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First results in modelling distribution patterns of anecic earthworms on catchment scale: a Boosted Regression Tree model approach

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Abstract

Earthworms can serve as indicator species for various important soil processes. Therefore we can link distribution patterns of earthworms to the incidence of induced soil processes. Species distribution models can help us to predict earthworm distributions on different scales. Studies on larger scales are rare due to large efforts in data acquisition, especially if the focus is on process understanding. The current study focuses on anecic earthworms using a Boosted regression tree model approach for predicting the earthworm distribution in an agricultural area in Baden-Württemberg (Germany). We surveyed management, topography, soil parameters and presence-absence, abundance and fresh weight of anecic earthworms (i.e. *Lumbricus terrestris*) at 75 locations within the Weiherbach catchment. Our final model has acceptable performance (AUC=0.76 after validation). Topographic indices (wetness and Beer's index) as well as soil parameters such as moisture, texture and tillage are the most relevant environmental predictors.

Keywords: species distribution models, earthworms, soil hydrology, boosted regression trees (BRT)

Schlüsselworte: Verbreitungsmodelle, Regenwürmer, Bodenhydrologie, Boosted Regression Trees (BRT)

1 Introduction

Earthworms can serve as indicator species for various important soil processes as they have an essential effect on soil quality and productivity, e.g., enhance soil aeration, decrease soil compaction and increase the decomposition of organic material and the availability of nutrients. In the face of climate change with predicted increasing frequency of extreme rainfall and drought events, the impact of earthworms on soil hydrology is coming into focus. It is known that earthworms play a major role in transport processes of water and solutes. Earthworm burrows are preferential flow pathways and affect water infiltration, surface runoff and the soil water holding capacity (Ernst et al., 2009). Burrow characteristics depend on earthworm activity and ecological type and strongly influence these processes.

In this project we focus on anecic earthworms and their burrows. They can reach depths of 3.5 m and therefore accelerate the transport of water and solutes (nutrients and pollutants) into deeper soil layers. In arable lands this results in an increased leaching of agrochemicals in subsurface or ground water. Regular soil tillage, varying climatic conditions, soil characteristics and interactions with other earthworm types (endogeics, epigeics) determine the connectedness and effectivity of anecic earthworm burrows. In this context, we use species distribution models to describe spatiotemporal relationships between earthworm distribution patterns and their environmental controls. With these models we can predict the occurrence

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probability and potential distribution of earthworms at different scales and thus facilitate our understanding of spatial variability of soil hydrological processes.
Here, we discuss a first modelling approach for distribution patterns of anecic earthworms using Boosted Regression Trees in order to analyse the relevant environmental predictors, describing the distribution of anecic earthworms on catchment scale.

2 Materials and Methods

2.1 Study site and earthworm sampling

The study site is the Weiherbach-catchment (Kraichtal, Baden-Württemberg), a well studied area in south-western Germany. Many site characteristics like soil type, soil texture, topographic indices and land use are documented and mapped in former field studies. The Weiherbach valley is a Loess area with intensive agricultural land use. During the last 20 years, soil management has changed to conservational methods here. In this study, soil tillage is classified as reduced ploughing (every five years, RP) vs. no ploughing (since 20 years, NP). The application of fertilizers varies between mineral, liquid manure (slurry) and organic manure.
Earthworm sampling took place in the fall of 2009 on 75 agricultural sites differing in topography (slope, elevation, Topographic Wetness index (TWI), Beer's index and solar radiation), land use (cropland, meadow, fallow land) and soil management (ploughing, fertilizing). Additionally, soil parameters such as moisture, temperature, texture, penetration depth, pH-value and organic matter content were determined at each sampling location. Earthworm extraction was performed with a hot mustard solution on a randomly chosen 0.5 x 0.5 m² plot. Additionally, the top 15 cm of soil were hand-sorted after extraction. Subsequently, we determined presence/absence, abundance and fresh weight of all earthworms.

2.2 Statistical analysis

To find the relevant environmental predictors for earthworm distribution we performed a Boosted Regression Tree model approach according to Elith et al. (2008). Boosted regression trees (BRT) are an additive model approach combining simple regression trees with a boosting algorithm. Regression trees apply binary recursive partitioning. With the boosting algorithm, many individual simple regression trees are fitted in a forward stagewise fashion. BRT has been shown to be one of the most powerful methods in species distribution modelling (Elith et al. 2006).

3. Results and Discussion

Earthworm sampling took place at the end of October 2009 when abrupt colder temperatures followed a dry period, so soil conditions for earthworm activity and earthworm sampling were suboptimal. After all, we found a total earthworm number between 4 and 260 earthworms / m² with a total earthworm biomass varying from 0.4 to 180 g fresh weight/m². The abundance data per m² for the three ecological earthworm types varying from 0-92 for anecics, 0-168 for the endogeics and 0-112 for epigeic earthworms. Anecic earthworms were present on 48 of the 75 observed locations, whereas endogeics were almost omnipresent (only absent on 4 plots reflecting recent soil tillage). Epigeics were mainly absent or in low abundance (present on 25 plots). Here, we focus on the distribution of anecic earthworms.

