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Spatial distribution of earthworms (Oligochaeta: Lumbricidae) and the relationship to environmental parameters in northern German wet grassland

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Summary

In 2011, the spatial distribution and the response to environmental parameteres of earthworm populations were investigated at three areas at Haseldorfer Marsch and one area at Beltringharder Koog (Schleswig-Holstein, northern Germany). There, the water regime has been continuously regulated since embankment. The aim was to study the effect of the water regime in both areas, in particular the backwater period, on the abundance and biomass of earthworms. A correlation was found between the soil pH, the sand content, the organic matter content, and the distribution of earthworms; moreover, elevation and the related backwater period are also correlated with these soil factors. According to our study the distribution of earthworms in such earlier river or tide floodplains is a result of former processes, e.g. sedimentation under natural conditions before embankment, and current processes, e.g. actual backwater period, soil pH, and organic matter accumulation.

Keywords: effect of embankment, inundation, backwater effects

Zusammenfassung

Dir räumliche Verteilung der Regenwürmer (Oligochaeta: Lumbricidae) und ihre Beziehung zu Umweltparametern in norddeutschen Feuchtgrünländern

Die Regenwurmpopulation in drei Flächen der Haseldorfer Marsch und einer Fläche im Beltringharder Koog (Schleswig-Holstein, Norddeutschland) wurde im Jahr 2011 erfasst, um die räumliche Verteilung und den Einfluss von Umweltparametern zu untersuchen. Das Wasserregime in beiden Gebieten wird seit der Eindeichung reguliert. Das Ziel der Untersuchung lag darin, den Einfluss des Wasserregimes, insbesondere der Überstauungszeit, auf die Dichte und Biomasse der Regenwürmer zu analysieren. Es wurde ein Einfluss des Boden pH Wertes, des Sandgehaltes und des Gehaltes an organischer Substanz auf die Verteilung der Regenwürmer gefunden, aber die Höhenlage und die damit zusammenhängende Überstauungszeit waren ebenfalls mit den Bodenparametern korreliert. Nach unseren Untersuchungen ist die Verteilung der Regenwürmer in solchen früher durch Überflutung der Flüsse oder durch Tiden beeinflusste Gebiete das Ergebnis früherer Prozesse, z.B. die Sedimentation vor der Eindeichung, und aktuellen Prozessen, z.B. die derzeitige Überstauungszeit, der Boden pH und die Anreicherung von organischer Substanz während der Überstauung.

Schlüsselwörter: Einfluss von Eindeichung, Überflutung, Einfluss von Überstauung

Introduction

In past decades, many wet grassland sites changed their natural water regime by drainage due to the intensification of agriculture and along rivers formerly inundated wet grassland was cut off from the river regime by embankment (BULLOCK & ACREMAN 2003). This development did not only change the ecological conditions for plants and animals, but also the ecosystem functions connected to them. Thus, one main aim of nature conservation in wet grassland is to bring water back into the systems. In particular, the conservation of wet grassland birds is of high interest; the abundance of birds from wet grassland has decreased in the last decade (HÖTKER & JEROMIN 2010). Earthworms are one of the preferred foods of many birds in wet grassland (BELTING & BELTING 1999, AUDSEN et. al. 2003, BOSCHERT 2006). A sufficient density is, therefore, a precondition for breeding success of many endangered wet grassland birds. The changing water regime can influence not only the earthworm population by suboptimal water conditions, but also the population of wet grassland birds by insufficient food supply.

These environmental problems are also found in the Haseldorfer Marsch, a former floodplain of the River Elbe (PETERSEN-ANDRESEN 2004, 2010). This grassland area was cut off from its former flooding regime after a dam was built along the riverside. Only one small channel remained as an outflow of surplus rainwater. Seasonal backwater situations occur with unknown effects on the earthworm population and the wet grassland birds depending on them. The effect of backwater situations on the earthworm population were studied in regard to the following questions: (i) what is the effect of the submergence time; (ii) is there a relationship between elevation and other environmental parameters that explain the spatial distribution of earthworms; (iii) are the effects of submergence and emergence similar in different regions?

