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Response of microannelids to tillage at soil-monitoring sites in Schleswig-Holstein, Germany

Anneke Beylich[1]*, Ulfert Graefe[1] and Dirk-Christian Elsner[2]

[1] IFAB Institut für Angewandte Bodenbiologie GmbH, Tornberg 24a, 22337 Hamburg, Germany
[2] State Agency for Agriculture, Environment and Rural Areas Schleswig-Holstein, Department 6: Geology and Soil, Hamburger Chaussee 25, 24220 Flintbek, Germany
* Corresponding author, e-mail: anneke.beylich@ifab-hamburg.de

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Abstract

Soil decomposer communities of farmland are strongly influenced by a diversity of management practices. Among these, tillage is one principal disturbance factor for soil fauna. Its effects depend on the frequency, depth and type of tillage practices, but also on soil properties like soil texture. A major scope of biological soil monitoring is to detect long-term changes caused by a change in environmental and anthropogenic factors, including management. Therefore, on soil monitoring sites in addition to the measurement of soil chemical and biological parameters, detailed data on management practices are collected. We analysed results from the assessment of microannelids on soil-monitoring sites in Schleswig-Holstein (Germany) in relation to tillage practices. The focus was on the effects of inverting tillage (ploughing) versus non-inverting tillage in the year of sampling and on the impact of the time span between tillage event and sampling of total microannelid abundance, species number and dominance of r-strategists (*Enchytraeus*-species mainly). The aim was to differentiate short-term effects of tillage from possible long-term effects on which soil-monitoring sites are targeted. Sites were grouped in sandy and loamy sites as varying effects were expected according to soil texture. Grassland sites served as comparison without tillage. They yielded a significantly lower dominance of r-strategists than tilled arable field sites. Concerning the time-span between sampling and tillage, at sandy field sites, the dominance of r-strategists was significantly higher when the soil had been ploughed a few weeks before sampling. Dominance of r-strategists and total abundance of microannelids tended to decrease with increasing time lag since the last ploughing, but this relation was weak. While in sandy soils ploughing seems to be of relative importance for total microannelid abundance and r-strategist dominance, in loamy soils the total number of tillage events seems to be more decisive. No short-term effects of tillage practices were detected for species number. It was therefore concluded that species number and species composition related parameters are suitable to detect long-term changes of the microannelid population at soil-monitoring sites.

Keywords Enchytraeids | r-strategists | ploughing | soil monitoring | texture

1. Introduction

Although it is generally accepted that tillage affects soil fauna, the effects of tillage practices are not so easy to predict for a given situation, as the nature of tillage impacts seems related to a variety of factors like tillage methods, soil texture, fertilization, season and climate. With regard to the advancement of sustainable agriculture, a broad knowledge on the effect of different tillage practices on soil fauna would be desirable, as soil organisms contribute considerably to soil fertility. While earthworms have been investigated comparatively often with respect to management practices, mesofauna groups, like microannelids (i.e. enchytraeids and some other species), are covered less frequently. Microannelids occur regularly in arable field soils in similar numbers as other mesofauna groups. Their contribution to decomposition processes and microstructure formation

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has been documented by a number of studies and should not be underestimated (Didden 1990, 1991, Van Vliet et al. 1993, 1995, Topoliantz et al. 2000).

The generally lower densities and species numbers of microannelids in field soils compared to grassland are often attributed at least partly to tillage impacts. Microannelids have been shown to exhibit lower abundance in ploughed soils in comparison to field soils with non-inverting tillage (Langmaack et al. 1996, Röhrig et al. 1998). However, there are also studies indicating no positive effects of reduced tillage or no-tillage practices on microannelids abundance or biomass (Parmelee et al. 1990, Severon et al. 2012, van Capelle et al. 2012). Distinct differences between ploughing versus non-inverting tillage have been reported concerning the vertical distribution of microannelids. Ploughing distributes harvest residues over a depth of about 20–30 cm. Consequently, microannelids (and other soil fauna) spread more or less evenly over this depth or even concentrate at lower layers (Zimmermann 1987, Röhrig et al. 1998, Severon et al. 2012). In comparison, in no-tillage or shallow tillage systems, decreasing densities from the soil surface downwards can be found, rather similar to the situation encountered in grassland. Tillage practices have an immediate effect on soil fauna, as animals are damaged, micro-habitats are destroyed, soil moisture is changed etc. On the other hand, long-term effects of certain tillage strategies are probable. Anyhow, field studies concerning tillage effects on microannelids have sometimes applied rather short-term approaches (< 18 months) (Langmaack et al. 1996, Röhrig et al. 1998). The time span, for which the tillage system investigated was implemented before the start of the study, varies considerably (van Vliet et al. 1995, Langmaack et al. 1996). Further, many studies on this topic fail to assess the populations at the species level (van Capelle et al. 2012). The examination at species level is advantageous as it enables to integrate our knowledge on ecological behaviour and strategy types of species into data interpretation. Second, species composition seems less prone to short-term fluctuations than e.g. total abundance (Beylich & Graefe 2014). According to several studies soil texture determines the sensitivity of the soil biocoenosis against management practices (Graefe 1999). Especially in sandy soils the effects of tillage can be more pronounced due to its susceptibility to desiccation and the low aggregate stability. Therefore, this aspect was included in the present study.

Soil-monitoring sites in Germany provide long-term observations of chemical, physical and biological soil properties. The aims are to detect soil threats and to establish reference data in order to support favourable soil management (Barth et al. 2000). In the federal state of Schleswig-Holstein there are at present 37 soil monitoring sites, representing common land-use types, soil types and soil substrates. Microannelids, as well as earthworms, have been investigated at these sites for more than 20 years (Beylich & Graefe 2014). Animals have been identified to species level, which allows the application of trait based approaches. As the aim of soil monitoring sites is the detection of long-term changes (time scale: years to decades), it should be possible to separate these from short-term changes (time scale: weeks to months). The latter are presumably linked to fast reacting parameters like the total abundance and abundance of r-strategist species, whereas long-term effects are expected to be related rather to the species number, species composition and parameters derived thereof, e.g. indicator values (Graefe & Schmelz 1999).

For the present study, data of all agricultural soil-monitoring sites in Schleswig-Holstein were utilized. The main aim was to find out whether short-term effects of tillage can be recognized and thus be distinguished from possibly occurring long-term changes of the microannelid population, either caused by changed management practices or other environmental factors. To achieve this, we assessed microannelid total abundance and dominance of r-strategist species, assuming these parameters to change quickly with time, as has been shown in studies on population dynamics (Nakamura et al. 2003, van Vliet 1995). Further, species number was assessed, representing a parameter, which we assume to react comparatively slowly. Grassland sites served as comparison without tillage. The following questions were addressed:

How does the range of dominance of r-strategists in arable soil-monitoring sites differ in comparison to grassland soil-monitoring sites in Schleswig-Holstein?

