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EDITED BY
Luís Carlos Iunes Oliveira Filho,
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Cankiri Karatekin University, Türkiye
Rodolfo Picchio,
University of Tuscia, Italy

*CORRESPONDENCE
Andrea Di Giulio
andrea.digiulio@uniroma3.it

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Fast soil recovery after a fire: case study in Maritime Alps (Piedmont, Italy) using microarthropods and QBS-ar index

Tommaso Fusco [1], Lorenzo Fortini [1], Francesca Casale [1], Carlo Jacomini [2] and Andrea Di Giulio [1,3*]

[1]Department of Science, University Roma Tre, Rome, Italy, [2]National Centre for the Italian Laboratories Network (CN_LAB), Biology Area, Soil and Land Ecology Laboratory, Italian Environmental Protection and Research Institute (ISPRA), Rome, Italy, [3]National Biodiversity Future Center (NBFC), Palermo, Italy

Soil is a very fragile ecosystem, often subject to many threats. Wildfires can affect edaphic communities depending on the intensity and seasonality of the fire. Different groups of soil fauna tend to respond differently to this type of disturbance, but the lack of data prevents to fully analyze the impact of fire. Soil microarthropods show a particular sensitivity to disturbances of different nature, making them excellent biological indicators. That is why in recent years many biotic indices to assess soil quality, like QBS-ar (Soil Biological Quality based on arthropods), have been developed. The objective of this study was to evaluate whether there might be a significant difference between areas affected or not by fire in the locality of Andonno (Piedmont, Italy) in terms of QBS-ar values, 18 years after this disturbance, and whether the reforestation intervention is having a positive effect on soil quality. Two sampling sites were selected within the sampling area and in each, six soil samples were taken. Microarthropods were extracted with a Berlese-Tüllgren extractor and soil biological quality was calculated using the QBS-ar index. No significant difference in QBS-ar values were found between the fire burned and unburned areas ($p=0.37$). The number of biological and euedaphic forms in the two sites was similar. It appears that microarthropod communities manage to recover in a short time, indicating that in the study area soil fauna has shown a fast recovery after extreme events like wildfires.

KEYWORDS

edaphic fauna, mesofauna, soil monitoring, soil quality, biological index, forest management, forest fire

1 Introduction

Soil is a very fragile ecosystem and often subject to many threats (Stolte et al., 2016), which risk causing a decline in the biodiversity of edaphic fauna, resulting in the loss of soil fertility and inability of soil to perform its functions (Orgiazzi et al., 2016; Coyle et al., 2017). Some of the main threats to soil fauna are listed by Jeffery et al. (2010) and Gardi et al. (2013), and include intensive agriculture (Beare et al., 1992; Baker, 1998; Dittmer and Schrader, 2000; Ayuke et al., 2011; Menta et al., 2011; Iordache, 2012), pollution (Cortet et al., 1999; Coyle et al., 2011; Kapusta et al., 2011), climate change (Meehan et al., 2010; McKenzie et al., 2013; Nielsen and Wall, 2013), and desertification (Pflug and Wolters, 2001; Tsiafouli et al., 2005; Maraldo et al., 2009). The lack of previous data regarding edaphic communities makes it difficult to assess their changes over time and thus to identify threats to soil biodiversity (Peng et al., 2022). Human activities often cause soil degradation that leads to reduced biodiversity and simplified edaphic communities (Jie et al., 2002; Ferreira et al., 2022).

