Science of the Total Environment 545–546 (2016) 11–20

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity

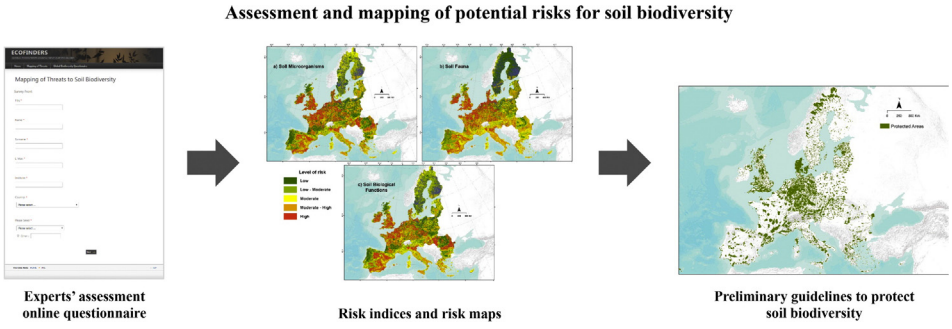
Alberto Orgiazzi [a,*], Panos Panagos [a], Yusuf Yigini [a], Martha B. Dunbar [a], Ciro Gardi [a,b], Luca Montanarella [a], Cristiano Ballabio [a]

[a] European Commission, Joint Research Centre (JRC), Institute for Environment and Sustainability (IES), Land Resource Management Unit, Via E. Fermi, 2749-21027 Ispra, VA, Italy
[b] European Food Safety Authority, Animal and Plant Health, Via Carlo Magno, 1A, 43126 Parma, Parma, Italy

HIGHLIGHTS

- Soil microorganisms, fauna and biological functions are subjected to different potential threats
- It is possible to map potential threats to soil biodiversity
- The majority of EU countries have soils with high level of risk to soil biodiversity
- Soil under pressure is not well protected, actions are needed to preserve soil biodiversity

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form 16 December 2015
Accepted 20 December 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Soil biodiversity
Risk assessment
Land-use planning
Soil biota conservation

ABSTRACT

Because of the increasing pressures exerted on soil, below-ground life is under threat. Knowledge-based rankings of potential threats to different components of soil biodiversity were developed in order to assess the spatial distribution of threats on a European scale. A list of 13 potential threats to soil biodiversity was proposed to experts with different backgrounds in order to assess the potential for three major components of soil biodiversity: soil microorganisms, fauna, and biological functions. This approach allowed us to obtain knowledge-based rankings of threats. These classifications formed the basis for the development of indices through an additive aggregation model that, along with *ad-hoc* proxies for each pressure, allowed us to preliminarily assess the spatial patterns of potential threats. Intensive exploitation was identified as the highest pressure. In contrast, the use of genetically modified organisms in agriculture was considered as the threat with least potential. The potential impact of climate change showed the highest uncertainty. Fourteen out of the 27 considered countries have more than 40% of their soils with moderate-high to high potential risk for all three components of soil biodiversity. Arable soils are the most exposed to pressures. Soils within the boreal biogeographic region showed the lowest risk potential. The majority of soils at risk are outside the boundaries of protected areas. First maps of risks to three components of soil biodiversity based on the current scientific knowledge were developed. Despite the intrinsic limits of knowledge-based assessments, a remarkable potential risk to soil biodiversity was observed. Guidelines to preliminarily identify and circumscribe soils potentially at risk are provided. This approach may be used in future research to assess threat at both local and global scale and identify areas of possible risk and, subsequently, design appropriate strategies for monitoring and protection of soil biota.

* Corresponding author.
E-mail address: alberto.orgiazzi@jrc.ec.europa.eu (A. Orgiazzi).

http://dx.doi.org/10.1016/j.scitotenv.2015.12.092

1. Introduction

Soil biodiversity is recognized as a crucial player in guaranteeing the functioning of soil and as a provider of several ecosystem services (Lavelle et al., 2006). At the same time it is known that soils are becoming more and more vulnerable due to several pressures: from pollution and salinization to erosion and compaction. As a direct consequence, also the soil-dwelling organisms are under threat. The decline in soil biodiversity has been identified as one of the major threats and issues to deal with in the coming years (McBratney et al., 2014). However, the overall relationship between pressures on soils and below-ground organisms has been poorly investigated to date. A common framework and, consequently, suitable actions to protect soil biodiversity are still missing. This is mainly due to the difficulty inherent to the disentangling of the real threats that can affect soil biodiversity and to the lack of data on the distribution of soil organisms at large scale. Many studies have investigated the impact of individual potential threats (e.g. intensive human exploitation or soil pollution) on specific groups of soil organisms (e.g. bacteria or earthworms) (Verbruggen et al., 2012). Therefore, we can assume that the scientific community has an appropriate level of knowledge on this topic and, therefore, a knowledge-based assessment of potential risk is possible. However, the variables to consider in this type of analysis are numerous and should be carefully examined. In particular, three different dimensions should be taken into account in order to obtain a satisfactory evaluation.