Are there effects of ploughing and non-inverting tillage concerning r-strategists dominance, total abundance of microannelids and species number?

Do possible effects of tillage differ between sandy sites (≤ 8 % clay content) and loamy sites (> 8 % clay content)?

Is there an effect of the time span between sampling and tillage?

It is obvious that the arable sites do not only differ concerning tillage and soil texture. As our studies showed that at single-site level effects of tillage can be quite distinct (Beylich & Graefe 2014), the point was to find out, if general trends can be detected *despite* the variety of site conditions.

2. Materials and methods

The data analysed in this work originate from investigations of soil monitoring sites ('Boden-Dauerbeobachtungsflächen', BDF) situated in Germany in the federal state of Schleswig-Holstein. In Schleswig-Holstein we find an oceanic climate with a mean annual temperature of 8.3 °C and a mean annual precipitation of 788 mm (DWD 2010). As the purpose of soil-monitoring sites is the detection of soil changes under the terms of customary land use and management practices, tillage and other practices were not controlled with respect to the aims of this study. Thus, there are no specified 'treatments' as in an experimental study. Instead, the data were grouped according to the information available on soil properties and tillage and these groups were checked for differences.

The data presented stem from 16 arable field sites and 13 grassland sites (appendix 1). For analyses the sites were grouped according to soil texture, where 'sand' means ≤ 8% clay content, 'loam' means > 8% clay content and 'peat' stands for more or less drained fen sites with peat as parent material (grassland only). Cultivation of the field sites comprised conventional tillage in most cases, including regular ploughing (not necessarily every year). Two field sites were managed according to organic farming regulations with crop rotation including catch crops and periods of reduced tillage frequency. To assess the influence of tillage on microannelids, the data from field sites were grouped further according to the time span between sampling and last tillage event in the year of microannelid sampling. Five categories were distinguished as presented in Tab. 1. Here, not the sites were grouped, but sampling occasions, as tillage practices at a site might vary from one sampling to another.

For checking the tillage impact over several years, we calculated the mean number of all tillage events per year (including ploughing, shallow tillage etc.) and separately the mean number of ploughing events per year for a time-span of 5–7 years before each sampling, including the year of sampling. The interval varies (5, 6 or 7 years) due to sporadically missing tillage data and irregular intervals between sampling in some cases.

Microannelids in this work comprise mainly enchytraeids and a few species from other families, like *Rhyacodrilus falciformis* Bretscher, 1901 and *Hrabeiella periglandulata* Pizl & Chalupský, 1984. The parameters studied were abundance of microannelids, vertical distribution of microannelids and species composition. Ten samples per sampling date were taken at each monitoring site. Sampling was generally repeated every 5–7 years, so that most sites have undergone three to four samplings since the start of the investigation programme in the early 1990s. If site numbers are given, the last number of the site code refers to the sampling campaign, e.g. BDF14-3 means third sampling on BDF14.

Soil samples for microannelids were taken according to DIN ISO (2006) with a split soil corer [diameter 3.8 cm (cropland) or 5 cm (grassland)]. With few exceptions, samples were taken in autumn (September – December). Sampling depth was 24 cm at cropland sites and 10 cm at grassland sites. The different sampling depths take into account that the vertical activity reaches farther down in cropland sites due to tillage. Samples were divided vertically into 4 sub-samples of equal height. Soil samples were extracted over 48 h by a wet-funnel technique without heating (following Graefe 1984, as cited in Dunger & Fiedler 1989, p. 301; DIN ISO 2006). The extracted animals were counted and identified alive, following the keys of Nielsen & Christensen (1959), Schmelz (2003) and Schmelz & Collado (2010).

The list of the species found at the arable field sites is shown in Appendix 2. For the assessment of the dominance of r-strategists, species of the genus *Enchytraeus* were pooled, as they mostly react quickly on environmental and management changes due to a short generation time and a high reproduction rate. Some *Enchytraeus*-species have even the ability to reproduce quickly by fragmentation.

Table 1. Grouping of sampling events according to time span since last tillage event. Figures 5–7 refer to this grouping.

	tillage category	**explanation**
sand **≤ 8% clay content**	ploughing 2–12 weeks before sampling	often, but not always: sampling in autumn, 2–12 weeks after sowing of winter wheat or winter rapeseed; the ploughing is succeeded by some sort of shallow tillage
	ploughing > 5 months before sampling	often, but not always: sampling in autumn, after corn harvest
loam **> 8% clay content**	ploughing 2–12 weeks before sampling	see above
	non-inverting deep tillage (grubber)	non-inverting tillage to a depth of 15–20 cm as opposed to ploughing, mostly 4–7 weeks before sampling, often succeeded by some sort of shallow tillage
	no deep tillage within the year of sampling	either only shallow tillage to a depth of 10 cm or no tillage at all within the year of sampling

Not included in this group was the moderately acid-tolerant species *Enchytraeus norvegicus* Abrahamsen, 1969, which belongs to a different strategy type. Further, the species *Buchholzia appendiculata* (Buchholz, 1862) was included in the r-strategist group due to its ability for rapid reproduction by fragmentation under favourable conditions.

Statistical analyses were performed with SYSTAT 13. Data were checked for normality with Shapiro-Wilk Test. Differences in r-strategist dominance at grassland and field sites were checked for significance with Mann-Whitney Test ($p < 0.05$). Comparison of different tillage groups was performed using Kruskal-Wallis Test and Mann-Whitney Test. Least squares linear regression was carried out for the number of tillage events in the years prior to sampling and microannelid parameters, using ANOVA for assessing the fit of the model.

3. Results

At grassland sites on sandy soils or peat the average dominance of r-strategist species was below 10 % (Fig. 1). At loamy grassland sites the average dominance was significantly higher than on peat or sandy substrate (23 %; Fig. 2) ($p < 0.01$). There was no site with permanently above-average dominance of r-strategists. A few sites tended to show below-average values (BDF13, BDF35). At arable field sites the dominance of r-strategists reached an average of 28.3 % (sandy soils; Fig. 3) and 39.2 % (loamy soils; Fig. 4) respectively (difference not statistically significant). Site BDF04 was excluded from further analyses, as acidification, liming and manure fertilisation caused strong fluctuations in total abundance, r-strategist dominance and species composition. At field sites, the percentage of r-strategist species was significantly higher than at grassland sites if the respective sandy sites and loamy sites of both land-use types were compared ($p < 0.01$).

