Anecic, endogeic, epigeic or all three - acknowledging the compositional nature of earthworm ecological group data in biodiversity analysis

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Abstract

Agriculture influences soil biodiversity through management activities whilst benefiting from services provided by the soil ecosystem. In this context, earthworms are particularly important as ecological engineers. Management systems and different habitat types can influence the provision of ecosystem services by soil organisms. Common biodiversity analyses did not show large differences in earthworm diversity in this study. Impacts on earthworm populations can also be assessed by analysing changes in the relative proportions of their three ecological groups. New statistical methods for compositional analysis revealed habitat class as a major factor influencing earthworm functional group composition. Management system impact was not significant and varied within different habitats. In conclusion, the methods used are recommended for studies involving the analysis of compositional data such as assessing changes in relative proportions of several components.

Introduction

Biodiversity loss has become a prominent issue in agriculture, which is said to exert considerable pressure on biodiversity. Consequently, there is public and political pressure on agriculture to become more sustainable and minimize its impact on biodiversity. Simultaneously, production systems need to be developed that utilize the benefits from biodiversity and related ecosystem functions. In this context one challenging task is to understand, monitor and manage soil biodiversity and its functions like maintaining soil fertility, soil structure or water infiltration.

To clarify these complex relationships and thus develop optimized management strategies, knowledge about species distribution and composition is crucial. Additional information on the presence, absence or proportion of specific species traits, e.g. their affiliation to functional groups that are relevant for the supply of ecosystem services, need to be assessed. Hence, species samples are collected for which various diversity measures or multivariate distance measures (e.g. Shannon diversity index) can be calculated. This applies in particular to appealing organism groups like earthworms, which are known to be good direct biodiversity indicators providing useful information on soil biodiversity and fertility.

One aspect frequently analysed in this context is the relative proportion of the three different ecological groups of earthworms. However, this is done either in a qualitative way by interpreting graphics like stacked box plots or by using standard statistical methods. This latter approach is problematic because it does not take into account that these datasets have special characteristics. For example, proportional data of ecological groups always adds up to a constant such as 100 % and thus, at the very least, the last component is not independent. Aitchison (1986) noted the problems with this kind of data, which he called compositional data, and developed a new mathematical framework to analyse such datasets. These methods recently became available with standard statistical software. We therefore apply a compositional data analysis to earthworm data collected on farmland to gain a better understanding of the relationships between management system, habitats and the functional composition of soil biodiversity.

Material and methods

Data was collected for the EU FR7 project BIOBIO (www.biobio-indicator.org). The German case study region was located in southern Bavaria. Within this region eight organic (org) and eight non-organic-respectively conventional (con) managed mixed dairy farms were randomly selected. In total 127 plots, representing the different habitat types found on these farms, were sampled (Herzog et al. 2012).

Earthworms were assessed with a combination of an expellant solution and a time-restricted hand sorting procedure according to BIOBIO standards (Dennis et al. 2012). All individuals were counted and weighed.

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The adult specimens were identified to species level. For each species the trait information on its ecological group was stored.

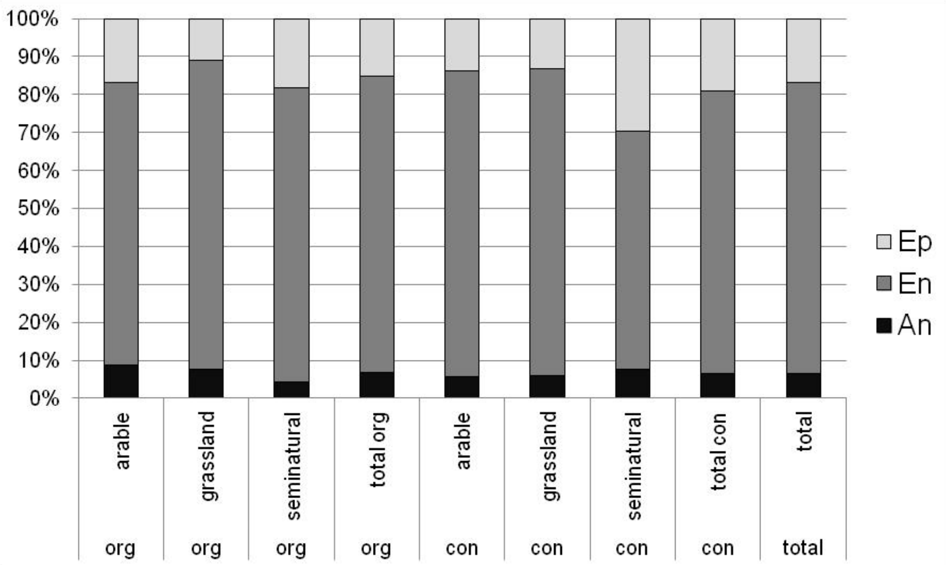

Figure 1. Classical stacked bar chart showing the different relative proportions in abundance of adult individuals within three ecological groups (Ep=epigeic; En=endogeic; An=anecic) for organic (org) and conventional (con) managed plots and three habitat classes (semi-natural; grassland; arable).

