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Spatial analysis of riparian forest soil macrofauna and its relation to abiotic soil properties

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ABSTRACT

Soil macrofauna play major roles in ecosystem functioning; however the ecological effects of macrofauna are influenced by their spatial distribution. Close relationships to soil properties are one major factor for determining spatial pattern of macrofauna. Information about macrofauna distribution pattern is scarce especially at regional scales. The limited numbers of studies available suggest a considerable influence of soil properties on macrofauna distribution. Therefore, this study was conducted in riparian forest to elucidate spatial patterns of soil macrofauna and their relationship to abiotic soil properties at regional scale. Soil macrofauna abundance, diversity, richness and evenness were analyzed at 200 sampling points along parallel transects which ran perpendicular to a river. The hierarchical sampling design comprised maximum distances of 0.5 km and minimum distances of 1 m between samples. Soil macrofauna was extracted from 50 cm × 50 cm × 25 cm soil monoliths by hand-sorting. At each transect point additional soil samples were taken for analysis of soil texture, standard soil properties and electrolytic conductivity. Data were analyzed using geostatistics (variograms and cross-variograms) in order to describe and quantify the spatial continuity of macrofauna characteristics and their relation to soil properties. The variograms revealed the presence of spatial autocorrelation in the majority of parameters. Also, relationships between macrofauna and soil properties such as soil texture and electrolytic conductivity, could be detected. To get more information about macrofauna distribution patterns and macrofauna–soil-relationships, subsets of the complete dataset were analyzed by means of applied time series analysis. The basic pattern of diversity value along the spatial series could be estimated by an autoregressive model. In addition, state-space analysis revealed that soil texture (silt) was important for estimating soil macrofauna diversity along transects. The study shows that geostatistical analyses as well as applied time series are suitable methods for analyzing macrofauna characteristics and for detecting relationships to soil properties. In contrast to geostatistics, state-space analysis yields additional information about the relative importance of different parameters for estimating macrofauna characteristics.

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1. Introduction

Invertebrate soil macrofauna play major roles in ecosystem functioning. Soil macrofauna such as millipedes (Blower, 1985) or insect larvae (Gonglanski et al., 2005) and earthworms affect the physical structure and function of soils and modulate the habitat for other species (Graff and Hartge, 1974; Lawton and Jones, 1995). Since macrofauna can be assessed by means of relatively simple methodological approaches, such as handsorting, soil macrofauna represents a good model for analysis of basic functional aspects of biodiversity in soil. Knowledge about invertebrate macrofauna may thus considerably improve the understanding of ecosystem functioning (Barrios, 2007).

The ecosystem effect of the soil macrofauna like any other component of soil biodiversity is dependent on the spatial distribution of the population (Lawton and Jones, 1995).

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Prerequisite of any estimation of functional effects of macrofauna is therefore an assessment of their distribution patterns. At the field scales, the spatial variability of macrofauna has been the subject of several publications (Guild, 1952; Poier and Richter, 1992; Rossi et al., 1997; Cannavacciuolo et al., 1998; Nuutinen et al., 1998; Decaens and Rossi, 2001; Jimenez et al., 2006; Joschko et al., 2006). Given the ample literature about spatial patterns at the field scale, spatial structures of earthworm populations at the regional scale appeared to be likely (Poier and Richter, 1992; Rossi et al., 1997; Nuutinen et al., 1998).

However, the analysis of biodiversity patterns and their relation to environmental factors at the regional scale is still a challenge for soil biodiversity research. For the regional scale, information about the variability of macrofauna is scarce (Joschko et al., 2006). It is however needed for better understanding the ecology of macrofauna, for predicting macrofauna activity and for designing appropriate management schemes at this scale. One main reason responsible for the absence of information about macrofaunal diversity at the regional scale is the lack of adequate methods for sampling and analyzing data at this dimension.

A key feature of soil information is that each observation relates to a particular location in space. Knowledge of an attribute value is thus of little interest unless location of measurement is known and accounted for in the analysis (Goovaerts, 1999). Including the sample locations in the analysis allows us to observe a spatial process within the sample domain. However, important information may be lost if locations of the observations are not considered (Nielson and Wendroth, 2003). The procedures which do not consider the spatial coordinates of the attributes, can lead to errors in the interpretation of the results (Nielsen and Alemi, 1989) for example the spatial process or the spatial continuity of the observations could not be captured (Nielson and Wendroth, 2003). Geostatistics provides descriptive tools such as variograms to characterize the spatial pattern of continuous and categorical soil attributes (Goovaerts, 1999; Gringarten and Deutsch, 2001). Also, applied time series analysis offers techniques to investigate spatial pattern of soil properties (Nielson and Wendroth, 2003; Timmer, 1998). The potential of applied time series techniques for improving soil biological studies has only started to be exploited (Joschko et al., 2006).

