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Lumbricid associations on a former open clay pit after recultivation with different tree species

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Abstract

The earthworm fauna was recorded from a former open clay pit five and seven years respectively after the area had been recultivated with various tree species. The highest abundances (200-245 specimens/m^2) and biomasses (46.8 to 48.4 g/m^2) were found in the following stand types: mixed woodland of balsam poplar (various sorts) and grey alder (*Alnus incana* (L.) MOENCH), mixed woodland of balsam poplar (Andoscoggin) and black alder (*Alnus glutinosa* (L.) GAERTN.), and a pure stand of black alder. Clearly lower values were found in a plot with common oaks (*Quercus robur* L.) in a dense shelterwood of naturally regenerated willows (*Salix spec*.), and a plot exclusively stocked with naturally regenerated willows. The rapid resettlement of the backfilled, compacted clay soil is above all explained by the high pH-values found in the surface soil. The differences between the studied plots regarding total abundance and biomass might be explained by the different qualities and amounts of litter. The highest species diversity - expressed by the Shannon-index - and the highest proportion of endogeic species, particularly *Aporrectodea caliginosa* Savigny 1826, were calculated for the two stands with a mixture of alder and balsam poplar. This result could have been caused by the lack of parent soil bed and the particularly high pH-value of the soils found there.

Key Words: Lumbricid associations, recultivation, former clay pit, alder, base rich

Zusammenfassung

Zur Struktur der Regenwurmpopulationen auf einer ehemaligen Tonerdeabbaufläche nach der Rekultivierung mit verschiedenen Baumarten

Auf einer ehemaligen Tonerdeabbaufläche bei Landshut im Wald der Universität München wurde fünf bzw. sieben Jahre nach der Rekultivierung mit verschiedenen

Baumarten die Regenwurmfauna erfasst. Die höchsten Abundanzen (200-245 Individuen/m^2) und Biomassen (46,8-48,4 g/m^2) wurden unter folgenden Bestandestypen festgestellt: einem Mischbestand aus Balsampappel (verschiedene Sorten) und Grauerle (*Alnus incana* (L.) MOENCH), einem Mischbestand aus Balsampappel (Andoscoggin) und Schwarzerle (*Alnus glutinosa* (L.) GAERTN.) sowie einem Schwarzerlenreinbestand. Deutlich geringere Werte fanden sich auf einer Parzelle mit Stieleichen (*Quercus robur* L.) unter einem dichten Schirm natürlich angekommener Weiden (*Salix spec*.) und einer ausschließlich von natürlich verjüngten Weiden bestockten Parzelle. Die Regenwurmpopulationen auf den Versuchsparzellen bestanden - in wechselnden Anteilen - aus folgenden Arten: *Aporrectodea caliginosa* Savigny 1826, *Aporrectodea rosea* Savigny 1826, *Lumbricus rubellus* Hoffmeister 1843, *Dendrobaena octaedra* Savigny 1826 und *Octolasion lacteum* Örley 1885. Auf allen Versuchsparzellen herrschen juvenile Individuen vor. Die größte Artendiversität, ausgedrückt durch den Shannon-Index, und die höchsten Anteile der endogäisch, d.h. ständig im Mineralboden lebenden Arten der Gattung *Apporectodea* errechneten sich für die mit Erlen-Balsampappel-Mischbeständen bestockten Parzellen. Dieser Befund könnte eine Folge des dort fehlenden Mutterbodenauftrags und des besonders hohen pH- Wertes sein. Keine wesentlichen Unterschiede zwischen den Parzellen ließen sich dagegen hinsichtlich des Auftretens der als intermediär geltende Art *L. rubellus* feststellen. Diese die Gesamtbiomasse aller Parzellen dominierende Art hält sich vorzugsweise, jedoch nicht ausschließlich in der Streuschicht auf. Konkurrenzeffekte zwischen den dominanten Gattungen *Lumbricus* und *Apporectodea*, d.h. das Vorkommen einer Art vor allem dort wo die andere Art fehlt, lassen sich aus den vorliegenden Daten nicht ableiten. Die rasche Wiederbesiedelung des wiederverfüllten, verdichteten Tonbodens mit Regenwürmern wird vor allem auf die hohen pH-Werte des Oberbodens zurückgeführt. Die Unterschiede zwischen den Versuchsgliedern hinsichtlich Gesamtabundanz und -biomasse erklären sich vermutlich durch die unterschiedliche Streuqualität und -menge. Besonders die von den beiden Erlenarten gelieferte Streu scheint sich auf die Entwicklung einer leistungsfähigen Regenwurmpolulation positiv ausgewirkt zu haben.