Sites and methods

In the western part of Schleswig-Holstein (northern Germany), two grassland sites were investigated according to the spatial distribution of earthworms: Haseldorfer Marsch and Beltringharder Koog (Fig. 1). Before the dam to the River Elbe was built in 1976, the Haseldorfer Marsch was an important area to wet grassland birds (HELM 1986). The study area is part of the 2.160 ha large nature reserve "Haseldorfer Marsch". It is located behind the dike and is bordered by two ditches. The Beltringharder Koog was diked in 1987 and was formerly characterised by salt marshes and sandy mudflats. This area is 3.350 ha large. Both areas are grazed by cattle. The Beltringharder Koog is grazed with approximately 0.5 cattle/ha. By establishing a regulated retention regime in 1992, backwater develops regularly in winter time.

Earthworms were sampled once between 16.9.2011 and 6.10.2011 at 3 areas in the Haseldorfer Marsch and at 1 area in the Beltringharder Koog from a 0.1 m^2 frame of approximately 23 cm depth. In total, 128 samples were taken and the coordinates in the field were determined by GPS. Distances between samples within an area were between 50 m and 100 m. The soil was distributed on a white plane and earthworms were collected directly from the sample (DUNGER & FIEDLER 1989). The anectic earthworms could only be partly sampled by this method, since using the formalin method in a nature conservation area was not possible. Furthermore, the ash-free dry-weight of earthworms was determined after incineration for 4 hours at 450°C. Ash-free dry-weight (af dw) is a measure for the biomass of earthworms. For the identification of the species, the keys of SIMS & GERARD (1999), WILCKE (1967) and BÄHRMANN (1995) were used.

Two replicate soil samples were taken at the same spots as the earthworm samples. In the lab, the soil pH was determined from the soil samples in deionised water using the pH-Meter pMX2000 (WTW). The organic mater content was determined after incineration of a dried soil sample. The sand content was measured from 10 g dried soil. The organic matter was destroyed by boiling the samples with 35 % H_2O_2. After that, 10 M hydrochloric acid was added and the total sand content was determined by sieving the dried sample with a 63 µm sieve.

The elevation data of the 128 sampling points were derived from a DGM 1 using the coordinates determined in the field. The backwater period was calculated using the elevation data and the water level data measured by the gauche date of the outflow. The results were later adjusted to the field observations.