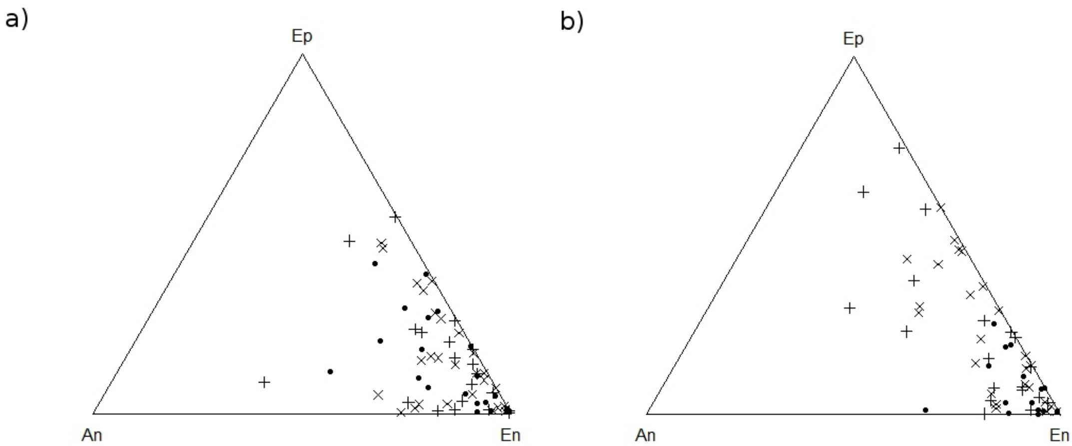

Figure 2. Ternary diagrams calculated in R. The corners of the diagrams represent a 100 % dominance in abundance of adult earthworms of the respective ecological group (Ep=epigeic; En=endogeic; An=anecic). Points are placed in the diagram according to the specific composition of the three ecological groups for each plot. a) shows the organic plots and b) the non-organic plots. Solid dots mark semi-natural plots, plus marks grassland plots and crosses mark arable plots.

For the analysis presented here only the data on abundance of adult specimens was used. Juveniles were excluded because these specimens cannot always be determined to species level, and thus the exact ecological group cannot be assigned. As for one plot no adult specimens could be found, it was treated as an outlier and therefore also excluded from the analysis.

For the statistical analysis in R 2.15.2 (R Development Core Team 2012) the package “compositions” (van den Boogaart et al. 2009) was used. Because numbers of earthworm individuals were recorded the function “ccomp” for count compositions was used to represent the data. To visualize the compositional data ternary diagrams were created. For detailed analysis on the relation between the count composition and the two factors management system and habitat class, a linear modelling approach as described by van den Boogaart et al. (2013) was applied.

Results

In total 9106 individuals were found and 11 species identified. 70 % of individuals and 42 % of biomass was comprised by juveniles. In organic plots eight species and in non-organic plots nine species were found. For both management systems an exponential Shannon index of 4.3 and an inverse Gini-Simpson index of 3.1 for organic and 2.7 for non-organic plots was calculated.

A qualitative assessment of both the stacked bar chart (Figure 1) and the ternary diagrams (Figure 2 & 3) suggested only small differences between the two management systems. In contrast, differences between habitat classes were perceptibly larger.

