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Monitoring soil restoration in an open-pit mine in northern Italy

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ABSTRACT

Mining causes significant damage to the environment: the removal of top layers of soil causes loss of structure and functionality, with a subsequent reduction in biodiversity. Soil communities are important for soil formation, they contribute to the improvement of several characteristics of soils and they play key roles in many processes that enhance the success of restoration. Unfortunately, soil fauna are poorly monitored even though they represent a good tool for assessing soil quality. The "La Speranza" quarry in northern Italy was studied from the start of the restoration process in 2008 until 2012. Six sites were selected and monitored annually. Microarthropods were extracted from three replicates of soil drawn from each site, identified to order level and then counted. Both the abundances of taxa and the soil biological indices applied (Shannon diversity index (H'), Pielou's evenness index (J), the Acari to Collembola ratio (A/C) and the QBS-ar index) revealed a good level of soil recovery over the years studied. Furthermore, the edaphic organisms that are generally associated with stable conditions in the soil (e.g. Symphyla, Protura, Chilopoda), appeared in the most recent of the years.

1. Introduction

Extraction activities have a significant impact on ecosystems, affecting both vegetation and soil fauna. In the process of open-cast mining, the vegetation and the topsoil are removed. The soil is stored in order to be reused once the extraction work has come to an end. As a result, horizons are shuffled and physical, chemical and biological conditions rapidly deteriorate. Ghose (2004) demonstrated that the proportion of particle sizes becomes unbalanced, with sand particles rising while silt and clay fall; porosity decreases as a result of compaction by machinery; the pH and the microbial population in the accumulated stockpile decreases dramatically. In addition, a significant period of time generally elapses between the initial removal of the topsoil and the redistribution of the same stored soil over the area. In the absence of any planned biological restoration, the properties and condition of the stored soil becomes unsuitable for promoting the spontaneous recovery of the ecosystem and the soil can become biologically sterile (Ghose, 2004; Andrés and Mateos, 2006). The driving force for successful restoration is the interaction between the various trophic levels of the ecosystem. Vegetation and soil fauna are strictly correlated, given that one affects the other, and a synchronization exists between changes in vegetation, soil and soil biota (Frouz et al., 2008).

Edaphic fauna, in particular the organisms that spend all or the major part of their life cycle in the upper soil layers, are significantly affected by the removal and storage of soil (Frouz et al., 2009; Kardol et al., 2009); besides, as with vegetation, the post-restoration recovery of soil microarthropods, both in terms of densities, richness and composition, usually improves with time even though it might take at least 15 years (Kumssa et al., 2004; Andrés and Mateos, 2006; Cristescu et al., 2012). The loss of soil fauna communities and the correlated ecosystem services that they provide are probably the most important consequences of mining. In fact, soil biota are important in many soil processes: they contribute to the distribution of organic matter and, as a consequence, they affect the rate of decomposition, they are involved in nutrient cycling and in the formation of soil structure, and they influence porosity, aeration and infiltration (Kremen et al., 1993; Lavelle et al., 1997; Bird et al., 2004; Frouz et al., 2008; Menta et al., 2010, 2011). Unfortunately, soil fauna are still infrequently monitored (Cristescu et al., 2012) and the reactions of terrestrial arthropods are still little known (Grégoire Taillefer and Wheeler, 2012), even though it is recognized that soil fauna, in particular microarthropod groups, are useful bioindicators of human disturbance and can be used to define mine-site soil condition and quality (Longcore, 2003; Zeppellini et al., 2009; Madjei et al., 2011). As reported by Dunger and Voigtländer (2005), soil-faunal groups are suitable for indicating successional stages if they can quickly and easily be sampled. Furthermore, they should show clear reactions to the ecosystem development, and their specific ecological potency must be known from literature.

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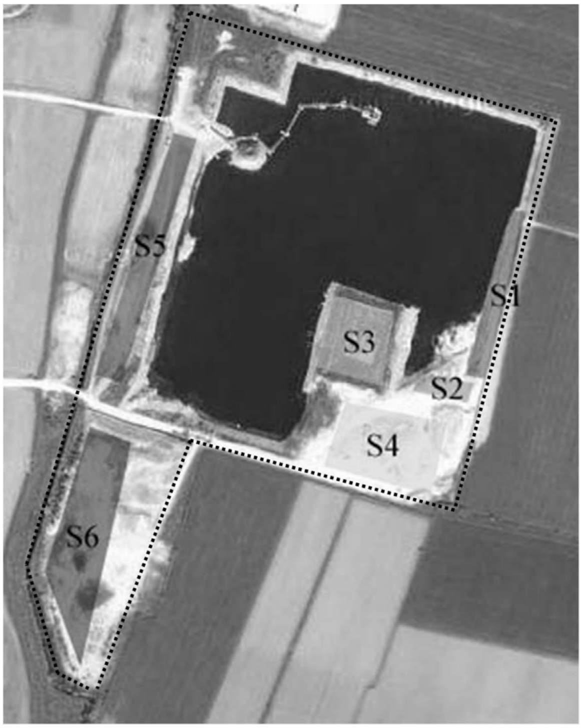

Fig. 1. Location of the six sites in the open-pit mine "La Speranza" (northern Italy): S1 East bank; S2 South bank; S3 archaeological site; S4 meadow; S5 hedge; S6 wood).