The first dimension is related to the large number of stresses that, in principle, can represent a threat to soil biodiversity. The factors that can impact soils are of varying nature, i.e. biotic or abiotic. Starting from the available literature we proposed and assessed the potential risk related to thirteen possible stresses: (1) climate change (global warming) (Van der Putten, 2012), (2) land use change (Spurgeon et al., 2013), (3) habitat fragmentation (Halme et al., 2013), (4) intensive human exploitation (Tsiafouli et al., 2015), (5) soil organic matter decline (Heenan et al., 1995), (6) industrial pollution (Hafez and Elbestawy, 2009), (7) nuclear pollution (radioactivity) (Brodie et al., 2006), (8) soil compaction (Whalley et al., 1995), (9) soil erosion (Pimentel et al., 1995), (10) soil sealing (Setälä et al., 2014), (11) soil salinization (Sardinha et al., 2003), (12) use of genetically modified organisms (GMOs) in agriculture (Verbruggen et al., 2012), and (13) introduction and diffusion of invasive species (Kourtev et al., 2002).

The second assessment dimension is linked to the complexity of soil biodiversity itself, which is composed of extremely varied organisms, from microorganisms to macro- and mega-fauna (Briones, 2014). Each threat may potentially impact each single entity of soil-dwelling organisms at a different level of intensity (Spurgeon et al., 2013). Furthermore, the pressures may also affect the functions carried out by soil biota. For the evaluation, we proposed three main potentially threatened components: soil microorganisms, soil fauna, and soil biological functions. In the text the term 'component' will be used to indicate these three categories of soil biodiversity.

The third dimension of evaluation to be considered is the absence of a common framework to equally assess the strength, and therefore the actual risk, of each threat to each of the different components of soil biodiversity. Lacking this evidence, scientists may arbitrarily consider certain events more dangerous than others. When detailed data are missing at large scale, a good way to obtain a consistent assessment is by referring to the current knowledge of experts. Therefore, three different categories of scientists, namely soil biologists, ecologists, and other soil scientists, were taken into account as they represent an approximation of the major field of research in soil biodiversity. Their knowledge was used in order to identify the commonly recognized threats.

At present, this stratified complexity is responsible for the difficulty in assessing the potential of each pressure on soil biodiversity and is preventing us from obtaining a common framework for both the monitoring and the protection of soil-dwelling organisms. However, a lot of data on chemical-physical properties and uses of soils are available (Lugato et al., 2014). These data could be combined in order to identify the areas of potential risk, considering that the spatial representations of threat processes is often used as a first step to identifying priority locations for conservation (Tulloch et al., 2015). Nevertheless, before doing this, the potential of each possible threat on soil biodiversity must be estimated in order to identify which ones should be considered. Therefore, the three dimensions described above were combined by means of an expert assessment and the results were used to generate normalized indices of threat. The indices allow us to design maps at pan-European level, including 27 countries of the European Union (EU), and identify areas of potential risk in this region. Subsequently, the maps were compared with spatial distribution of land cover types, biogeographic regions and protected areas in order to identify common patterns and propose preliminary guidelines to start developing measures to preserve soil life.

2. Material and methods

2.1. Expert assessment

A list of potential pressures was subjected to evaluation by experts (i.e. researchers in this field). In order to assess the relevance of threats, an opinion poll was carried out whereby soil science experts expressed an opinion on a 0–10 scale (0 = minimum potential, 10 = maximum potential). The relevance of the threats was assessed on three different components of soil biodiversity: microorganisms, fauna, and biological functions. A dedicated questionnaire was developed and temporarily made available online (see Appendix A for full questionnaire). The questionnaire was firstly addressed to a pre-established list of experts (i.e. EcoFINDERS project partners). Subsequently, in order to increase the response rate from experts, a specific news item was sent out through the official the questionnaire was advertised through the European Soil Data Centre (ESDAC; Panagos et al., 2012) newsletter. A brief explanation of the purpose and use of the questionnaire was described on a page before proposing the three main steps of the questionnaire. Furthermore, a helpdesk service was made available to all experts so that they could contact us in case of need.

Firstly, the experts were asked to declare some of their personal details, including their field of expertise (soil biology, soil ecology, soil science, or other). Secondly, participants were asked to state whether the assessment of potential threats needs to be measured separately for the three main pre-established components of soil biodiversity or not. If the respondents replied affirmatively, they were asked to rank, on a scale from 0 to 10, a list of the 13 potential threats to each of the three components. If not, they were asked to rank the potential in relation to soil biodiversity as a whole. In the latter case the same values were copied in all three categories of soil biodiversity for further analyses. Lastly, experts were asked to declare whether they had already published peer-reviewed papers on one or more of the classes of threat and, if so, to indicate which among the 13. The replies to the last question were compared to data from a desk-based meta-search of the papers published to date in peer-reviewed journals for each of the potential threats as recorded in March 2015 in the largest database of peer-reviewed literature, SCOPUS Database (www.scopus.com; Appendix B). Each list of publications was checked in order to consider the appropriate ones.

In order to avoid any over- and under-evaluation of the values, all the obtained questionnaire scores of each expert were normalized and mean-centred, in order to obtain scores in the range between 0 and 1 for each expert. Data were tested for normal distribution (Appendix C). The significance of differences among the threats was performed through the non-parametric Kruskal-Wallis test. *Post-hoc* pairwise comparisons were calculated through the Mann–Whitney pairwise test (adopting Bonferroni correction) in order to assess the significance of inequality at pairwise level. On the basis of the obtained results, the threats were classified as (1) with low potential (score significantly