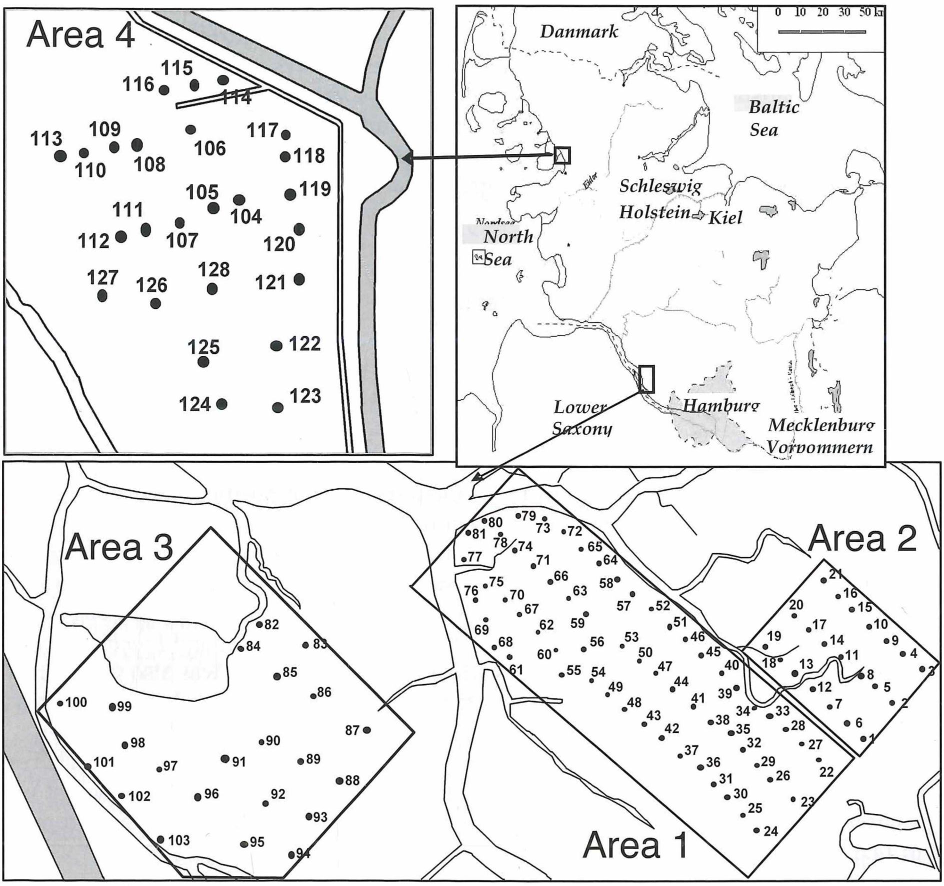

Fig. 1: Map of the two study areas and their location in Schleswig-Holstein (northern Germany); dark grey - road on dike; light grey - water.

For the statistical analysis, the programs Statistica 6.1 (STATSOFT 2004) and PAST version 2.15 (HAMMER et al. 2010) were used. The data were tested to normal distribution using the Kolmogorov-Smirnov test. Non-parametric tests were used for non-normally distributed data. The soil parameters and the abundances of the different earthworm species were analysed using the one-way ANOVA and the Kruscal-Wallis ANOVA, respectively, with subsequent use of the multiple comparison test or the post-hoc test (Tukey-Test). Furthermore, the Detrended-Correspondence Analysis was used to find differences between the earthworm assemblages of the 4 areas using only the data identified to species level. Correlations between the abundances of species and the earthworm biomass were analysed using the Spearman-Rank correlation or the Pearson correlation. The emerged and submerged areas were compared using the t-test, as were the short-term and long-term submerged areas.

The elevation data were derived from a DGM 1 using the coordinates of samples determined in the field. The period of backwater for each sampling point was calculated by means of the elevation data using the difference between the water level data measured at the outflow and the elevation of the sampling point. The calculated data were corrected by field observations in case of equivocal results. For the Beltringharder Koog only two kinds of backwater could be separated: longer than 50 days and shorter than 50 days.

Geometric statistics were calculated for the biomass values using the program PAST 2.15. For spatial autocorrelation, Moran's I was determined and the critical distance at $p < 0.05$ calculated using 10 distance classes. Values in shorter distances can be considered to be autocorrelated. Furthermore, semivariogram analyses were performed to find nugget and sill variances and ranges.

Results

Species composition and spatial distribution

The results of the four areas of the Haseldorfer Marsch and the Beltringharder Koog are given in Table 1. In total, 11 earthworm species were recorded. The mean density ranged between 280 ind. m^{-2} and 490 ind. m^{-2}; the biomass ranged between 4.9 g af dw m^{-2} and 8.7 g af dw m^{-2}.

The four areas differ slightly according to their species composition and their soil parameters without showing any statistically significant differences. The species *Lumbricus festivus* was only recorded in the Belteringharder Koog, whereas *Octolasium cyaneum, Lumbricus castaneus*, *Aporectodea rosea*, and the subspecies *Eiseniella tetraedra heveynia* were only found at Haseldorfer Marsch. In area 2 of the Haseldorfer Marsch, the density of *Eiseniella tetraedra* was at least four times higher than in all other areas, and *Lumbricus castaneus* was absent in the Beltringharder Koog area. The mean biomass was also very similar in the four areas. It was highest in area 3 of the Haseldorfer Marsch and lowest in area 2 and 4, with a significant difference. In the Haseldorfer Marsch only area 2 and 3 differ.

Overall, the organic matter was highest in area 2 of the Haseldorfer Marsch, whereas soil pH showed significantly highest values in the Beltringharder Koog. Sand content was not significantly different between the four areas, although mean values ranged from 4.8 % to 14.8 %.

Tab. 1: Mean and standard deviation (SD) of abundance (Ind./m²), biomass (g/m²), and soil parameters in the four areas; different exponents indicate significant differences; ad. = adult, juv. = juvenile.