In sandy soils, the dominance of the r-strategist species was significantly higher when the last ploughing occurred only 2–12 weeks prior to sampling (Fig. 5). The mean values for total abundance and species number were higher as well, but this difference was not statistically significant (Figs 6 and 7). At single sites, the effect of ploughing was quite obvious: For example the first two samplings at BDF19 (SH19-1 and SH 19-2 in Fig. 3), being conducted more than six month after ploughing, produced r-strategist dominances below the average, while the third sampling, eight weeks after ploughing, resulted in a dominance twice the average (SH19-3). At loamy fields, the mean values for r-strategist dominance, total abundance and species number showed very similar values for sites ploughed 2–12 weeks before sampling and sites without deep tillage in the year of sampling.

The linear regression showed no significant dependence between the zoological parameters and the time span since the last ploughing (Figs 8 and 9). The coefficient of determination (R^2) was slightly higher in sandy soils than in loamy soils (Tabs 2 and 3). Although the relationships are not statistically significant, the slope of the linear regression suggests that possible relations between the time-span since last ploughing and the total abundance as well as the proportion of r-strategists would be rather negative than positive.

To assess long-term effects of tillage practices, the mean number of tillage events per year in the 5–7 years preceding the sampling was plotted against microannelid total abundance and r-strategist abundance (Figs 10 and 11). The goodness of fit for the linear regression was poor for the sandy sites. R^2 was highest for the mean

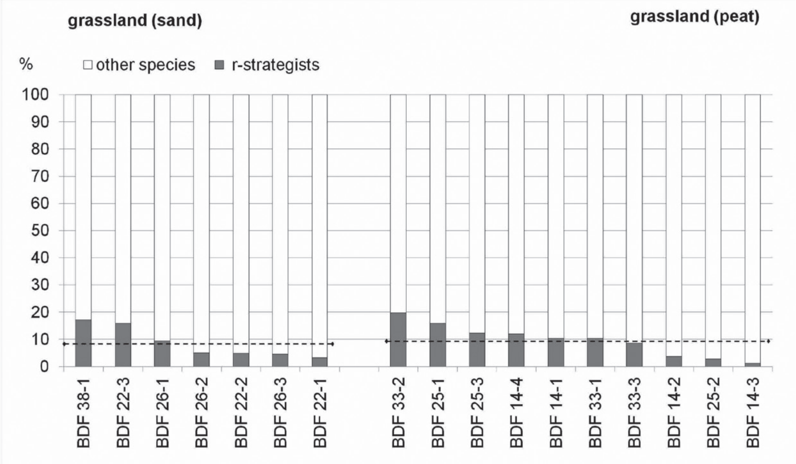

Figure 1. Dominance (%) of r-strategist species (grey) at grassland sites on sandy sites and on peat (fen). Dotted line: arithmetic mean (sand: 8.6 %, sd = 5.75; peat: 9.7 %, sd = 5.86).

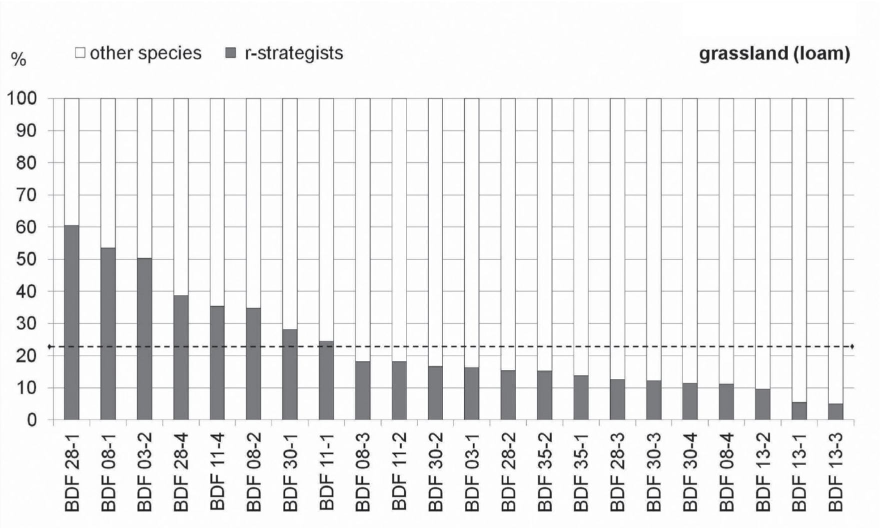

Figure 2. Dominance (%) of r-strategist species (grey) at grassland sites on loamy sites. Dotted line: arithmetic mean (23.0 %, sd = 15.87).

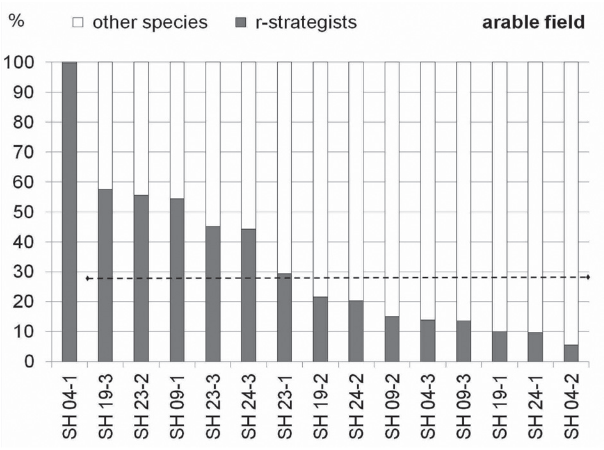

Figure 3. Dominance (%) of r-strategist species (grey) at arable field sites on sandy sites. Dotted line: arithmetic mean (28.3 %, sd = 19.08). Data of SH04-1 not included in the mean (and all further analyses) due to exceptional conditions.

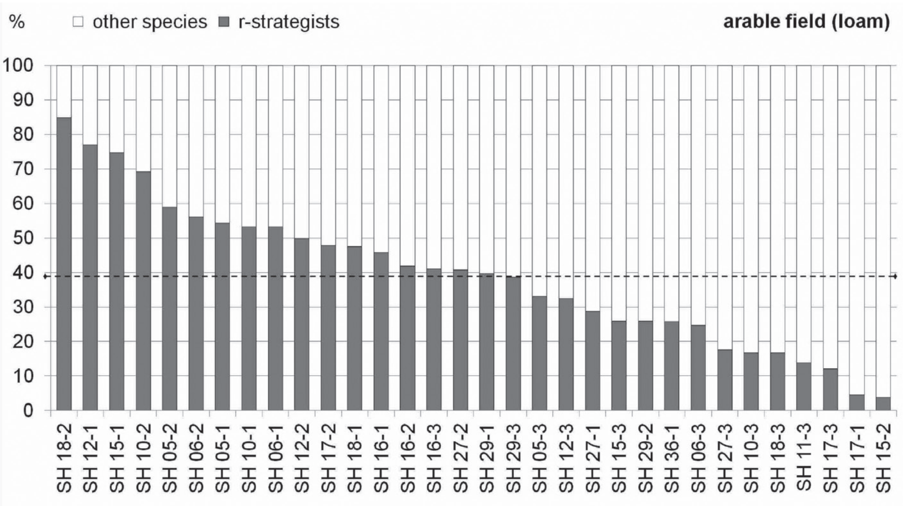

Figure 4. Dominance (%) of r-strategist species (grey) at arable field sites on loamy sites. Dotted line: arithmetic mean (39.2 %, sd = 20.87).