The aim of this study was to evaluate the recovery of damaged soil in a pit using soil microarthropod communities as a bioindication tool. In our opinion the monitoring of soil fauna communities in mine sites could be a very useful instrument for evaluating the success of a restoration process after the refilling of a mine.

2. Materials and methods

2.1. Study area

The study was carried out in the open-pit mine "La Speranza" (44°51′22″ N, 10°15′01″ E) near the city of Parma in northern Italy. The quarry (350 m × 550 m in size, covering approximately 15.50 hectares), is located on the right bank of the Taro river, separated from a riparian forest by a canal and immersed in an agricultural landscape. It was used to extract construction aggregate such as sand and gravel from 2002 to 2007. The maximum depth reached by the excavation was 19 metres; after excavation, a part of the abandoned pit was filled by resurgence water and maintained as an artificial lake (Fig. 1). The superficial soil excavated (70–75 cm from the plain land) was stored in a deposit area, and utilized at the end of the excavation. This soil was accommodated in embankments and compacted partly to avoid mineral and organic matter loss. The entire area was affected by the continual passage of excavators which had serious well known consequences such as loss of vegetation cover, soil compaction and a reduction of biodiversity. At the end of the excavation, the soil around the artificial cavity was ploughed and the stored soil was distributed around the cavity and used to create its borders. The restoration activities were started in 2007 and have included:

The creation of wood formations ascribable to meso-hygrophilous wood.
The creation of hedges.
The planting of climbing plants.
The seeding of herbaceous plants.

The purpose of those activities was to create an environment that could become a biodiversity reservoir of fauna (both invertebrates and vertebrates) in the middle of a typical agricultural ecosystem such as is found in the Po valley (northern Italy) which features intensive soil use, low organic matter content and a dramatic loss of biodiversity.

Six sites were selected in order to consider areas with different characteristics at the time the extraction activities came to an end (Fig. 1). The general characteristics of the sites are summarized in Table 1. The first and second sites (S1 and S2 respectively) had different starting conditions but a similar anticipated evolution and no artificial planting. They were the East and South banks of the quarry. S1 contained some young *Populus nigra* trees and *Xanthium* sp. and *Cirsium vulgare* bushes, while S2 was almost totally devoid of plant cover. Three sites (S4, S5, S6) had the same conditions of lack of plant cover at the beginning of the restoration process since they had been sites for stockpiling soil and they were artificially planted in 2008. They should evolve respectively into meadow, hedge (with mulberry *Morus* L.) and wood (with white poplar *Populus alba*). Finally, one site (S3), located inside the pit in a fenced area, was characterized by a more complex vegetational structure, with a herbaceous layer, bushes (*Rubus* sp. and *Sambucus* sp.) and trees (black poplar, *Populus nigra*, and field elm, *Ulmus minor*), as a result of an earlier interruption of extraction activities due to the discovery of some archaeological remains. This site was used as a control since it could act as a source of colonists. In 2012, the pH and organic matter content of each site were analyzed (Table 1): pH was estimated in potassium chloride (KCl); organic matter content was estimated by the "loss of weight on ignition" (LOI) method (Schulte et al., 1991). Only the first 10 cm of each soil profile was analyzed.

2.2. Microarthropod community sampling

Three soil cores 100 cm^2 and 10 cm deep were sampled in each site annually from 2008 to 2012 (11/2008, 3/2009, 5/2010, 6/2011 and 10/2012) at optimal periods for the density and biodiversity of soil fauna. Microarthropods were extracted using a Berlese–Tüllgren funnel; the specimens were collected in a preserving solution (75% ethyl alcohol and 25% glycerol by volume) and identified to different taxonomic levels (class for Myriapoda and order for Insecta, Chelicerata and Crustacea). The organisms belonging to each biological taxon were counted in order to estimate their density at the sampled depth (10 cm) extrapolating the number of individuals to 1 m^2 (ind/m^2).

The biodiversity of soil animal communities was evaluated using the number of observed taxa (NT), the Shannon diversity index (H') and Pielou's evenness index (J). These latter measures were calculated using the number of specimens observed in each sample for each taxonomic level. Soil quality was estimated with the Acari to Collembola ratio (A/C, Bachelier, 1986) and the QBS-ar index (Parisi et al., 2005). The A/C is the ratio of mite to collembolan specimens, which is greater than one in natural conditions, whereas it decreases in the event of soil degradation. The QBS-ar index is based on the following concept: the higher the soil quality, the higher will be the number of microarthropod groups which are well adapted to soil habitats. QBS-ar is applied to soil microarthropods, separated in accordance with the biological form approach (sensu Sacchi and Testard, 1971), with the intention of 1) evaluating the microarthropods' level of adaptation to life in the soil environment (Parisi, 1974), and 2) overcoming the well-known difficulties of taxonomic analysis to species level for soil mesofauna. Edaphic microarthropods show morphological characteristics that give evidence of adaptation to soil environments, such as reduction or loss of pigmentation and visual apparatus; streamlined body form, with reduced and more compact appendages (hairs, antennae, legs);