0P1C0, H0P2C0, H0P1C1, H0P2C1, H0P1C2, H0P2C2, H1P1C0, H1P2C0, H1P1C1, H1P2C1, H1P1C2, H1P2C2, H2P1C0, H2P2C0, H2P1C1, H2P2C1, H2P1C2, H2P2C2
Aporrectodea rosea	H0H1	P1P2	C0C1C2	H0P1C0, H0P2C0, H0P1C1, H0P2C1, H0P1C2, H0P2C2, H1P1C0, H1P2C0, H1P1C1, H1P2C1, H1P1C2, H1P2C2
Aporrectodea longa	H0H1	P1P2	C0C1C2	H0P1C0, H0P2C0, H0P1C1, H0P2C1, H0P1C2, H0P2C2, H1P1C0, H1P2C0, H1P1C1, H1P2C1, H1P1C2, H1P2C2
Allolobophora chlorotica	H1H2	P1P2	C0C1C2	H1P1C0, H1P2C0, H1P1C1, H1P2C1, H1P1C2, H1P2C2, H2P1C0, H2P2C0, H2P1C1, H2P2C1, H2P1C2, H2P2C2
Aporrectodea limicola	H2	P0P1	C2	H2P0C2, H2P1C2
Dendrobaena octaedra	H1	P0	C1C2	H1P0C1, H1P0C2
Dendrodrilus rubida	H1	P0P1	C1C2	H1P0C1, H1P0C2, H1P1C1, H1P1C2
Eiseniella tetraedra	H2	P1P2	C2	H2P1C2, H2P2C2
Lumbricus castaneus	H1H2	P1	C1C2	H1P1C1, H1P1C2, H2P1C1, H2P1C2
Lumbricus rubellus	H1H2	P0P1	C1C2	H1P0C1, H1P0C2, H1P1C1, H1P1C2, H2P0C1, H2P0C2, H2P1C1, H2P1C2
Lumbricus terrestris	H0H1	P1P2	C0C1C2	H0P1C0, H0P2C0, H0P1C1, H0P2C1, H0P1C2, H0P2C2, H1P1C0, H1P2C0, H1P1C1, H1P2C1, H1P1C2, H1P2C2
Octolasion cyaneum	H0H1	P1P2	C0C1C2	H0P1C0, H0P2C0, H0P1C1, H0P2C1, H1P1C0, H1P2C0, H1P1C1, H1P2C1, H0P1C2, H0P2C2, H1P1C2, H1P2C2
Octolasion tyrtaeum	H1H2	P1P2	C0C1C2	H1P1C0, H1P2C0, H1P1C1, H1P2C1, H1P1C2, H1P2C2, H2P1C0, H2P2C0, H2P1C1, H2P2C1, H2P1C2, H2P2C2

A simple evaluation approach is provided for the respective habitat by means of the matrix reflecting the ecological requirements and the estimated population parameters. For several reasons, the species, referred to the desired-value, may not be present. These reasons may be: very low pH-values, contamination with pollutants, intensive exploitation, improper application of pesticides. But also a long-term drought (as in summer 2003) might be the reason for low population parameters.

Tab. 6 reveals, for example, the complete assessment of the lumbricid occurrence in the field habitats. The setting of the desired-value was done by the formal comparison between the particular habitat and the species code: in case of the same code for both of them the respective species should occur in this habitat under natural conditions. For the quantification of differences between the actual- and the desired-value, the number of species, absent in this habitat, is indicated in per cent of the total number of all species. Species, additionally occurring in this habitat, were not taken into account.

The classification is applied to the evaluation of the population parameters biomass and lumbricid number per m^2 (Tab. 4). The species diversity was included as additional parameter. The values of biodiversity should be preferred to quantitative parameters like abundance in the assessment of habitats. Repeated sampling may reduce the deficit in the great variation of the abundance.

From Tab. 6 is apparent that 9 of the monitored sites (marked) with 3 or 4 minus signs do not correspond to the ecological habitat requirements of the lumbricids. For this several explanations can be given:

- Soil monitoring site 30, 32, 34 - 1, 34 - 2, 35, 39, 46, 47, 50 - 1: intensive cultivation with negative effects on species diversity, biomass, and abundance
- Soil monitoring site 46: high copper amounts in the soil
- Soil monitoring site 34 - 2: soil still too dry at the time of the investigation (after the dry summer 2003).