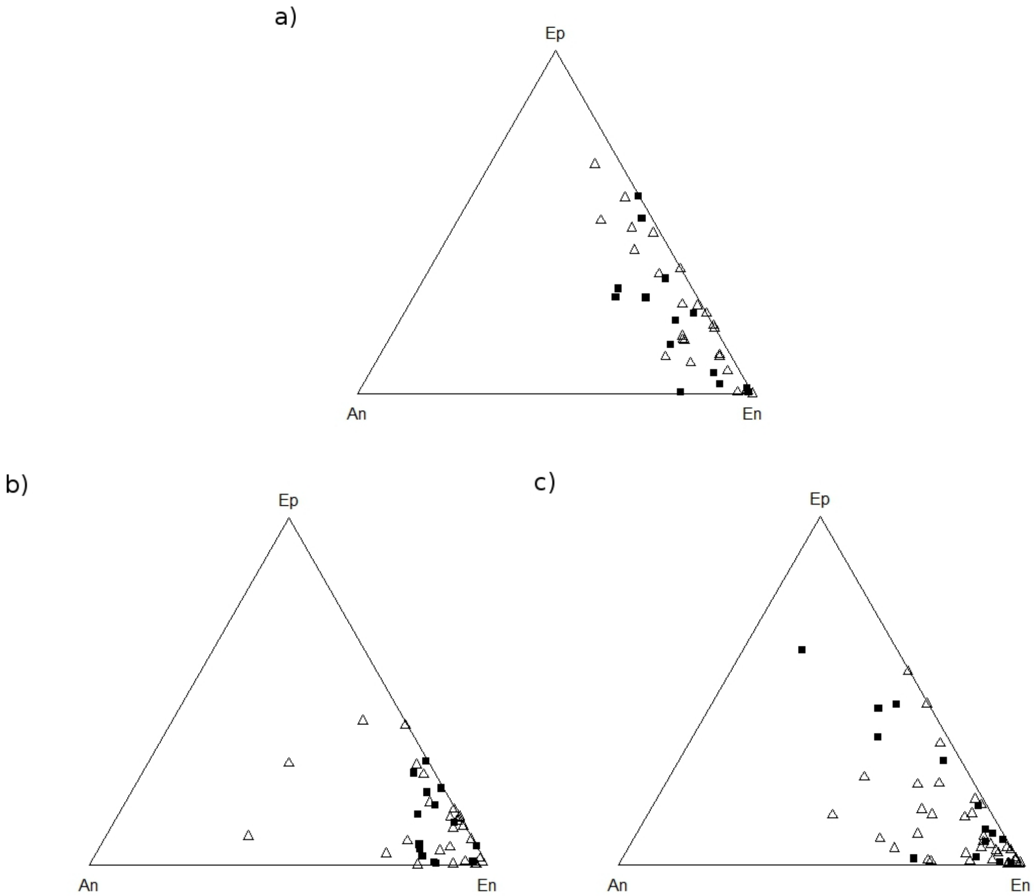

Figure 3. Ternary diagrams calculated in R. The corners of the diagrams represent a 100 % dominance in abundance of adult earthworms of the respective ecological group (Ep=epigeic; En=endogeic; An=anecic). Points are placed in the diagram according to the specific composition of the three ecological groups for each plot. a) shows semi-natural plots, b) the grassland plots and c) the arable plots. Solid squares mark organic plots and triangles mark non-organic plots.

To support visual interpretation six linear models with the earthworm ecological group composition as response variable and management system and habitat class as independent variables were tested. Only the intercept term and the habitat class produced highly significant results (Table 1). The impact of management system was not significant. Nevertheless, the full model revealed an interaction between management system and habitat class; however this interaction was not statistically significant. All models performed reasonably well. Taking into consideration the R^2 values of the models, the model considering habitat class only performed best.

Table 1: Results for analysis of variance of full linear model (R^2 = 0.338).

	Df	Pillai	approx F	num Df	den Df	Pr(>F)	Significance
Intercept term	1	0.745	114.868	3	118	< 0.001	***
Management system	1	0.012	0.493	3	118	0.688	n.s.
Habitat class	2	0.328	7.784	6	238	< 0.001	***
Interaction term (Management : Habitat)	2	0.089	1.847	6	238	0.091	.
Residuals	120						

n.s. not significant; **.** not statistically significant (p<0.1); * significant (p<0.05); ** very significant (p<0.01); *** highly significant (p<0.001)

Discussion

Common biodiversity analyses did not show large differences in earthworm diversity between organic and non-organic plots. With a total number of only 11 species, one additional species in non-organic plots may have been due to chance. However, higher values for the inverse Simpson index in organic plots gave evidence for higher evenness in the species' relative abundances. Crowder et al (2010) found a similar pattern in studies of natural enemies and concluded that the higher evenness in organic systems may foster the provision of beneficial ecosystem services.

A closer look at the impacts of management system and habitat class on the relative proportions of earthworm ecological groups revealed noteworthy relationships. Compared with the values of semi-natural habitat the results of the model suggested a positive influence of grassland on anecic earthworms but a negative influence on epigeic earthworms. Arable land had lower values for all three groups. For this dataset, although not significant, organic farming seemed to have a positive influence only on endogeic earthworms. For anecic earthworms a slightly negative and for epigeic worms even a perceivable negative impact was observed. The habitat classes seemed to be much more important for earthworms than the management system. However, the almost statistically significant interaction effect suggests that the effect of organic farming is dependent on the habitat class. Accordingly, results indicated that organically farmed arable land had a lower negative impact on endogeic earthworms and even a positive impact on anecic and epigeic earthworms. Managing grassland organically also promoted anecic and epigeic earthworms but seemed to hamper endogeic worms. These results may be partly explained by differences in tillage and fertilization practices, as well as different treatment of crop residues.

In terms of methods, this study proved that the new methods for the analysis of compositional data provide a good framework for investigating species data. In particular, for the analysis of earthworm ecological group data, the approach yielded better and more useful results than a mere graphical interpretation. In addition, pitfalls due to the compositional structure of the data were avoided.

Organic farming is dependent on utilizing beneficial ecosystem services related to biodiversity. An objective assessment of functional biodiversity components and scientifically sound methods to relate these components to site and management parameters is therefore of particular importance. In conclusion, the methods used are recommended for studies involving the analysis of compositional data such as assessing changes in functional group proportions or the relation of crop biomass in roots, shoots and fruits.

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