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1 Introduction

A number of authors have drawn attention to the significance of tree species composition in a stand for the decomposition of litter (e.g. WITTICH 1953, MUYS et al. 1992). Hence, in addition to soil type and climate, stand type is an important factor influencing soil fertility (REHFUESS 1990, MUYS and LUST 1992). In conjunction with economic requirements these findings are of great importance for silviculture in order to establish productive and stable stands. This is of particular importance for the afforestations of mined areas where the soil has a very special chemistry and physics which must be taken into consideration when choosing the tree species for the future stand.

It has been recognised that earthworms play a significant role in both soil fertility (EDWARDS and LOFTY 1977) and plant growth (GRAFF 1977, SCHEU and PARKINSON 1994). The reported positive effects concern improvements in nutrient availability and soil texture (BOUCHÉ 1972, EDWARDS and LOFTY 1977). Therefore it is particularly beneficial for the soil of the aforementioned mined areas assigned for recultivation if a productive population of earthworms is obtained. It is possible to achieve this by introducing the earthworms to the area (DUNGER 1969, VIMMERSTEDT and FINNEY 1973). Moreover, successful natural colonisations has already been observed in small pits (DUNGER 1969) and after the reapplication of woodland soil (TOPP et al. 1992).

However, less is known about the tree species suitable for recultivation former clay pits (THOMASIUS et al. 1996). In addition with regard to the very special site conditions of these pits, there is a lack of information about the composition of the earthworm population and its interactions to the afforested stand type. The paper describes the condition of the earthworm population in a former clay pit some years after afforestation with different tree species.

2 Materials and Methods

2.1 Site

LÜDEMANN (1988) and AMMER et al. (1994) have described the study site in detail. It is an 8 hectare site 25 km from Landshut (Bavaria) and consists of high quality clay (‘Bentonit’) which was mined from 1978 to 1986. The exploited pit was reclaimed with mined material of an other pit. Before afforestation the mined area was partly covered with humus soil (0-10 cm). The site conditions after reclamation and before afforestation can be characterised comprehensively as follows: claydominated (clays were found in the upper 40 cm of 80 % of the 107 samples), base-rich (the median pH-value (H_2O) of the 107 samples at a depth of 10 to 20 cm was 7.45) and compressed by bulldozers (LÜDEMANN 1988).

2.2 Plantations

The suitability of several tree species for the recultivation of this special site has been investigated in an experiment which was started in 1987. For details of the experimental design see AMMER et al. (1994). The research involved planting 18 tree species and sowing *Quercus robur* L. In 1994 earthworm populations of the following plots were investigated: poplar (hybrid „Androscoggin“) mixed in rows with *Alnus glutinosa* (L.) GAERTN. (planted in spring 1988), *Alnus glutinosa* (planted in spring 1989), poplar (different hybrids of section Tacamahaca) mixed in rows with *Alnus incana* (L.) MOENCH. (planted in spring 1987), *willow (Salix spec*., naturally regenerated from 1987 on) and *Quercus robur* (L.) (sowed in autumn 1988) which were at the time of the inventory under a dense shelter of naturally regenerated willows.