4. Discussion

The species structure is mainly influenced by the type of land use, the intensity of exploitation, the soil type, the pH-value of the soil and soil humidity. The pollution level, especially by heavy metals, reduces only in few cases the biomass and the species diversity. Only one species, *L. terrestris*, was shown to occur on two soil monitoring sites with high copper content in the soil (> 60 mg/kg) (Tischer & Tanneberg 2003). The highest individual numbers as well as the biomass were found in the grassland. With respect to the biomass, the following order of the land use types can be established: grassland > field (sandy soil) > deciduous/mixed forest > mine spoil > field (S/C-soils) > coniferous forest. The great differences of agricultural soils between sandy and S/C-soils could be explained by the lower tillage intensity in the sandy habitats (Makeschin 1990). The high dominance of both species, *A. caliginosa* and *A. rosea* in agricultural soils, exhibits obviously their tolerance towards an intensive soil tillage (Makeschin 1990). The areas with *A. rosea* as the only species are characterised by intensive cultivation with a high proportion of

Tab. 6 Assessment of absent species according to ecological requirements on fields (in per cent); the difference between desired- and actual value is indicated as well as the assessment* deduced from that and the habitat classification for the biomass and the abundance of the lumbricids

Sites	Perm. Plot Number	Proportion of absent species		Biomass g/m²		Number/m²		Species diversity + assessment	Total assessment
		species (%)	assessment	Biom. +class	assessment	Number +class	assess ment		
Sandy soils									
Erxleben	2	25	+	28.0 (3)	+	48 (2)	-	0.97 (+)	+ + - +
Klossa	17	75	-	19.4 (3)	+	104 (4)	+	0 (-)	- + + -
Krevese	4	75	-	40.5 (4)	+	94 (3)	+	0 (-)	- + + -
Miesterhorst	26	25	+	98.7 (5)	+	657 (5)	+	0.40 (-)	+ + + -
Querstedt	1	50	-	38.3 (4)	+	90 (3)	+	0.64 (+)	- + + +
Senst	12	0	+	41.4 (4)	+	179 (5)	+	1.13 (+)	+ + + +
Silty/Clay soils									
B. Lauchst.	**34-2**	**60**	-	**4.3 (1)**	-	**21 (1)**	-	**0.34 (-)**	- - - -
Barnstädt	**35**	**40**	-	**11.9 (2)**	-	**55 (3)**	+	**0.50 (-)**	- - +
Biere	**30**	**80**	-	**2.0 (1)**	-	**8 (1)**	-	**0 (-)**	- - - -
Brücken	24	25	+	51.1 (4)	+	120 (4)	+	0.91 (+)	+ + + +
Cattau	33	20	+	6.0 (2)	-	12 (1)	-	1.10 (+)	+ - - +
Eilenstedt	43	33.3	-	43.3 (4)	+	179 (5)	+	1.06 (+)	- + + +
Etzdorf	**34-1**	**60**	-	**1.1 (1)**	-	**5 (1)**	-	**0.69 (+)**	- - - +
Kleinwanzl.	**32**	**40**	-	**9.9 (2)**	-	**98 (3)**	+	**0.14 (-)**	- - + -
Ladeburg	28	25	+	35.4 (4)	+	187 (5)	+	0.64 (+)	+ + + +
Leimbach	36	33.3	-	54.9 (4)	+	256 (5)	+	0.45 (-)	- + + -
Lettewitz I	**50-1**	**60**	-	**10.3 (2)**	-	**9 (1)**	-	**0.57 (+)**	- - - +
Lettewitz II	50-2	40	-	36.6 (4)	+	66 (3)	+	0.94 (+)	- + + +
Lodersleben	38	50	-	25.9 (3)	+	78 (3)	+	0.40 (-)	- + + -
Mildensee	64	20	+	19.6 (3)	+	55 (3)	+	1.25 (+)	+ + + +
Plötzkau	23	40	-	16.9 (3)	+	57 (3)	+	0.99 (+)	- + + +
Polleben	**46**	**80**	-	**19.2 (3)**	+	**20 (1)**	-	**0 (-)**	- + - -
Querfurt	37	33.3	-	28.4 (3)	+	66 (3)	+	0.90 (+)	- + + +
Rodersdorf	31	50	-	45.9 (4)	+	194 (5)	+	0.42 (-)	- + + -
Scheiplitz	**39**	**80**	-	**0.9 (1)**	-	**2 (1)**	-	**0 (-)**	- - - -
Seeben	49	0	+	68.0 (5)	+	213 (5)	+	0.94 (+)	+ + + +
Siptenfelde	62	33.3	-	25.1 (3)	+	52 (3)	+	1.09 (+)	- + + +
Teutschent.	**47**	**80**	-	**2.0 (1)**	-	**11 (1)**	-	**0 (-)**	- - - -

* Assessment:

- Species being absent: + < 30 % of the species are absent in the habitat
  – > 30 % of the species are absent in the habitat
- Classes biomass and abundance: + class 3 – 5; – class 1 – 2
- Species diversity: + for > 0.5; – for < 0.5

cereals and sugar beets in the crop succession. HEMANN (1994) and BAUCHHENSS (1998) reported similar results. Apart from the exploitation of the soil, the application of agrochemicals (pesticides) and the use of liquid manure (expelling effect) play a role in these processes, too (ERNST 1995).