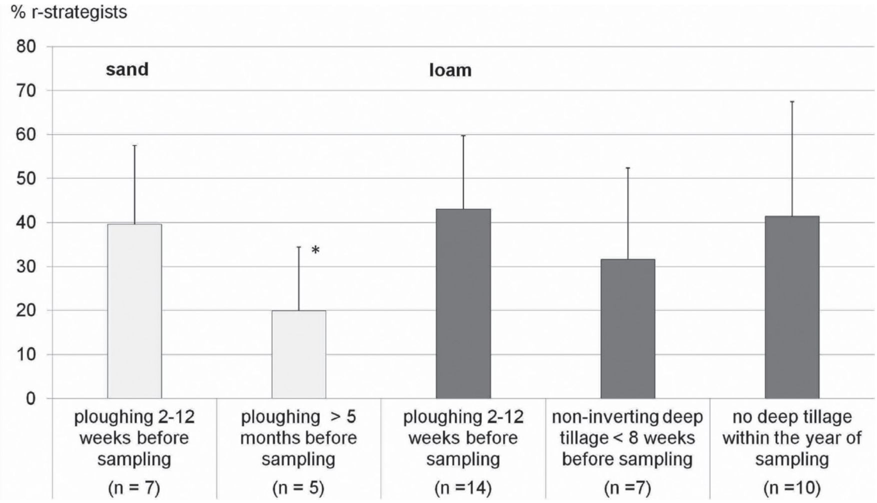

Figure 5. Dominance of r-strategist species in loamy and sandy field soils, grouped according to time span since last tillage event. *: sandy sites significantly different (Mann-Whitney Test, $p < 0.05$), loamy sites show no significant differences (Kruskal-Wallis Test, $p < 0.05$).

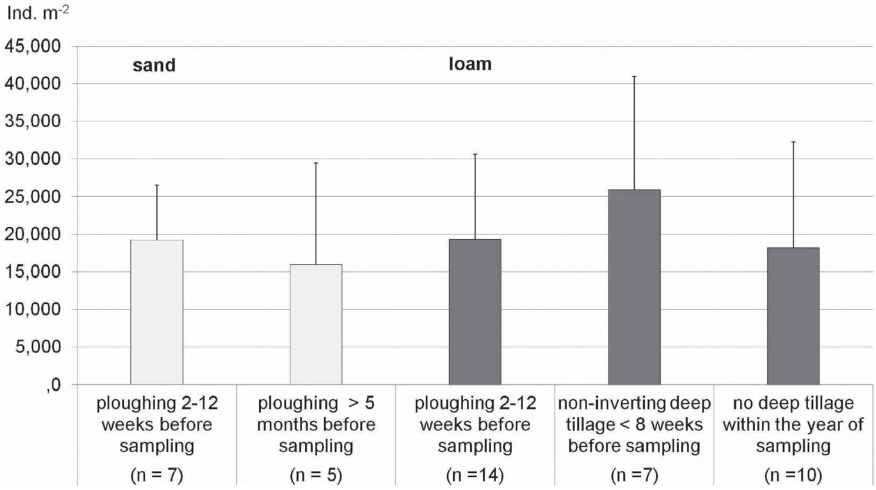

Figure 6. Total abundance of enchytraeids in loamy and sandy field soils, grouped according to time span since last tillage event. Sites show no significant differences (sandy sites: Mann-Whitney Test, loamy sites: Kruskal-Wallis Test).

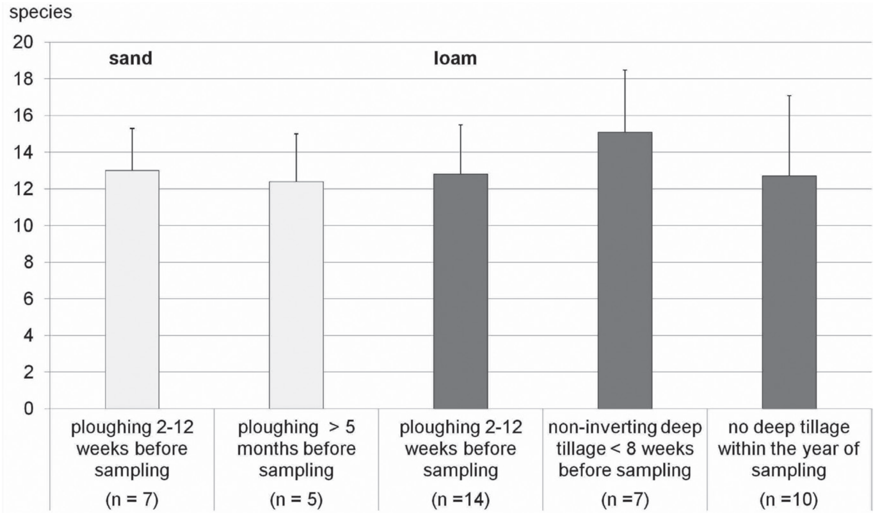

Figure 7. Total species number in loamy and sandy field soils, grouped according to time span since last tillage event. Sites show no significant differences (sandy sites: Mann-Whitney Test, loamy sites: Kruskal-Wallis Test).

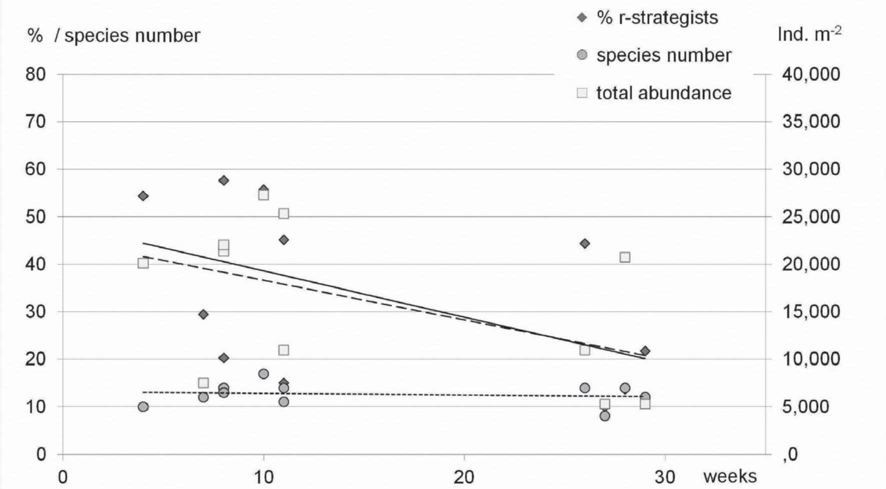

Figure 8. Linear regression for time span (weeks) since last ploughing event in the 12 months preceding sampling (independent variable) and dominance of r-strategist species (solid line), species number (dotted line) and total abundance (dashed line) respectively in **sandy soils.** R^2 and p see table 2.