	Haseldorfer Marsch						Beltring-harder Koog	
Area	1		2		3		4	
Number of samples	60		21		22		25	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
PH	^{a} 7.1	0.4	^{a} 7.1	0.2	^{a} 6.9	0.4	^{b} 7.3	0.1
Org. matter (%)	^{a} 7.9	2.7	^{b}10.2	3.8	^{a} 8.3	2.2	^{a} 6.3	0.7
Sample number sand content	15		6		5		5	
Sand content (%)	^{a} 14.8	12.4	^{a} 4.8	4.8	^{a} 13.4	3.0	^{a} 5.9	2.2
Allolobophora chlorotica ad.	41.2	46.5	53.8	53.9	54.1	88.5	50.8	101.6
Allolobophora chlorotica juv.	34.5	47.8	42.4	64.9	24.1	33.3	23.6	52.5
Aporectodea sp. ad.	0.2	1.3	.	.	.	.	.	
Aporectodea sp. juv.	54.2	89.4	102.9	206.3	68.2	95.1	32.8	53.3
Aporectodea antipai ad.	0.2	1.3	0.5	2.2	.	.	.	.
Aporectodea caliginosa ad.	33.8	46.5	21.9	34.7	44.6	56.5	29.6	60.6
Aporectodea caliginosa juv	82.0	135.3	16.7	36.2	106.4	139.5	48.0	80.3
Aporectodea cupulifera ad.	.	.	.	.	.	.	0.4	2
Aporectodea rosea ad.	9.0	20.7	1.4	3.6	10.0	18.5	.	.
Aporectodea rosea juv	6.3	21.0	.	.	6.8	29.8	.	.
Eiseniella tetraedra ad.	8.0	18.5	33.8	66.7	3.2	6.5	6.8	13.8
Eiseniella tetraedra heveynia ad.	0.2	1.3	0.5	2.2	0.5	2.1	.	.
Eiseniella tetraedra heveynia juv.	.	.	0.5	2.2	.	.	.	.
Eiseniella tetraedra juv.	9.2	21.9	37.1	69.6	8.2	18.4	10.8	28.1
Lumbricus sp. ad.	.	.	.	.	0.5	2.1	0.4	2.0
Lumbricus castaneus ad.	5.2	14.1	.	.	1.8	5.9	.	.
Lumbricus castaneus juv.	5.3	13.8	.	.	2.3	8.7	.	.
Lumbricus festivus ad.	.	.	.	.	.	.	4.8	22.0
Lumbricus sp. juv.	28.7	38.5	26.7	23.5	37.7	40.9	27.2	36.1
Lumbricus rubellus ad.	19.2	23.0	14.8	24.4	47.3	56.8	24.0	41.6
Lumbricus rubellus juv.	23.0	23.0	15.7	22.3	38.6	48.4	29.2	49.9
Lumbricus terrestris ad.	0.3	1.8	.	.	0.5	2.1	.	.
Lumbricus terrestris juv.	0.2	1.3	.	.	.	.	.	.
Octolasium cyaneum ad.	3.8	8.8	9.5	26.7	10.0	16.0	.	.
Octolasium cyaneum juv.	3.0	8.7	.	.	7.3	33.1	.	.
Biomass	^{a} 5.5	3.8	^{ab}5.0	3.2	^{b} 8.6	6.7	^{a} 5.0	5.7

The spatial distribution of the earthworm biomass showed a large heterogeneity particularly in area 1 of the Haseldorfer Marsch. As Table 2 indicates, the spatial autocorrelation was different between the areas. In area 1 and 4 biomass values were autocorrelated at 85 m and 119 m indicating that samples are influenced by each other if they are closer than those distances. The semi-variogram analyses of the two areas yielded ranges from 90 m to 125 m, which is slightly higher than the critical distances determined by the Moran's I. Nevertheless, only directly adjacent biomass values can be considered to be dependent on spatial factors. For areas 2 and 3 neither Moran's I nor the semi-variogram analysis yielded significant results, which means that the biomass values are not spatially autocorrelated.