2.3 Inventory of earthworm populations

When deciding the method for catching earthworms the experiences of TERHIVUO (1982, 1989) and GARCEAU and CODERRE (1991) were taken into account. Hence a combination of hand sorting (litter) and formalin application (on the surface of the mineral soil) was used. The formalin was applied at a concentration of 10 l of 0.12% to a sample plot measuring 1600 cm^2. The plot size of the different plantations was taken into consideration when determining the number of sample units per variant. There were ten sample units of *Populus/A. incana* and *Salix spec*. and 8 sample units of *Populus/A. glutionsa*, *A. glutinosa* and *Salix/Q. robur*. The extracted earthworms were preserved in a mixture of 70 % ethanol and 5% formalin. The preserved worms were weighed with electronic scales 3-4 months after sampling. The following species were identified: *Aporrectodea caliginosa* Savigny 1826, *Aporrectodea rosea* Savigny 1826, *Lumbricus rubellus* Hoffmeister 1843, *Dendrobaena octaedra* Savigny 1826 and *Octolasion lacteum* Örley 1885. SIMS and GERARD (1985) were followed for the nomenclature.

2.4 Statistics and indices

The data were evaluated with analysis of variance using SAS 6.08 statistics software. In general the Tukey-test was applied, however, where there was unbalanced data the Scheffé-Test was used as recommended by Dufner et al. (1992) and Precht and Kraft (1993).

As an index of species diversity the Shannon-index based on individuals per species was calculated. The formula is (see Mühlenberg 1989):

$$H' = -\sum_{i=1}^{S} p_i * \ln p_i$$

where H' = Shannon-Index, S = number of species, $p_i = n_i/N$ (n_i = number of individuals of species i, N = total number of individuals). A t-distributed test statistic is given by Mühlenberg (1989). As an index of equitability of abundance the eveness (E = H'/lnS) was calculated. In order to characterise the composition of a earthworm population at a site concerning ecological categories Nordström and Rundgren (1973) introduced the following index:

$$I_v = \frac{A + 1.5B + 2C}{A + B + C}$$

where A = number of individuals of epigeic, B = number of individuals of intermediate (= e.g. L. rubellus) and C = number of individuals of anesic and endogeic species.

3 Results

Table 1 shows the abundance and biomass of the earthworm populations of four different stand types 5 and 7 years respectively after the beginning of the experiment. The largest earthworm populations were found on the alder plots. These three stand types reached the highest values in terms of number and biomass. In almost all cases the differences in abundance and biomass between the alder plots and the two other stands are statistically significant. Differences between the two alder/poplar mixtures and the pure *A. glutinosa* stand are evident concerning the proportion of species contributing to the total abundance and total biomass. Thus the *Aporrectodea* genus appeared much more frequent on the poplar/alder plots. Whereas, the percentage of juvenile *Lumbricus* and particularly the *Dendrobaena* genus was obviously lower on these plots than on the *A. glutinosa* plot. Moreover, the species composition of the *A. glutinosa* plot was rather similar to that of the *Salix/Q.*

robur plot. The *Octolasion* genus reached highest relative frequencies on the plot afforested by succession (*Salix spec*.). On all plots the populations are dominated by juvenile individuals. Their proportion in the total number of earthworms ranges from 65 % (*Salix spec*. plot) to 86 % (*A. glutionsa* plot).

Include here table 1

The highest values of species diversity were calculated for the *Populus-A. glutinosa*-plot (table 2). The equitability of abundance is rather high in all cases except for *Salix.* This indicates that the populations are not controlled just by one dominant species. As the I_v-index shows, on all plots endogeic species (habitat: upper mineral soil) contribute markedly to the earthworm population. Reiterating, the highest value was found for the *Populus-A. glutinosa*-plot (table 2). In contrast to the SHANNON-index the NORDSTRÖM-RUNDGREN-Index could be calculated for each sample unit. Hence standard deviations could be specified for each plot. These values indicate that the differences between the sample units per plot were rather low. Thus the species occuring in a stand are distributed more or less all over the plot.

include here table 2

Due to the partly overlapping habitat demands of *L. rubellus* and *A. caliginosa* competitive effects between these two species seem to be possible. The hypothesis was, that *L. rubellus* reachs high numbers of individuals in sample units where the abundance of animals of the genus *Apporectodea* is low vice versa. As figure 1 shows this was not the case.