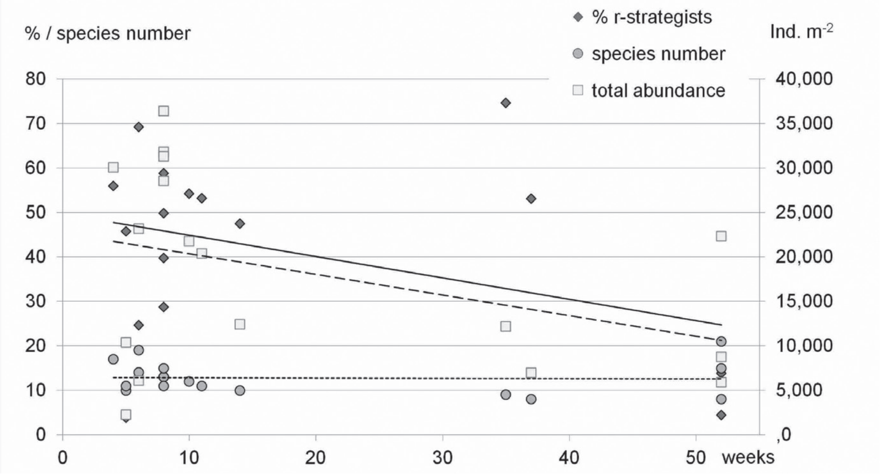

Figure 9. Linear regression for time span (weeks) since last ploughing event in the 12 months preceding sampling and dominance of r-strategist species (solid line), species number (dotted line) and total abundance (dashed line) respectively in **loamy soils.** R^2 and p see table 3.

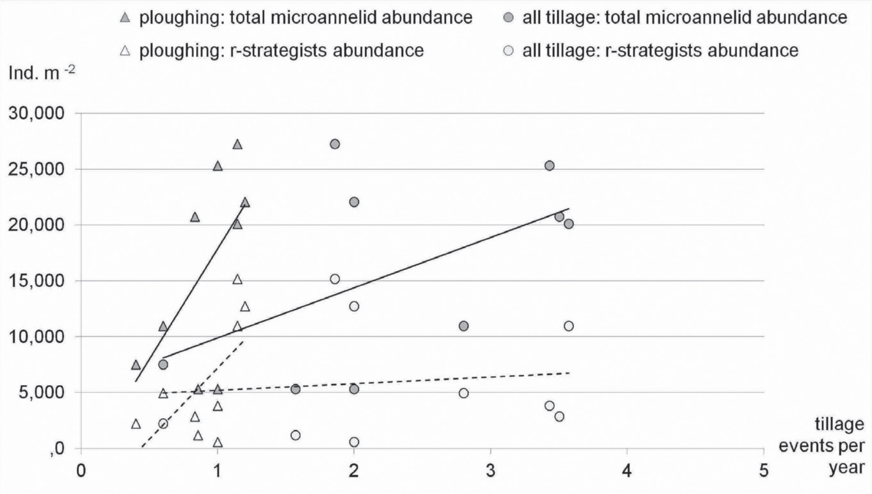

Figure 10. Linear regression for mean number of tillage events per year in the 5–7 years preceding the zoological sampling and the total abundance of enchytraeids (grey symbols) or the abundance of r-strategist species (white symbols) in **sandy soils**. Circles: all tillage events (including ploughing), triangles: ploughing only. R^2 and p see table 2.

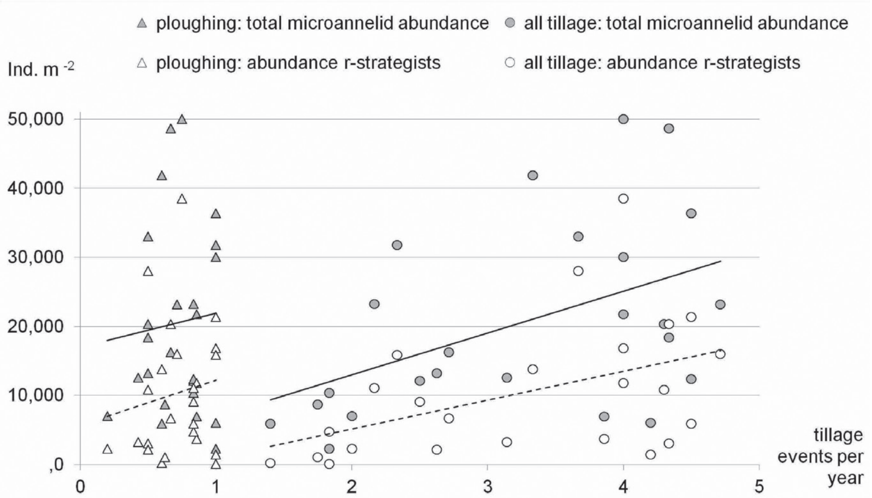

Figure 11. Linear regression for mean number of tillage events per year in the 5–7 years preceding the zoological sampling and the total abundance of enchytraeids (grey symbols) or the abundance of r-strategist species (white symbols) in **loamy soils**. Circles: all tillage events (including ploughing), triangles: ploughing only. R^2 and p see table 3.

Table 2. Linear regression results for **sandy sites**: R^2 and p-values of the ANOVA for assessing the fit of the model (least squares linear regression).

Independent variable	**Dependent variable**	**R^2**	**p**
time span since last ploughing event in the 12 months preceding sampling (→ Fig. 8)	total abundance	0.250	0.117
	r-strategist dominance (%)	0.272	0.100
	species number	0.016	0.707
mean number of all tillage events (→ Fig. 10)	total abundance	0.275	0.147
	r-strategist abundance (ind m^{-2})	0.013	0.773
	r-strategist dominance (%)	0.002	0.913
	species number	0.000	0.989
mean number of ploughing events (→ Fig. 10)	total abundance	0.358	0.089
	r-strategist abundance (ind m^{-2})	0.389	0.073
	r-strategist dominance (%)	0.107	0.389
	species number	0.030	0.658

Table 3. Linear regression results for **loamy sites**: R^2 and p-values of the ANOVA for assessing the fit of the model (least squares linear regression).

