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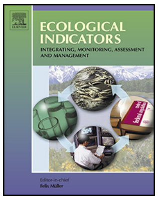

The dark side of biodiversity: Spatial application of the biological soil quality indicator (BSQ)

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ABSTRACT

We conducted a comprehensive assessment of soil quality in South Tyrol, Italy by combining spatial land use and land cover data with field surveys studying soil microarthropods. The biological soil-quality index (BSQ) proposed by Parisi et al. (2005) is based on the assumption that higher soil quality is associated with the occurrence of more microarthropod groups that are well-adapted to soil habitats. We used the BSQ concept in the context of a state-wide sustainability assessment on a municipality level. Many soil animals fulfil key ecosystem functions that are the basis for significant and broadly used ecosystem services. These functions and services are essential for any sustainable agriculture type. To determine if and how BSQ values are influenced by land use characteristics, we analysed field data from 243 sampling sites comprising eleven different land cover or land use types. An ordinary least square regression (OLS) was used to assess the influence of land use types, altitude, aspect, slope and geology as independent variables on BSQ values ($R^2 = 0.60$; $p < 0.001$). In addition to high variability in soil microarthropod communities, there were significant differences in BSQ values among most land use types. BSQ values were highest in forest ecosystems and lowest in arable fields. The parameters of the linear regression model were used together with spatial comprehensive GIS data to predict BSQ values spatially. The predicted values ranged from 0 to 198 and were used to calculate area-weighted mean BSQ values for all municipalities in South Tyrol. Our results show that the BSQ reacts sensitively to land use and hence can serve as an important surrogate indicator for sustainable land use practices.

1. Introduction

Soil conditions influence the soil capacity for agricultural production and the provision of key ecosystem services. Healthy soils are essential contributors to biodiversity (Doran and Zeiss, 2000; Wagg et al., 2014) and are a prerequisite for sustainable development. Despite the on-going discussion concerning the definition of sustainable development including its creative ambiguity and openness to interpretation (Robert et al., 2005), this topic is on the top of the agenda in the 21st century. The quality and health of soil is often directly influenced by land use and management practices (DeFries et al., 2004). We define soil health according to van Bruggen & Semenov (2000) by its stability, resilience to disturbance or stress, biological diversity, and level of internal nutrient cycling. While most authors relate soil quality to possible functions and services of soils, soil health can be viewed with a more holistic approach to understand the soil system (Garrigues et al., 2012). The increasing awareness regarding the importance of healthy soils for human well-being culminated in the “International Initiative for the Conservation and Sustainable Use of Soil Biodiversity” established by the Conference of Parties (COP) to the Convention on Biological Diversity (CBD) at its 6th meeting in Nairobi in 2002 (COP decision VI/5, paragraph 13). Local and regional initiatives are joining forces and building supra-regional alliances such as the European Land and Soil Alliance (ELSA), the Global Soil Biodiversity Initiative or the Global Soil Map initiative (Sanchez et al., 2009). The Food and Agriculture Organization of the United Nations (FAO) together with the European Commission launched the Global Soil Partnership (GSP) in 2011 to promote sustainable management of soil resources (Montanarella and Vargas, 2012). Sustainable management requires data on soil characteristics that is still very limited. Indicators of soil quality are needed to facilitate practical assessments of soil health and aid stakeholders and politicians in implementing and stimulating sustainable land use practices.

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Measurements of soil organisms meet many criteria for useful indicators: soil organisms are sensitive to anthropogenic perturbations and they correlate with beneficial soil functions (Culman et al., 2010). Furthermore, they can serve as excellent teaching tools (Doran and Zeiss, 2000). Therefore, authors such as Fox (2005), Bispo et al. (2009), and Gardi et al. (2009) proposed the use of soil organisms to monitor soil health and evaluate the sustainability of land use practices. Unfortunately, there is no worldwide consensus on a biological soil monitoring scheme. Paz-Ferreiro and Fu (2013) critically reviewed soil quality indices based on soil biological and biochemical activities and emphasised the importance of further investigations into the spatial and temporal characteristics of indices that integrate faunal and microbial measurements. Havlicek (2012), Pulleman et al. (2012) and Turbé et al. (2010) reviewed and discussed the use of soil biodiversity indicators and emphasized their importance as monitoring and decision supporting tools.

The biological soil-quality index (BSQ) proposed by Parisi et al. (2005) is a meaningful and widely applicable bio-indicator that could serve this purpose. It is based on the assumption that soil quality is associated with the occurrence of microarthropod groups that are well adapted to soil habitats (Paolo et al., 2010). This life form approach uses an eco-morphological index (EMI) for soil microarthropods and hence does not require species level identification. In contrast to indicators that focus on single taxa, the BSQ considers the whole soil microarthropod community and is applicable for large-scale monitoring. This biodiversity index reacts sensitively to land use and management practices (Gardi et al., 2002; Parisi et al., 2005) as well as heavy metal pollution (Santorufo et al., 2012) and it was validated with the use of other soil quality indicators including soil aggregate stability and soil organic carbon (Gardi et al., 2002). Applications of BSQ (sometimes named QBS) were published by Parisi (2001), Gardi et al. (2008), Mazzoncini et al. (2010), Paolo et al. (2010), Begum et al. (2011), Madej et al. (2011), Menta et al. (2011), Raglione et al. (2011), Visioli et al. (2013), Blasi et al. (2013), Galli et al. (2014) and Menta et al. (2014). Yan et al. (2012) amplified the concept of the BSQ through the integration of abundance data instead of the pure presence or absence data.