Wildfires are a type of threat that primarily impacts terrestrial animals and plant communities, but they can also affect edaphic communities depending on the intensity and seasonality of the fire (Lisa et al., 2015), since they lead to physical, chemical, and biological changes (Callaham et al., 2012). It appears that some microarthropods may decrease in abundance in the months following fire (Jeffery et al., 2010), as most taxa are unable to take refuge in the deeper layers of soil (Coleman and Rieske, 2006). In general, different groups of edaphic organisms tend to respond differently to this type of disturbance (Fattorini, 2010; Radea et al., 2010; Menta and Remelli, 2020); particularly fungal biomass, microbial biomass carbon (C), soil respiration, autotrophic respiration, and C acquisition enzymes decrease in response to fire (Hu et al., 2023), but still much work has to be done to fully understand the impact of fire (Sgardelis and Margaris, 1993; Zaitsev et al., 2016; Turco et al., 2018; Hu et al., 2023). It has been speculated that often the observed changes in edaphic communities do not depend on the disturbance itself, but on the changes that occur to plant communities during succession (Callaham et al., 2003) and the alteration of the nutrient cycle. Soil arthropods and fungi seem to respond particularly to fire of different intensity and temperature (Bezkorovainay et al., 2007; Rutigliano et al., 2013), but their analysis can be long and complex to be performed, due to the richness in species and the need to identify all of them for a thorough assessment (Schatz et al., 2021).

Edaphic microarthropods show a particular sensitivity to disturbances of different nature, making them excellent biological indicators. That is why in recent years many indices that use these organisms to assess soil quality have been developed (Paoletti and Hassall, 1999; Parisi et al., 2005; Nuria et al., 2011).

The QBS-ar (Soil Biological Quality based on arthropods) index was introduced by Parisi (2001) and Parisi et al. (2005) and uses the degree of soil adaptation of different groups of edaphic arthropods to assess soil biological quality. The main advantage of this index is that it does not require recognition at the species level, but only at the order or class level, making it possible to simplify and speed up the process of assigning a soil quality score. It is not necessary, therefore, to count individuals, since for the QBS-ar index just the presence/absence is sufficient to represent the adaptability of that group. This index has become very popular in recent years, partly due to its easy application, robustness, and affordability, and is used for different types of monitoring in different parts of the world (Menta et al., 2018; Venanzi et al., 2019; Galli et al., 2021; Hernández-Tirado et al., 2022; Latterini et al., 2022; Çakır et al., 2023; Kurniawan et al., 2023; Latterini et al., 2023; Reilly et al., 2023). Despite this, it is still scarcely used to assess the impact of fire on soil quality, and the first studies on this are still pretty local and partial (Lisa et al., 2015; Mantoni et al., 2020; Certini et al., 2021; Galli et al., 2021; Lisa et al., 2022).

The objective of this study was to evaluate whether there might be a significant difference between the burned and unburned sites in the Andonno area in terms of QBS-ar values. Our hypothesis is that there are significant differences in the composition of microarthropods at the two study sites and that the QBS-ar index is able to detect these differences even 18 years after the fire. Although the present work represents a restricted case study, this can contribute to the discussion on understanding how soil microarthropod communities react long after such strong disturbances and whether the reforestation intervention is having a positive effect on soil quality. Case studies can be very useful in forestry because they represent the basis for further deeper investigation by meta-analysis.

2 Materials and methods

2.1 Study area

For this study, an area in the Southern Piedmont region, near Andonno (CN), was selected. This area was affected by a fire in 2003 that destroyed about 1,076 hectares of forest in the Valle Gesso, leaving an open area where reforestation has been ongoing since 2013. Two sampling sites in the study area were chosen, located, respectively, in the burned and unburned areas within the Special Area of Conservation (SAC) IT1160056 Alpi Marittime (Figure 1). Samplings took place in June 2020 and July 2021.

There is a different vegetation composition within the two areas. The unburned area is characterized by a mixed coniferous forest of *Larix decidua* Miller, 1768 and *Abies alba* Miller 1758, while the burned area has a predominance of herbaceous species with the presence of maples, downy oaks and birches that are part of the reforestation program.