include here figure 1

4 Discussion

Comparison between our results and the literature indicates that earthworm habitats as presented here have rarely been described up to now. According to LEE (1985) almost nothing is known regarding the population density and the species composition of earthworm populations in soils having a pH-value over 7.5. Compared to densities known from different pit afforestations (cf. e.g. DUNGER 1969) the abundances found five and seven years respectively after the recultivation were surprisingly high. This is particularly true for plots stocked with alders and balsam poplars, which are almost completely lacking a parent soil bed. The earthworm population densities found there are already as high as those typical of European deciduous forests (LEE 1985). Comparably high values in forests were found by NORDSTRÖM and RUNDGREN (1974) in southern Sweden only in elm-ash-stands. TERHIVUO (1989) recorded similar earthworm abundances in shore alder thickets in Finland, and TOPP et al. (1992) in a former lignite tip (without parent soil bed) under a poplar pioneer crop. In contrast, MUYS (1992) found considerably higher values under black alders. However, the stands studied by him were clearly older; moreover, these stands were an afforestation of meadows. The fact that earthworms with large bodies such as *Lumbricus terrestris* and *Aporrectodea longa* are (still?) missing, might explain why the biomasses found in the present study are smaller than those found in the studies cited above. It is true that the abundances of the two plots characterised by willows which grew naturally were only barely half as high as those found by MAKESCHIN et al. (1989). Admittedly, the latter studies were carried out on a willow plantation on formerly arable land.

The high pH-values measured in the upper mineral soil presumably account for the fact that the backfilled soil was colonised successfully within a short period of time in all test variants. Therefore, the positive correlation between earthworm density and pH-value stated by numerous authors (BOUCHÉ 1972, NORDSTRÖM and RUNDGREN 1974, AMMER 1992) could also be valid beyond the neutral point.

Besides the high pH-value, also the high Ca-saturation of the backfilled soil in the recultivated area (LÜDEMANN 1988) could have accounted for the rapid development of a high population of specimens. MAKESCHIN (1991) found that the population densities, particularly of the endogeic species, rise with increasing Ca-concentrations at the exchanger and in the soil solution. Furthermore, the fact that ingestable litter was promptly available probably favoured the rapid growth of an earthworm population. The different tree species provide litter in different amounts and of different decomposability. This possibly accounts for the fact that different results were obtained in the test variants, regarding the total abundance and biomass of the earthworms. It is known from numerous studies (e.g. SATCHELL and LOWE 1967) that the litter of *A. glutinosa* is very attractive to earthworms due to the high N-concentration of the leaves. The fact that the tree already begins to shed green leaves in summer (BARTELS 1993) may have a positive effect. According to WITTICH (1943 and 1953) among the trees studied here only *A. incana* provides food which can be decomposed more or less as easily as that of the black alder. In contrast, poplars and willows shed leaf litter which decomposes more slowly. This could explain why the plots stocked with alders exhibit a higher total abundance and biomass than the plots dominated by willows (table 1). In addition in 1991 the alders were already 1.5 to 3 times higher than the willows (AMMER et al. 1994). Hence the amount of food provided by the alders was probably higher than that provided by the willows.

Although the earthworm density is very high, the number of species forming the populations is small in all test variants. Hence the diversity values found in all plots are below the values stated for various beech stands by PHILLIPSON et al. (1976). Since these and other authors (e.g. NORDSTRÖM and RUNDGREN (1973)) found up to 11 species in productive deciduous forests, it is in fact possible that the number of species will increase in the course of succession of the soil fauna. TOPP et al. (1992) also only found a 4-species system four years after recultivation, while DUNGER (1969) already recorded 7 species 17 years after the afforestation of tip soils. In contrast, comparing various succession stages PIZL (1992) discovered that, with increasing succession of the vegetation, it was not the number of species which changed, but the earthworm community structure. In this context the question arises, whether the almost identical composition of species found in the poplar-alder-plots represents an early or a late succession stage. In the two plots the highest proportion of endogeic species could be ascertained (table 2). Especially *A. caliginosa* seems to have found more favourable conditions there than in the remaining plots. This could have several reasons. First, in the two plots mentioned the parent soil bed was missing completely. As a result, almost no ground vegetation had developed there. The resulting lack of litter before the afforestation might have given *A. caliginosa* an advantage over *L. rubellus* and *D. octaedra*. Second, *A. caliginosa* is capable of aestivaton (EVANS and GUILD 1948). Hence it might have been better prepared to survive a periodical drying out of the clay soil, which in the beginning was almost free of vegetation. PIZL (1992) also found that the proportion of *A. caliginosa* in the total population decreased, as the degree of ground flora cover increased. Therefore, DUNGER (1969) even classifies this species as a pioneer species. Both point to the fact that the structure of species found in the poplar-alder-plots ought to be assigned to an earlier succession stage. However *A. caliginosa* might also have benefited from the pH-values, which were particularly high in these plots (up to 8.9, LUDEMANN 1988). According to ABRAHAMSEN (1972), as well as HUHTA and KULMALA (1987), *A. caliginosa* is thus less tolerant to acid conditions than *L. rubellus*. From this it could be concluded that *A. caliginosa* competes better in the basic range. According to GUILD (1948) and PHILLIPSON et al. (1976) this species is moreover especially capable of colonising dense soils. However, as figure 1 indicates competitive effects between *A. caliginosa* and *L. rubellus* are not preceptible.