The endogeic, small, short-lived species with a higher reproduction rate than the anecic species react to favourable weather conditions with a short-term increase or to unfavourable ones with a decrease in the population. They can better survive interferences (e.g. intensive tillage) than anecic species because they produce more cocoons for reproduction PAOLETTI (2001). According to PAOLETTI (2001), the endogeic species *A. caliginosa, A. rosea,* and *A. chlorotica* produce 8 – 27 and the anecic species *L. terrestris* only 3 – 8 cocoons per animal and year. The more intensive the tillage in an area, the lower the proportion of anecic species because these species react, in the long term, more sensitively due to a lower reproduction. The anecic species have, therefore, an indicator function for interferences caused by an intensive tillage in an area (FRAHM 2000, HOFMANN et al. 2003).

Further habitat investigations are needed for a generalisation of habitat classification because the evaluated plots are largely located in Central Germany, a low-precipitation area. Either a shortage or a surplus of water can more effectively influence the soil organisms than the soil type or the humus content. Establishing a parameter hierarchy that should depend on the cultivation could put things right (HÖPER & RUF 2003).

Many authors refer to the influence of pH-value (SATCHELL 1955, CURRY 1998), humus content and soil humidity on the occurrence of lumbricids (SATCHELL 1983, LEE 1985, DAUGBJERG 1988). BRIONES et al. (1995) investigated 20 soil parameters and their impact on the single lumbricid species. Apart from the three influencing parameters mentioned above, they identified the exchangeable cations, especially calcium and aluminium, as supplementary distinguishing factors.

Data in the literature on various lumbricid species differ strongly from each other. Comparing, for example, the ecological requirements from the developed matrix for the species *A. chlorotica* with the results of other scientists (RÖMBKE 1997), one can notice differences in the classification. According to RÖMBKE (1997) this species meets only the humidity class B2 (high soil moisture). In the present investigations, *A. chlorotica* occurred mainly in fields and other habitats that are characterised by a medium soil humidity (B1). The species with the largest ecological range, which merely does not occur in very acid soils, is *A. caliginosa*. According to RÖMBKE (1997) and other authors the pH-value applies only to P1. This has to do with the ranges of classification. *A. caliginosa* is also in very young mine spoils (less than 10 years) usually the only species appearing. The comparison of the measured pH-values for the particular lumbricid species with data from the literature consequently reveals some differences. According to CURRY (1998), the earthworms are absent in acidic soils with pH-values less than 3.5 and appear only scarcely at pH-values < 4.5. The lowest habitat pH-value we found in the present study was 2.7 for a coniferous forest site. The only species living there was *D. octaedra*.

Römbke (1997) referred in his matrix to humus types because his habitat classification was established for forests. In this paper, such a classification is not presented because there are continuous transitions between the humus types and this assessment depends on subjective views. The use of C_{org}-contents (from the Ah/Ap-horizon) is rather proposed as the determined quantity to be. The C_{org}-contents can be used for the evaluation of habitat requirements because they are known and the investigation of habitats needs a complex approach. Apart from the obligatory parameters (pH-value, soil moisture, soil type/clay content), the vegetation and, therefore, the nutrient supply play a decisive role. The decomposition rate of the organic substance is influenced by the soil factors which, on the other hand, is attributed to the composition of the soil fauna. Graefe (1993) developed for this the term »decomposer communities« in order to evaluate the habitats. This method can only be restrictedly applied to agricultural soils. Furthermore, the abundance of the organisms was ignored in classifying the seven decomposition communities though it can be an approximate characteristic of the habitat (Höper & Ruf 2003). Half-quantitative parameters (dominance) should be preferred to quantitative ones (abundance), which are too variable in space and time. Moreover, they provide sufficient reliable data only after extensive and repeated sampling. Since the occurrence of one species is related to the whole settlement-density if applying the dominance, deviations can be balanced and it helps to better understand the role of a single species in the community. That means that the structure of the biodiversity should be preferred to the quantitative parameters (Beck et al. 2001). This criterion meets the inclusion of species diversity into the habitat assessment.

5. Acknowledgements

I am grateful to the staff of the Department for Soil Conservation in the State Agency for Environmental Protection of Saxony-Anhalt, especially to Mr U. Gutteck, for the financial support of the research project and the long-term good cooperation. I would like to thank Mrs H. Brezina for measurement of the humus contents at the Institute for Soil Science and Plant Nutrition for the experimental support.

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Manuscript accepted: 19 January 2005

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