Tab. 2: Results of the spatial autocorrelation (Moran's I) and of the semivariogram analysis using the Gaussian model

	Area 1	Area 2	Area 3	Area 4
Moran's I critical distance (m)	85	-	-	119
Pairs	1039	208	209	201
Nugget variance	2.0	-	-	2.0
Sill variance	15	-	-	35
Range (m)	90	-	-	125

Relation between earthworm density and biomass and environmental parameters
In the Haseldorfer Marsch, the abundance of earthworms and their biomass showed significant relations to all soil parameters. The correlation coefficients are lower when using the elevation data than when using the soil pH or the sand contents. On average, the abundance and biomass of earthworms decreased with an increase in organic matter content and backwater time, and increased with an increase in soil pH, sand content, and elevation. However, the correlations between elevation and soil parameters showed that the elevation was also closely correlated to all soil parameters. Therefore, the elevation seems to be primarily responsible for the development of soil parameters and the earthworm population. In average, the biomass of earthworms on submerged sites was 2 g m^{-2} lower than on sites without backwater situation (Fig. 2). This difference was even more distinct at area 1. Here, the difference was more than 4 g m^{-2}.

Tab. 3: Spearman Rank-correlation coefficients of the Haseldorfer Marsch and the Beltringharder Koog (Pearson), underlined values are significant at $p < 0.05$

	pH	Org. matter	Sand content	elevation	Backwater
	Haseldorfer Marsch (n=103)				
Abundance	<u>0.39</u>	<u>-0.27</u>	<u>0.44</u>	<u>0.32</u>	<u>-0.30</u>
Biomass	<u>0.31</u>	<u>-0.20</u>	<u>0.41</u>	<u>0.26</u>	<u>-0.22</u>
Elevation	<u>0.63</u>	<u>-0.62</u>	<u>0.70</u>		<u>-0.81</u>
	Beltringharder Koog (n=25)				
Abundance	<u>0.44</u>	-0.36	0.62	<u>0.55</u>	<u>-0.46</u>
Biomass	<u>0.47</u>	-0.31	0.52	<u>0.45</u>	<u>-0.40</u>
Elevation	0.33	-0.12	0.66		<u>-0.66</u>

At the Beltringharder Koog, elevation and backwater period were also responsible for the development of the abundance and biomass of earthworms. The abundance and biomass decreased with increasing backwater time, but increased with increasing elevation and soil pH. However, no correlations were found to sand content and organic matter. Biomasses on sites of the Beltringharder Koog that were submersed more than 50 days exhibited even less than 6 g m^{-2} biomass than sites without submergence.

Discussion

According to investigation of polder systems of the Netherlands, dispersal rates of earthworms ranged between 10 m and 13 m per year (STEIN et al. 1992). Large areas in which earthworms have been extinct after long-term floods can, therefore, hardly be recolonised in a few months. Long-term backwater situations with oxygen deficits will consequently exhibit high losses of earthworms within several years. The negative effects of floods on the earthworm communities in grassland were also supported by IVASK et al. (2007). They referred the lower abundance and species richness to the anaerobic conditions during the flooding period. AUDSEN et al. (2001) found different recolonisation times in grasslands and referred this to the mosaic of sites with optimal and suboptimal situations. Sites that are close to optimal sites can be recolonised faster than more distant sites. AUDSEN et al. (2001) also stated that the recolonisation of sites submerged during the winter time is slower than recolonisation of emerged sites. Overall, earthworms prefer moist sites but pH, organic matter contents, and particle size of soils are more important for several species (IRMLER 1999, DIDDEN 2001). ZALLER & ARNONE (1999) even found that increased soil moisture by additional rain had no effect on earthworm density. Soil type and organic matter contents also affect the response of earthworms to floods (PLUM & FILSER 2005). In peat soils, earthworms became extinct after summer floods, whereas under summer droughts, earthworms are absent in gley soils. PLUM & FILSER (2005) supposed that water holding capacity and organic matter are important factors affecting the response of earthworms to extreme hydrological regimes.