The characteristics described above combined with its robust and comprehensive design make BSQ an ideal option for use as an indicator for soil health in the context of regional sustainability assessments and monitoring systems. Data from such systems should aid policy-makers and stakeholders in their decision-making processes (Tasser et al., 2008). In spite of the large amount of published studies using BSQ as an indicator for soil health, we are not aware of any study or application that used BSQ values together with land use and land cover (LULC) data to spatially evaluate and model biological quality of soils at the landscape level.

In this article we present results of a comprehensive assessment of soil microarthropods collected from different LULC types in South Tyrol, Italy. We used field data from 243 sites and 11 LULC types to examine if and how LULC influences BSQ values. The results of an ordinary least square regression were used to spatially predict BSQ-values and calculate area-weighted mean values for municipalities. Finally, we discuss the application of BSQ in the context of an already existing sustainability assessment tool at the municipality level (www.sustainability.bz.it).

2. Methodology

2.1. Study site and field sampling

Our study area was the Autonomous Province of South Tyrol situated in the northern part of Italy in the central Alps. It covers an area of 7399 km^2 and is divided into 116 municipalities. The smallest municipality covers 1.6 km^2 while the largest covers 302.3 km^2. A total of 22.5% of the area is used for agriculture (Tasser et al., 2008). For a representative assessment of soil microarthropoda composition and biomass from different land use and natural habitat types we used pooled data from former studies in which the same sampling method (described below) was utilised. This data pool contained data from 173 different sites in North and South Tyrol. To encompass all predominant LULC types occurring in South Tyrol and guarantee a minimum of 5 sampling sites for each LULC type the existing data were complemented with a stratified sampling campaign at 70 sites. Site selection within one land use type was random. The additional sampling took place in 2011 and resulted in a final dataset with 243 sites and 11 different LULC types (Table 1). The predominant soil type was Cambisol followed by sites with Leptosol, Stagnosol, Gleysol and Podsol.

Soil fauna were sampled using the same sampling methodology at least twice at all sites (once in spring and once in autumn). A soil core of 30 cm diameter and 15 cm depth was drilled out and transported in a cotton bag to the laboratory. To guaranty a successful extraction of soil microartropoda the soil core was divided into two layers (0–7.5 cm and 7.5–15 cm) and placed in an adapted Kempson-extractor (Meyer, 1996) within 24 h. The samples were kept there for up to 14 days until they were completely dry. The extracted animals were transferred from the fixation solution (picric acid) into ethanol (75%). Soil microarthropoda were identified, counted and sorted under a binocular microscope. The sorted taxa were weighed on a Sartorius R200D with an accuracy of 0.00001 g. The abundance and biomass were expressed as individual m^{-2} and mg m^{-2}, respectively. Prior to the analysis the annual mean was calculated using spring and autumn values.

2.2. Estimating the biological soil-quality index (BSQ)

For calculation of BSQ values we adopted the methodology proposed by Gardi et al. (2002) and Parisi et al. (2005). While referring to the same concept some authors call the biological soil quality indicator QBS (coming from the Italian ‘qualità biologica del suolo’). To avoid confusion we will use the abbreviation BSQ even if some of the cited authors used the term QBS. Parisi et al. (2005) proposed two different types of BSQ: one based on microarthropods (BSQ-ar) and one based on Collembola species only (BSQ-c). We based our indicator estimation on soil microarthropoda and subsequently called it BSQ-ar. Soil microarthropods present in the samples were classified into systematic groups. Each group was associated with a score named the eco-morphological index (EMI) according to their adaptation to the soil environment. We applied the EMI proposed by Parisi et al. (2005) that ranged from 1 to 20. While epi-edaphic (surface-living) forms such as Dermaptera or Psocoptera score 1, forms adapted to soil-living (eu-edaphic) such as Protura or Diplura generally score 20. Hemi-edaphic (i.e. intermediate) forms such as Isopoda or Opiliones received a score in proportion to their degree of specialization. If a specific taxon was present, the EMI of this taxon was counted. While some taxa are associated with a single EMI, others such as Chilopoda or Diplopoda display a range because these groups include species with very different morphotypes (Parisi et al., 2005). EMI of all taxa present at a site were summed up to calculate site-specific BSQ-ar values. The BSQ estimation does not consider abundance within taxa. We decided to use the BSQ concept in our study and not the method proposed by Yan et al. (2012) which integrates abundance data, because there are far more applications of BSQ and hence more experience with this indicator. Furthermore the indicator proposed by Yan et al. (2012) normalizes soil quality values based on the site with the highest soil quality values - limiting its comparability over extensive areas or different study