The evenness values are very similar in four of the five plots (table 2). This means, that the higher diversity values of the poplar-alder-plots and the *Salix-Q. robur* plot result from the fact, that there the number of species is higher. They are not due to a more even distribution of the species. According to the studies presented by PIZL (1992), however, the number of species does not indicate that a specific succession stage has been reached. The distinctly lower diversity and evenness-values obtained from the *Salix* plot probably result from the dominance of *O. lacteum* and may reflect the frequent water excess on this plot. According to PEREL (1975*) O. lacteum* is a species which tolerates very well a permanently high soil water content. BERNIER and PONGE (1994) proved impressively how the species structure of the earthworm fauna can change on a small scale, and how it can characterise the corresponding site and stand situation.

In all cases the high number of individuals of *L. rubellus* confirms how efficiently this species is able to settle new habitats (MARINISSEN and VAN DEN BOSCHE 1992). So far anesic species, such as *Lumbricus terrestris*, which are able to penetrate soil layers of more than one meter in depth and can contribute to the drainage of the soil considerably (SATCHELL 1967), are missing completely. However, KNIGHT et al. (1992) points out that a high water table at the surface during autumn, winter and early spring can exclude these species. If *L. terrestris* migrates anyway, passively or actively, this species should be able to settle large portions of the open clay pit. This was the case for example in the first settlement of a former limestone quarry as stated by VIMMERSTEDT and FINNEY (1973). In any case, it seems interesting to continue studying the course of succession of the earthworm fauna parallel to the soil development and in dependence on the stocking.

5 Conclusions

The results show, that a rapid resettlement of a backfilled compacted clay soil by earthworms is possible in less than 10 years. As the earthworm colonization was successfull above all on the alder plots, reforestations with *Alnus* seem to be promising. Especially *A. glutinosa* which can also accomplish silvicultural interests, is recommended for afforestations of former clay pits with high pH-values of the reclaimed soil.

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table 1: Abundances and biomasses of earthworms per m^2. Also given are the standard deviations (in parantheses) and the percentage of each species on total earthworm number and biomass. Different letters label statistical significant differences at a level of p=0.01.

Tabelle 1: Abundanzen und Biomassen der Regenwürmer / m^2. Angegeben sind auch die entspechenden Standardabweichungen (in Klammern) und der Anteil der einzelnen Arten an der Gesamtabundanz bzw. -biomasse jeder Parzelle. Unterschiedliche Buchstaben kennzeichnen statistisch signifikante Unterschiede zwischen den Versuchsvarianten (p = 0.01).