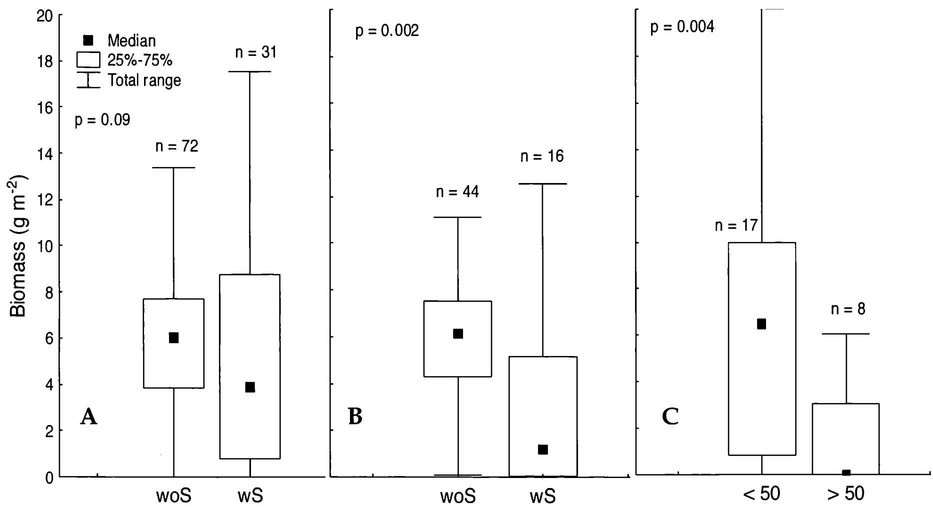

Fig. 2: Biomass of earthworms on submerged sites (wS), sites without submergence (woS), and sites with less than 50 days submergence (< 50) or more than 50 days submergence (> 50) for all sites of Haseldorfer Marsch (A), sites of area 1 of Haseldorrfer Marsch (B), and sites of Beltringharder Koog (C).

According to our investigations, earthworm biomass and abundance respond to different soil and flood parameters. Autocorrelation between adjacent sample sites could not explain the spatial pattern of abundance or biomass at the selected sampling distances of 50 m and 100 m. This corresponds to results found by CANNAVACCIOLO et al. (1998). In their geostatistical studies of different species, ranges varied between 18 m and 29 m, which is much smaller than the distances used in our investigation. Sand content, soil pH, and organic matter content were the main soil factors affecting the density and biomass of earthworms in the four areas. However, these three soil parameters may be controlled by the elevation, as can be seen by the high correlation coefficients between these factors. Sand content was certainly influenced by floods of the river Elbe or tidal gates before the embankment of the two areas. Heavy sand particles were deposited close to the stream channel, whereas finer particles were deposited at a further distance. Therefore, more clay sediments are found on higher elevated sites than on lower elevated sites today. As sand content of the soil affects earthworm densities and biomasses negatively, this effect can be referred to former processes of sedimentation by the river Elbe at Haseldorfer Marsch or tidal gates at Beltringharder Koog. In contrast to the sand content, soil pH and organic matter content may be additionally influenced by the actual water regime, because they depend on biotic processes. A longer backwater period may reduce the decomposition of litter and produce higher organic matter contents in the soil. Thus, the actual earthworm densities and biomasses reflect former and current processes. The effect of elevation on densities and biomasses of earthworms must be referred to former sedimentation processes and the current water regime, producing backwater situations with anaerobic conditions.

The density of earthworms between 280 ind. m^{-2} and 490 ind. m^{-2} is within the range of other German and European grasslands. IRMLER (1999) found average densities of 113 ± 138 ind. m^{-2} on wet grassland in Schleswig-Holstein. In Sachsen-Anhalt, 111 – 364 ind. m^{-2} were found on fallow grassland, but distinctly lower densities on grazed areas (HELLING & KÄMMERER 1998). Grassland on gley soils exhibited higher densities, with 186 ± 240 ind. m^{-2}, than on peat sites, with 38 ± 27 ind. m^{-2} (PLUM & FILSER 2005). Moreover, density and biomass seem to increase during succession of grassland (MAKULEC 1997). Overall, the variation of earthworm density on grassland seems to be high, and many factors besides the soil conditions and flooding regimes are involved, e.g., age of fallow and grazing regime. It seems that the actual water regime with partial backwater situations at both areas has no severe effect on the earthworm density and biomass.

The original motivation for the present study was the reduction of pewit at Haseldorfer Marsch because there has been a reduction of earthworm food resources induced by anaerobic conditions under long backwater periods. The results of the study have shown that the water regime at Haseldorfer Marsch is not responsible for a reduction in the earthworm density. The densities are relatively high in comparison to densities on other European grassland sites. Therefore, the earthworm densities cannot be responsible for the reduced pewit population at Haseldorfer Marsch.

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