Our BRT shows that landscape indices like TWI and Beer's index, as well as soil parameters like clay and silt content (10.73%), soil moisture, soil penetration and the intensity of ploughing have the greatest influence on the occurrence of anecic earthworms, here represented by the species *Lumbricus terrestris* only. Fig.1 depicts the relationship between some of these predictors and the predicted occurrence probability. TWI and

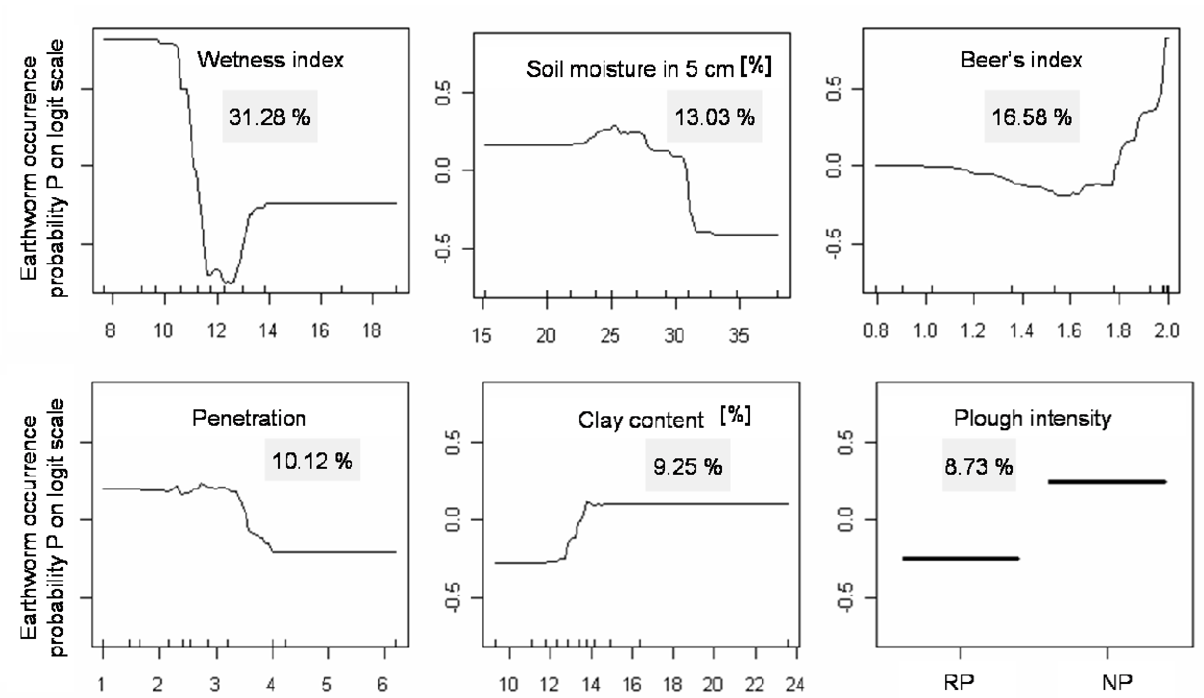

Fig. 1 Partial dependency plots depicting the relationship between predictors and incidence of anecic earthworms (penetration = depth/effort *100 [cm/kN *100], plough intensity: RP= reduced plough, NP= no plough). Y = logit (P) = ln(P/(1-P)). Percentages grey underlined are contributions of parameters to model performance.

soil moisture both show a negative relation to the anecic earthworms.

The interpretation is difficult because on one hand earthworms are affected by soil water content but - as ecosystems engineers - also affect water distribution in soils due to their activity. The relation with soil moisture content measured in the first 5 cm could reflect the ability of anecic earthworms to increase the water infiltration rate and the rapid transport of water in deeper soil layers. So the interpretation of the negative correlation could be that in soils with anecic earthworms the soil moisture content in the first 5 cm is reduced (cf. Ernst et al. 2009). On the other hand, large TWI-values reflect areas with a large contributing area that may expect outflow processes (e.g., subsurface and overland flow) and may have a low groundwater level. Therefore, the negative correlation with TWI may result from the avoidance of anecic earthworms of wetter soil conditions due to their nature as deep burrowing earthworms. Beer's index is a topographic parameter showing the coolest (= 2) and warmest slopes (= 0), depending on orientation and solar radiation. The positive relation to it shows that anecic earthworms are present in soils with less radiation input. Furthermore we see that anecic earthworms are more present in soils without ploughing and with less compacted soils (penetration as a coefficient of penetration depth and the effort to penetrate the soil, with higher values meaning stronger compaction) and higher clay content.

The high variability in earthworm data (standard deviations are as high as average values) explicates an explained variance of the final model of 36%. The model predictions are satisfactory. The apparent AUC value (performance criterion) of the final model is with 0.92 excellent. After internal model validation AUC is reduced to 0.76, due to the high number of predictor variables, but still acceptable (AUC ranges from 0.5 for the null model to 1.0 for perfect classification). Estimating BRT for abundance and biomass data gives quite similar results.

4. Conclusions

Boosted Regression trees are well-suited to predict earthworm distributions and to find the relevant predictors determining distribution patterns. The model results show that topographic indices (TWI and Beer's index) as well as soil parameters (moisture, texture and tillage) have important effects on the distribution, abundance and biomass of anecic earthworms (*Lumbricus terrestris*). Earthworm observations were sampled on 0.5 x 0.5 m² plots only. Aggregation patterns increase the heterogeneity of our field data. We enlarge our sample size on several spatial scales to minimize the variability in dataset. Additionally, we'll apply model approaches that explicitly consider spatial heterogeneity and temporal dynamics. Since the presence of other earthworm ecotypes affects the distribution of anecic earthworms, we will include predicted distributions of those species in our analysis.

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