Independent variable	**Dependent variable**	**R^2**	**p**
time span since last ploughing event in the 12 months preceding sampling (→ Fig. 9)	total abundance	0.155	0.118
	r-strategist dominance (%)	0.161	0.110
	species number	0.001	0.916
mean number of all tillage events (→ Fig. 11)	total abundance	0.216	0.022 *
	r-strategist abundance (ind m^{-2})	0.216	0.022 *
	r-strategist dominance (%)	0.227	0.019 *
	species number	0.028	0.434
mean number of ploughing events (→ Fig. 11)	total abundance	0.014	0.577
	r-strategist abundance (ind m^{-2})	0.035	0.383
	r-strategist dominance (%)	0.045	0.319
	species number	0.005	0.749

number of ploughing events and abundance data (Tab. 2), while the species number showed extremely low R^2. Further, the coefficients of determination were generally higher considering ploughing only in comparison with the total number of tillage events. At the loamy sites, R^2 was highest for the mean number of tillage events and abundance data as well as the r-strategist dominance (Tab. 3). The linear regression showed to be a good fit for these parameters. In contrast to the sandy sites, a regression with the mean number of ploughing events alone produced considerably lower R^2 values than with all tillage events. Also at loamy sites, species number showed low R^2 values. It should be noted that the mean number of tillage events in the 5–7 years preceding sampling was higher at loamy sites, whereas the mean number of ploughing events per year was slightly lower (comp. Figs 10 and 11).

4. Discussion

While the total abundance of microannelids can reach the same range in field soils as in grassland soils (Beylich & Graefe 2009), our results suggest that the relative abundances of opportunistic r-strategist species are often higher in arable fields. For some grassland sites a continuously low dominance of r-strategists was probably favoured by specific site conditions, like absence of organic fertilisation (BDF35) or groundwater-affected topsoil causing particular species composition (BDF13). Two samplings at an organic farm site showed comparatively low dominances of r-strategists (BDF17), possibly due to reduced tillage frequency. Only few dominance data for species or genera at agricultural sites were published elsewhere. From Poland high percentages (34–71 %) of *Enchytraeus* species in agricultural fields (loamy sand) were reported by Nowak (2004). Kasprzak (1982) found lower values for *Enchytraeus buchholzi* Vejdovský, 1879 in several arable fields (7–43 %). Further, a dominance of *Enchytraeus buchholzi* of 57 % and 65 % was found in two fields in the Netherlands by Didden (1990). Compared with the present study, these values are partly above average.

The higher dominance of r-strategists shortly after ploughing may indicate that tillage is one reason for the predominance of these species in tilled soils compared to not tilled grassland soils. However, it must be kept in mind that other disturbances, like fertilization and pesticide application, might have an effect as well (Standen 1984, Römbke et al. 2009), thus causing a high variability of r-strategist dominance in field soils. Further, sandy grassland soils often show a lower pH than loamy grassland soils and field soils and therefore potentially host a higher number of acidity tolerant species, reducing the percentage of r-strategists which are less acidity tolerant (Graefe & Schmelz 1999).

It was hypothesized that the time-span between sampling and the preceding ploughing has an effect on microannelid parameters. At sandy soil-monitoring field sites, a stimulation of r-strategist species following ploughing was obvious when compared with sites sampled not until at least five months after ploughing. For loamy soils, the r-strategist dominance was also high shortly after ploughing, but no samplings with a longer time span between ploughing and sampling were available for comparison. A stimulating effect of inverting tillage on r-strategists could not be established for loamy soils, as sites with no deep tillage in the year of sampling showed an equally high percentage of r-strategists. As the different tillage categories in Figs 5–7 apply only to the year of sampling, while in experimental studies the different tillage systems mostly are in use several years prior to sampling, comparison with other publications should be handled with caution. Reviewing several studies on tillage-induced changes, Van Capelle et al. (2012) discovered a general tendency of positive effects of non-inverting conservational tillage on microannelid density, while no-tillage systems reduced abundance. Deviating findings by Nakamura et al. (2003) indicating positive effects of no-tillage systems on total abundance might be attributed to different climatic conditions and soil properties. Vavoulidou et al. (1999) found higher abundances in reduced tillage treatments compared to ploughing and no-tillage treatments for winter samplings in Greece, while no-tillage treatments had a positive effect only in dry summer months. This suggests that tillage affects microannelids via soil moisture: Tillage practices increase evaporation from the soil and thus, no-tillage systems might prove favourable under dry conditions. This was also assumed by Severon et al. (2012), investigating sandy sites in the federal state of Brandenburg (Germany) with a more continental climate than Schleswig-Holstein (mean annual precipitation lower by approx. 200 mm). Unexpectedly, these authors found higher microannelid densities in ploughed fields in comparison to fields with reduced tillage combined with considerably higher abundance fluctuations over time in the ploughed fields. They assume the ploughing-in of harvest residues to have favourable effects on soil moisture and availability of food resources for microannelids. It seems plausible to us that harvest residues are more easily decomposed when moved to a moist layer by ploughing than when remaining at the soil surface and drying out, especially in sandy soils. When studies also comprise repeated sampling after different time spans after ploughing, sampling falls partly in the unfavourable dry summer season, which sheds a light on interactions between tillage effects and weather conditions, but impedes an insight into the relation between microannelid population and time lag since the last ploughing (Langmaack et al. 1996, Vavoulidou et al. 1999, Severon et al. 2012). In our study, different periods of time between the sampling in autumn and the last ploughing were resulting from the different crops cultivated.

An important aspect influencing the effects of tillage is the different modes of mixing organic matter into the soil by different tillage practices. By ploughing the harvest residues are buried at 20–30 cm depth, the vertical structure of microhabitats and food availability being turned upside down. The vertical distribution of microannelids usually reacts to this situation by increasing densities in deeper layers (Zimmermann 1987, Röhrig et al. 1998, Graefe & Beylich, unpublished reports). This vertical restructuring might favour r-strategist species that can cope fastest with disturbance or temporarily unfavourable conditions and reproduce quickly with abundant food resources available. Our results indicate however that this is rather a short-term effect occurring within weeks after ploughing. In contrast to ploughing, no-tillage leaves harvest residues at the soil surface and vertical habitat structures undisturbed. Not-overturning tillage will mix organic matter into the soil predominantly in the upper 10 cm, keeping the litter moist and the soil well aerated, and at the same time avoiding detrimental effects of overturning the vertical structure of microhabitats altogether. Several studies report higher amounts of organic carbon and nitrogen and a higher microbial biomass for the upper centimetres of the soil in no-tillage and non-inverting tillage systems in comparison with ploughed sites (Hendrix et al.1986, Ulrich et al. 2010). Further, Kainiemi et al. (2015) found significantly higher water contents in the topsoil of shallow tillage treatments compared to ploughed treatments in a loamy soil. We would argue that non-inverting tillage might be favourable for a greater number of species of different strategy types, so that r-strategists have a lower competitive advantage here compared to ploughed soils. According to Hendrix et al. (1986), we have to consider also different decomposer food web types depending on tillage systems: Conventional tillage (ploughing) is supposed to enhance bacteria-dominated food webs, comprising organisms with short generation times and rapid dispersal, where microannelids play a major role, while no-tillage systems favour fungi-dominated food webs in the litter layer, where earthworms play a major role. We would agree with this concept insofar as r-strategist microannelid species are apparently favoured by ploughing, while earthworms are rather not. However, other factors, like soil texture and climate, play a role as well, and the interaction of tillage with environmental factors might cause food-web shifts from one year or season to another, favouring different groups of decomposers (e.g. van Vliet et al. 2000).