2.2 Soil sampling, microarthropod extraction, and QBS-ar calculation

In each sampling site (80 m^2), six random samples of soil measuring 10x10x10 cm were taken using a steel square corer and placed in plastic bags sealed and marked with a tag so that they could be brought to the laboratory. For each sampling area, different data were recorded in order to characterize the different sites (Table 1). Tree, shrub and herbaceous coverage were recorded in the field as a percentage, slope was measured in degrees, and rockiness was

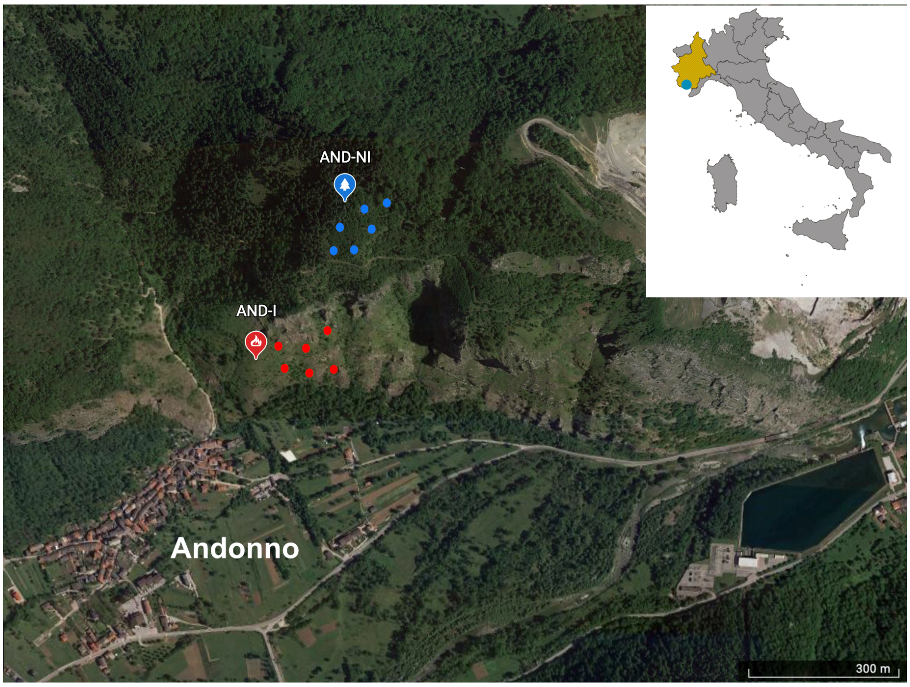

FIGURE 1
Map showing sampling sites (©Google Earth). Red, burned site; Blue, unburned site.

estimated using three levels (low, medium, high). Soil samples were transferred to the laboratory where microarthropods were extracted with a Berlese-Tüllgren extractor for 12 days and stored in containers filled with 2/3 alcohol and 1/3 glycerol. Next, they were then divided to order level using a stereo microscope and soil quality was calculated using the QBS-ar index (Parisi et al., 2005). Soil organisms were separated into biological forms, and each was assigned an EMI (Eco-Morphological Index) score ranging from 1 to 20 based on the degree of adaptation to edaphic conditions. The QBS-ar value is obtained by summing the EMI scores of each group, and if there are several scores for a single group, the highest is chosen.

2.3 Statistical analysis

A Student's t-test was carried out to assess whether there is a significant difference in soil quality between the burned and unburned areas. Before carrying out the analysis, a Shapiro-Wilk test was conducted to evaluate the normality of distribution and an F-test to test if the variances are equal. The data was normally distributed ($p> 0.05$), and the variances were equal ($p>0.05$). Tests were performed using Rstudio version 1.3.1093 (R Development Core Team, 2021).

3 Results

The results are summarized in Table 2; QBS-ar values obtained in the unburned site span between 179 and 227, with a high number of both overall biological forms (range between 14 and 17) and euedaphic forms (between 7 and 10). The maximum QBS value was obtained in the burned site (253), where in general the range of values is wider compared to the unburned site (range between 118 and 253). The number of biological and euedaphic forms in the burned site were similar to the ones of the unburned site, varying from 10 to 19 for the former and between 5 and 10 for the latter.

There was no significant difference in QBS-ar values between the fire-affected and non-fire-affected areas ($p=0.37$; Figure 2).