	Populus/ A. glutinosa	A. glutinosa	Populus/ A. incana	Salix spec./ Q. robur	Salix spec.
N/m^2	245.3 (94.7) a	216.4 (86.0) a, b	200.0 (101.3) a, b	86.7 (34.6) b, c	65.6 (20.9) c
A. caliginosa (%)	5	1	6	3	-
A. rosea (%)	2	-	1	2	-
A. juvenil (%)	38	10	31	7	2
L. rubellus (%)	5	7	7	6	12
L. juvenil (%)	23	45	27	37	28
D. octaedra (%)	-	1	2	4	2
D. juvenil (%)	5	12	5	14	11
O. lacteum (%)	8	5	8	4	21
O. juvenil (%)	14	19	13	23	24
g/m^2	47.7 (26.1) a	48.4 (21.2) a	46.8 (16.9) a	17.2 (8.6) b	15.8 (7.9) b
A. caliginosa (%)	11	2	13	5	-
A. rosea (%)	3	-	1	2	-
A. juvenil (%)	18	7	9	2	1
L. rubellus (%)	21	30	32	26	29
L. juvenil (%)	26	41	19	43	32
D. octaedra (%)	-	1	1	2	1
D. juvenil (%)	-	2	1	3	2
O. lacteum (%)	15	7	19	9	30
O. juvenil (%)	6	10	5	8	5

table 2: Shannon-index (H') and Evenness (E) per plot based on the number of individuals. Different letters label statistical significant differences at a level of p=0.01. I_v designates the Nordström-Rundgren-index which characterises the composition of an earthworm population. The standard deviations are given in parantheses.

Tabelle 2: Shannon-index (H') und Evenness (E) berechnet auf der Grundlage von Individuenzahlen. Unterschiedliche Buchstaben kennzeichnen statistisch signifikante Unterschiede zwischen den Versuchsvarianten (p = 0.01). Der Nordström-Rundgren-index I_v charakterisiert den Aufbau der Regenwurmpopulation. Er wird um so höher, je mehr Individuen der den Mineralboden bewohnenden und für den Stoffumsatz bedeutsamen Arten vorkommen. In Klammern sind die Standardabweichungen angegeben.

	Populus/A. glutinosa	A. glutinosa	Populus/A. incana	Salix spec./Q. robur	Salix spec.
H'	1.44 b	1.19 ac	1.36 b	1.36 ab	1.07 c
E	0,899	0.859	0.846	0.842	0.772
I_v	1.79 (0.08)	1.61 (0.08)	1.71 (0.13)	1.57 (0.15)	1.67 (0.13)

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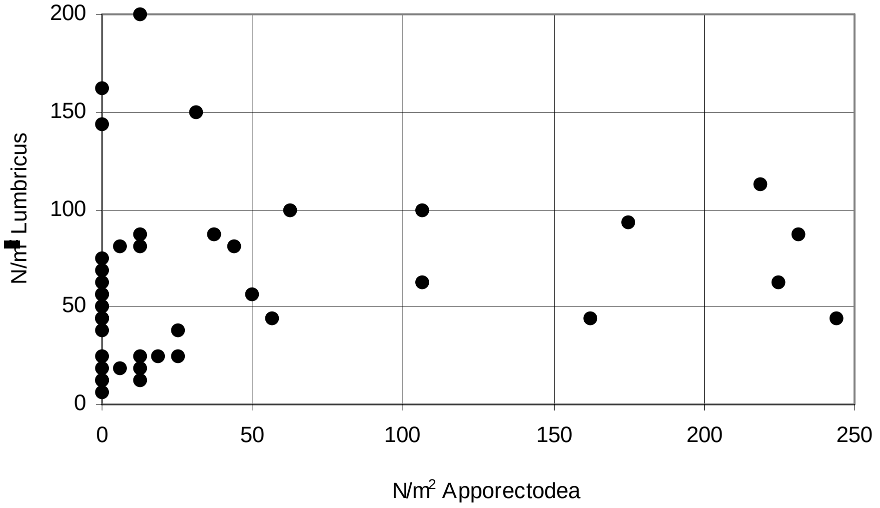
figure 1: Numbers of individuals of the genus *Apporectodea* and *Lumbricus* per sample unit.

Abbildung 1: Punktdiagramm zur Überprüfung der Hypothese, daß Individuen der Gattung *Apporectodea* vorzugsweise dann vermehrt vorkommen, wenn der Probepunkt von nur wenigen Exemplaren der Gattung *Lumbricus* besiedelt ist (und umgekehrt). Dies ist hier jedoch nicht der Fall.



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