The stimulating short-term effect of ploughing on r-strategists can be expected to lessen with time. Consequently, in our study the dominance of r-strategist species decreased with increasing time-span between the last ploughing and sampling. The total abundance showed the same behaviour, however, the relation was weak. The coefficient of determination (R^2) was somewhat higher for sandy soils, which indicates that soil texture should be considered when assessing tillage impacts on soil fauna. It has been stated previously that soil texture determines the sensitivity of the soil biocoenosis against management practices due to the lower structural stability and buffering capacity of sandy soils (Graefe 1999). The impact of texture becomes most evident when we consider the effects defined as ‘long-term’ in the present study. The mean number of ploughing or total tillage events per year in the 5–7 years before sampling seemed to be of little relevance at sandy sites. In contrast, at loamy sites the frequency of all tillage events was at least partly determining microannelid total abundance and r-strategist abundance, while the frequency of ploughing on its own was apparently irrelevant. Unexpectedly the relation between tillage frequency and abundance was a positive one. This was obviously owed to the fact that not only the relative abundance of r-strategists was increased by tillage practices, but also the absolute numbers of these species, contributing to a higher total abundance of microannelids. One could argue here that the positive effect of tillage in loamy soils might be related to soil moisture. Loamy soils are less susceptible to desiccation than sandy soils. In case of stagnic soil properties, which are common in soils on loamy substrate in Schleswig-Holstein, periods with oxygen deficiency may occur. Tillage contributes to aeration and may thus have a positive effect on soil fauna. In this context it might be interesting to consider that Schleswig-Holstein is the only federal state in Germany with a documented increase of mean precipitation for the summer months (6.8 %, period under observation: 1881–2009), while all federal states show a more or less pronounced precipitation increase in the winter months (14–32 %) (DWD 2010).

A distinction should be drawn between the fact that texture affects the impact of tillage itself, and the fact that sandy and loamy sites are managed differently concerning tillage frequency, tillage depth and agricultural machinery employed. The latter aspect could not be organized in a more standardized way in the present study, as we are not dealing with experimental sites here but with sites under normal agricultural practice by various farmers. This touches also the comparability with other studies. In our study, in the term ‘no deep tillage’ a variety of tillage practices was covered. Further, for the regression analyses of all tillage practices, we took into account every tillage event documented in the database, no matter if two events were recorded for the same day, two successive days or with an interval of several weeks. The underlying assumption was that every tillage measure will damage a certain number of worms.

Our results showed no effect of tillage on species number. This could be expected for short-term effects, as appearance or extinction of species is a long-term process. As interfering short-term effects are missing, species number seems an appropriate parameter to assess possible long-term effects. In our study, no long-term effects concerning relations between tillage and species number were detected either. It has to be taken into account that no sites with long-term no-tillage or non-inverting tillage scenarios were investigated. All sites were tilled somehow and most sites were ploughed more or less regularly, although not always in the year of microannelid sampling. A general tendency towards profound changes in tillage practices was not discovered.

Typically, arable field sites show lower species numbers than grassland sites, as the latter offer microhabitats in the litter layer and thus host species with a preference for litter horizons that would not occur at field sites (Beylich & Graefe 2007, 2009). However, even ploughing a grassland site does not necessarily reduce species number immediately, as became apparent at one of the grassland monitoring sites (BDF11) that was converted into a field between two samplings. While abundance of microannelids (and earthworms) decreased significantly, species number remained more or less stable also five years after the conversion. Therefore our results add evidence to the conclusion that the species composition and parameters derived thereof are appropriate for detecting long-term soil changes, as these parameters underlie far less short-term fluctuations caused by tillage events than e.g. abundance and dominance.

As many apparent tendencies of tillage effects were not significant in this study, further investigations appear desirable. This is all the more the case, as our findings hint towards a dependence of effects on soil texture that was difficult to assess due to low case numbers for some combinations of tillage type and texture. Further, as evidence suggests that earthworms and microannelids respond quite differently to tillage practices (Hendrix et al. 1986, Severon et al. 2012, van Capelle et al. 2012), interactions between these two groups should also be considered.

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Appendix 1. List of soil-monitoring sites of the federal state of Schleswig-Holstein (Germany) included in the data analysis of the present study. German ecoregions: marsh - landscape formed by marine sediment deposition and land reclamation; geest - landscape formed by Saale glaciations; top moraine - landscape formed by Weichselian glaciations; pH: range of several samplings; texture according to IUSS Working Group WRB (2014); NSG: nature reserve

BDF No.	land-use	german ecoregion	texture topsoil	pH ($CaCl_2$) topsoil	sampling				notes
					1.	2.	3.	4.	
05	field	top morraine	sandy loam	6.6-6.9	1997	2003	2010	2014	
10	field	top morraine	sandy loam	6.5-6.9	1993	1999	2006		
12	field	top morraine	sandy loam	6.6-7.1	1998	2004	2011	2014	
15	field	top morraine	sandy loam	6.6-7.0	1996	2002	2011		
16	field	top morraine	sandy loam	6.7-6.8	1998	2004	2012	2014	
17	field	top morraine	sandy loam	6.0-6.4	1995	2001	2010		organic farming
18	field	top morraine	sandy loam	6.7-6.8	1997	2003	2011	2014	
27	field	top morraine	sandy loam	5.6-6.5	1997	2003	2010	2014	
36	field	top morraine	sandy loam	6.1	2004				organic farming
24	field	top morraine	sand – loamy sand	4.2-4.8	1992	1998	2005		
29	field	top morraine	loam	6.2-6.3	1998	2004	2011	2014	
04	field	geest	sand	4.2-4.7	1996	2003	2009		acid soil, solid manure sometimes
09	field	geest	sand	4.6-5.5	1996	2003	2009		
19	field	geest	sand – loamy sand	5.5-5.7	1996	2002	2009		
23	field	geest	loamy sand	5.8-5.9	1996	2002	2009		
06	field	marsh	loam	7.1-6.9	1996	2003	2010	2014	
08	grassland	top morraine	sandy loam	4.6-4.9	1993	1999	2006	2013	
35	grassland	top morraine	loamy sand – sandy loam	5.2	2005	2013			organic farming, no fertilizer
11	grassland / field	geest	sandy loam	5.0-5.1	1994	2000	2007	2013	field 2002-2009
22	grassland	geest	loamy sand	4.5-4.7	1994	2000	2007		
26	grassland	geest	sand - loamy sand	4.9-5.6	1992	1998	2005		
28	grassland	geest	loamy sand	5.0-5.1	1994	2000	2007	2013	
03	grassland	marsh	loamy sand	4.8-5.0	1994	2000	-	-	monitoring given up after 2000
30	grassland	marsh	silt clay loam	5.4-5.8	1994	2000	2007	2013	
38	grassland	marsh	loamy sand	4.7	2005				
13	grassland	marsh	clay loam	5.4-5.6	1995	2002	2008		groundwater-affected topsoil
14	grassland	geest	peat	4.7-5.1	1994	2000	2007	2013	groundwater-affected topsoil
25	grassland	marsh	peat	4.9-5.2	1995	2002	2008		groundwater-affected topsoil
33	grassland, NSG	top morraine	peat covered by sand layer	5.2	1993	1999	2006		groundwater-affected topsoil