4 Discussion

The results obtained in this research differ from other studies conducted shortly after fires (Mantoni et al., 2020). Most soil microarthropod groups are present even though the area in question has undergone major changes in vegetation. Fires can have a great impact on edaphic fauna both directly and indirectly. Heat waves can

TABLE 1 Characteristics of sampling sites.

Site	Tree coverage	Shrub coverage	herbaceous coverage	Rock outcrop	Slope	Altitude
AND-I	5%	30%	70%	high	25°	850-880 m a.s.l.
AND-NI	70%	10%	5%	medium	25°	992-1028 m a.s.l.

TABLE 2 QBS-ar values, number of biological and edaphic forms for each site and replicate.

Site	Replicate	Biological forms	Edaphic forms	QBS-ar
AND-I	R1	10	5	118
AND-I	R2	12	6	139
AND-I	R3	16	8	212
AND-I_MAX1	ALL	18	9	233
AND-I	R4	16	6	174
AND-I	R5	16	6	174
AND-I	R6	19	10	253
AND-I_MAX2	ALL	21	10	264
AND-NI	R1	17	8	208
AND-NI	R2	16	7	179
AND-NI	R3	14	8	197
AND-NI_MAX1	ALL	18	8	213
AND-NI	R4	14	7	182
AND-NI	R5	15	7	192
AND-NI	R6	16	10	237
AND-NI_MAX2	ALL	18	10	252

QBS-ar values are indicated for the single replicates and the maximum value for each site is indicated with "all". The maximum QBS-ar value is obtained by adding the highest value of EMI for each biological form for each of the three replicates.

cause the death of soil organisms but also change the availability of organic matter, nutrients, and pH (De Marco et al., 2005; Capogna et al., 2009; Pellegrini et al., 2022; Arunrat et al., 2023; Zhang et al., 2023). There are three types of strategies soil organisms can adopt to survive forest fires: flee, hide, and protect. Soil invertebrates usually have low mobility and are therefore more susceptible to fires (Jeffery et al., 2010). Since 2013, in the study area, reforestation has begun with the planting of about 11,000 trees, including birch, oak, rowan, and lodgepole pine. In general, areas where reforestation is underway tend to have low diversity, biomass, and density of soil fauna in the early years, due to the difficulty of dispersal of many of these groups (Petersen, 1995; Lindberg and Bengtsson, 2006). For example, it has been reckoned that, in the absence of disturb, euedaphic collembola need about 30 years to move about 30 m (Ojala and Huhta, 2001). Despite these limitations, it seems that microarthropods manage to newly colonize the affected area in a few decades (Blasi et al., 2013; Galli et al., 2021). In the case study, it appears that the microarthropods are at an advanced stage of recovery in a very short time, less than 20 years, suggesting that here, soil fauna has a fast recovery even after extreme events such as a fire. Importantly, no significant difference was found between the QBS-ar values obtained in the burned and the unburned areas (a mixed coniferous forest), similar to what Galli et al. (2021) pointed out in their study of native forests of secondary growth after fires. If we examine the QBS-ar values obtained in the present study, however, we see that in the burned area these show a great variability, ranging between 118 and 253, probably due to the very large diversity of microhabitats in this area after reforestation. In the unburned area, the values obtained are less variable, between 179 and 227, indicating that this area has a more stable microarthropod community, typical of healthy forest soils (Parisi et al., 2005; Blasi et al., 2013; Galli et al., 2014; Galli et al., 2015; Menta et al., 2017; Menta et al., 2018; Galli et al., 2021; Mantoni et al., 2020; Szigeti et al., 2022). Euedaphic microarthropods (EMI = 20) such as Pauropoda, Symphyla, and Diplura were found in almost all replicates. Diplopoda and Chilopoda are less common but well represented in the samples. Various biological forms of Coleoptera were found in both the burned and unburned sites, including euedaphic forms such as Leptotyphlinae. The presence of most of the euedaphic microarthropods in both sites shows that the burned area is at a good point of restoration regarding soil communities. It might be interesting to continue to monitor changes in the microarthropod presence in this area, in order to delineate transitions to a stable community during reforestation.