Species distributional patterns are likely to be controlled by many factors acting at different scales (Jimenez et al., 2001). Factors that determine spatial patterning of soil macro-organisms can be divided into two categories: abiotic factors such as climate, soil physical and chemical properties or resource availability, and biotic factors such as inter- and intra-specific competition or dispersal abilities (Aubert et al., 2003; Sereda et al., 2012). Little is known about the factors that control or influence the observed spatial pattern of soil macro-fauna at different scales; presumably, abiotic factors are responsible at least partly, for the spatial pattern of soil macro-invertebrates (Jimenez et al., 2001). In agricultural soils, close relationships between earthworm species and abiotic soil properties have been detected by spatial methods (Joschko et al., 2006).

As factors shaping the spatial pattern of macrofauna, soil properties such as soil texture (Joschko et al., 2006, 2009) have been ascertained. The underlying mechanism of the relationship between macrofauna and abiotic soil properties such as soil texture is their moisture requirement (Graff and Hartge, 1974). Spatial analysis of the relationships between macrofauna and soil properties may be a first step for better understanding macro-ecological principles in different landscapes.

In the last 15–20 years, riparian forests have become recognized as important components of landscapes and serve as a vital link between the aquatic environment and upland ecosystems (Giese et al., 2000). Riparian ecosystems are aquatic-terrestrial ecotones with unique biotic, biophysical and landscape characteristics (Lyon et al., 1998). They are an essential ecotone, since they contribute to restoring and maintaining regional diversity, besides controlling surface water quality by regulating the nutrient inputs (Fernandez-Alaez et al., 2005). Accordingly, sustainability and maintenance of riparian vegetation or restoring of degraded sites is critical to sustain inherent ecosystem function and values (Giese et al., 2000).

The first objective of this study is to analyze spatial relationships between macrofauna (abundance, evenness, richness and diversity) and abiotic soil properties (soil clay and silt content, ECe and organic matter) at the regional scale in an Iranian riparian forest. The basic hypothesis for this study was that spatial analysis may considerably improve the estimation of macrofauna community properties from soil properties compared to classical correlation analysis. The estimation of macrofauna community properties from soil properties would possibly enable prediction of macrofauna distribution from relevant soil maps and could serve as an important tool for regional scale biodiversity studies. The second objective of this study is to evaluate different statistical approaches for modelling spatial relationships between macrofauna and abiotic soil properties. Close links between soil macrofauna and soil properties such as soil texture and soil organic matter are to be expected due to their habitat and feeding requirements. Since soil properties are usually spatially structured in most soils (Goovaerts, 1999), classical correlation analysis is insufficient to detect these relationships (Taylor and Bates, 2013). Two different approaches to spatial analysis were taken: geostatistical analysis and time series analysis. Within the time series analysis approach, the autoregressive and the state-space methods were applied.

A third objective arises from the sampling design. Since the sampling design of the study was optimized for geostatistical analyses with hierarchically organized data sets, the question has to be addressed how time series analysis can be adapted to analyze geostatistically optimized data sets.

2. Materials and methods

2.1. Location and experimental design

The study was carried out in Wildlife Refuge of Karkhe in the riparian forest of the south-western Iran (31°57′–32°05′N and 48°13′–48°16′E). The climate of the study area is semi-arid; average yearly rainfall is about 325.8 mm with a mean temperature of 24 °C. Plant cover mainly comprises *Populus euphratica* and *Tamarix* sp. The sampling was done in March 2009 within a period of 15 days. At this time moisture and temperature are suitable and soil macrofauna reach their highest abundance.

Spatial sampling has to regard the extent, the sampling interval, and the support (area or volume of an individual sample) (Legendre and Legendre, 2012). These parameters must be chosen based on the scientific question as well as physical and practical limitations. According to Mathieu et al. (2004); soil biodiversity is shaped by the co-action of numerous factors. Because these factors act at different spatial scales, and may interact, ecological processes are scale dependent and hierarchically structured. Thus, the study tries to consider spatial variation of soil macrofauna from the local (quasi-homogeneous units of some square meters) to the regional scale (several square kilometres). To address the regional scale, the extent of the study has to stretch over several hundred meters. However, to reveal spatial variation starting at the topic dimension, sampling intervals must include distances of less than 10 m. Due to limited resources (time, workforce) only a certain number of samples could be analysed. Also, the sample support has to be small enough to resolve spatial variation within a few meters, but being large enough suppress micro-variability (within the sub-

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