Appendix 2. Species list for the investigated sites (arable fields). An x signifies that the species occurred at the respective site at least at one sampling. The list includes four hitherto undescribed species that occur regularly on some of the soil-monitoring sites in Schleswig-Holstein.

site number	**04**	**05**	**06**	**09**	**10**	**12**	**15**	**16**	**17**	**18**	**19**	**23**	**24**	**27**	**29**	**36**
MICROANNELIDS: ENCHYTRAEIDAE																
Achaeta																
aberrans Nielsen & Christensen, 1961	x			x									x			
abulba Graefe, 1989	x			x												
sp. nov. (affinoides)	x											x	x			
bibulba Graefe, 1989	x			x									x			
bifollicula Chalupský, 1992				x												
bohemica (Vejdovský 1879)														x		
diddeni Graefe, 2007				x								x				
pannonica Graefe, 1989											x	x	x			
unibulba Graefe, Dózsa-Farkas & Christensen, 2005													x			
Buchholzia																
appendiculata (Buchholz 1862)								x				x	x			
fallax Michaelsen, 1887		x	x		x	x								x		
Cernosvitoviella																
atrata (Bretscher 1903)					x											
Cognettia																
sphagnetorum (Vejdovský, 1878) s.l. 1)													x			
Enchytraeus																
buchholzi Vejdovský, 1879	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
bulbosus Nielsen & Christensen, 1963		x	x		x	x	x	x	x	x	x	x		x	x	
capitatus von Bülow, 1957		x	x						x	x				x		
christenseni Dózsa-Farkas, 1992 2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
coronatus Nielsen & Christensen, 1959	x															
crypticus Westheide & Graefe, 1992					x	x			x							
dichaetus Schmelz & Collado, 2010						x										
lacteus Nielsen & Christensen, 1961		x	x					x		x	x			x	x	x
norvegicus Abrahamsen, 1969	x			x									x			
Enchytronia																
annulata Nielsen & Christensen, 1959				x							x	x				
christenseni Dózsa-Farkas, 1970		x	x			x	x	x	x					x		
minor Möller, 1971				x	x						x	x	x			x
parva Nielsen & Christensen, 1959				x								x	x			
sp. nov. (omni)														x		
sp. nov. (plic)				x												
sp. nov. (pygm)				x								x				
sp. nov. (sept)	x			x												

site number	**04**	**05**	**06**	**09**	**10**	**12**	**15**	**16**	**17**	**18**	**19**	**23**	**24**	**27**	**29**	**36**
Fridericia																
bisetosa (Levinsen, 1884)	x								x				x			
bulboides Nielsen & Christensen, 1959	x	x	x	x	x	x		x	x	x	x	x	x	x	x	
christeri Rota & Healy, 1999	x	x	x		x	x	x	x	x	x	x	x		x	x	x
connata Bretscher, 1902											x	x				
cusanica Schmelz, 2003												x				
deformis Möller, 1971		x	x				x	x	x	x				x	x	x
galba (Hoffmeister, 1843)		x	x		x	x	x	x	x	x	x			x	x	x
glandifera Friend, 1913			x					x								
granosa Schmelz, 2003		x					x				x	x	x			x
isseli Rota, 1994		x	x		x	x	x	x	x	x				x	x	x
lenta Schmelz, 2003									x							
maculatiformis Dózsa-Farkas, 1972		x	x				x	x					x	x	x	x
minor Friend, 1913					x	x	x				x		x			
nix Rota, 1995			x													
paroniana Issel, 1904						x			x	x						
ratzeli (Eisen, 1872)												x				
singula Nielsen & Christensen, 1961					x									x		
sylvatica Healy, 1975		x		x			x					x			x	
tuberosa Rota, 1995			x				x									
ulrikae Rota & Healy, 1999		x	x					x	x	x				x		x
waldenstroemi Rota & Healy, 1999		x														
Henlea																
perpusilla Friend, 1911	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
ventriculosa (Udekem, 1854)	x	x			x	x			x		x	x	x	x		
Marionina																
achaeta Lasserre, 1964								x	x							
argentea (Michaelsen, 1889) s.l. [3]		x	x		x					x				x	x	x
communis Nielsen & Christensen, 1959							x		x			x	x			
MICROANNELIDS, TUBIFICIDAE																
Rhyacodrilus																
falciformis Bretscher, 1901			x					x	x					x	x	
MICROANNELIDS, POLYCHAETA																
Hrabeiella																
periglandulata Pizl & Chalupský, 1984				x												

[1] *Cognettia sphagnetorum* sensu latu, species complex not further differentiated here. The species has been recently split into four distinct species under the synonym genus *Chamaedrilus* Friend, 1913 (Martinsson et al. 2015). As this case will be submitted to the International Commission on Zoological Nomenclature with the intention to conserve the name *Cognettia sphagnetorum*, we still use this name here.

[2] with pale granula in the lymphocytes, as described in the original description of *Enchytraeus minutus* by Nielsen & Christensen (1961) (later renamed to *Enchytraeus christenseni* by Dozsa-Farkas, 1992).

[3] *Marionina argentea* sensu latu, species complex not further differentiated here (comp. Rota 2013).

Remark: Our investigations date back to the early 1990s. As fixed specimens are available only for some samplings, subsequent adjustment of species determination according to new taxonomic developments was often not possible (e.g. *C. sphagnetorum, M. argentea*).