Our initial hypothesis that there would be a different microarthropod composition and different QBS-ar values in the two study sites was not confirmed. It would therefore seem likely that the study area is either recovering from the damage caused by the 2003 fire or alternatively the QBS-ar index is not sensitive enough to show a difference after 18 years. Mantoni et al. (2020) have shown how the index can be sensitive to this type of impact after a short period of time, but it is likely that these differences become less noticeable over the years. It must be considered that the QBS-ar gives absolute values based on the presence and absence and biological form of certain groups of microarthropods, but does not consider the species composition, which is likely to change in response to certain types of disturbance. In the present case study, the vegetational transition from mature mixed coniferous forest to a more open

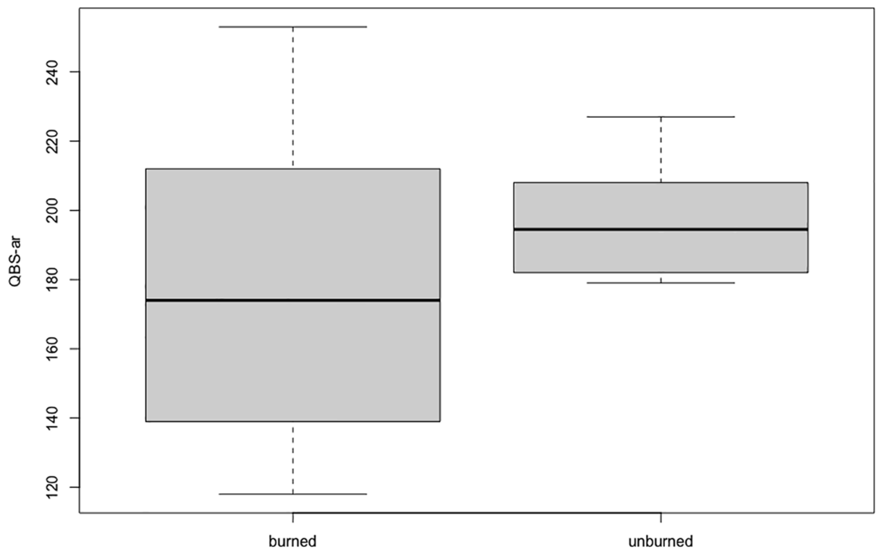

FIGURE 2
QBS-ar values recorded in burned (AND-I) and unburned (AND-NI) sites. The central box represents the interquartile range, the line in the center represents the median value, the upper and lower whiskers represent values outside the middle 50%.

reforestation area may have led to changes in the edaphic community that cannot be appreciated using the QBS-ar index.

In conclusion, the QBS-ar index could be a good method for assessing changes in soil quality after events such as fires and other disturbances, but it is probably much more sensitive shortly after the disturbance. It would be useful to assess changes in soil microarthropod communities over the various years so that we can understand how they recover their function over time. It has already been seen in other studies (Blasi et al., 2013; Menta et al., 2018) how the QBS-ar index is sensitive to disturbances of different types, but it would also be useful to assess over time whether beneficial events such as reforestation succeeded in restoring the soil to good health. This study shows that correct management activities can bring fast benefits for restoration of soil microarthropod composition and be a useful tool for the conservation of this important environment.

Case studies like this can be very useful to understand whether certain methodologies can be applicable in different situations, but they also have many limitations as they are restricted studies. Long-term monitoring and the application of other indices, both biological and chemical, would be needed to get a more complete picture of the situation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The manuscript presents research on animals that do not require ethical approval for their study.

Author contributions

TF: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. LF: Data curation, Investigation, Methodology, Writing – review & editing. FC: Methodology, Writing – review & editing, Investigation. CJ: Methodology, Writing – review & editing, Investigation. AG: Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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