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Review

Utilization of earthworms and termites for the restoration of ecosystem functioning

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ABSTRACT

Soil engineers, such as earthworms and termites, are key organisms in soil functioning. They are involved in many ecological processes and play a central role in numerous ecosystem services. This review discusses the management of earthworm and termite activity for the restoration of ecosystems. We review methods to promote soil engineer activity either directly through field inoculation or stimulation or indirectly through the utilization of vermicompost. Examples of their use for the restoration of acid, compacted or crusted, polluted, and eroded soils are also discussed. Finally, we summarize the major obstacles hampering the utilization of soil engineer activity for the restoration of ecosystems, consider new research topics that need further development and highlight the need to consider the interactions between the functions and services influenced by soil engineers.

Contents

1. Introduction

Human societies derive many essential environmental goods and services from ecosystems, i.e. the so called ecosystem services (Costanza et al., 1997; de Groot et al., 2002). These services include the natural processes that support the production of food, the regulation of water quantity and quality, the emission of greenhouse gases. Following Kibblewhite et al. (2008) ecosystems services are under the regulation of four key ecosystem functions: (i) C transformations, (ii) nutrient cycling, (iii) soil structure and maintenance, and (iv) biological population regulation. A substantial body of literature suggests that these four functions are mainly, but not exclusively, under the regulation of soil biodiversity (Lavelle et al., 2006; Barrios, 2007; Bullock et al., 2011).

Soil organisms regulate key biogeochemical cycles (see Lavelle et al., 2006; Barrios, 2007 for reviews on this subject). Among soil invertebrates, soil engineers (*sensu* Lavelle et al., 1997; Jouquet et al., 2006) appear to play a more prominent role. Earthworms and termites are the major and most studied soil engineers, due to their dominant abundance and biomass in temperate and tropical soils. However, although less widespread than these two taxa, other organisms can also play important role in regulating ecosystem functions in some environments (i.e., dung beetles, Brown et al.,

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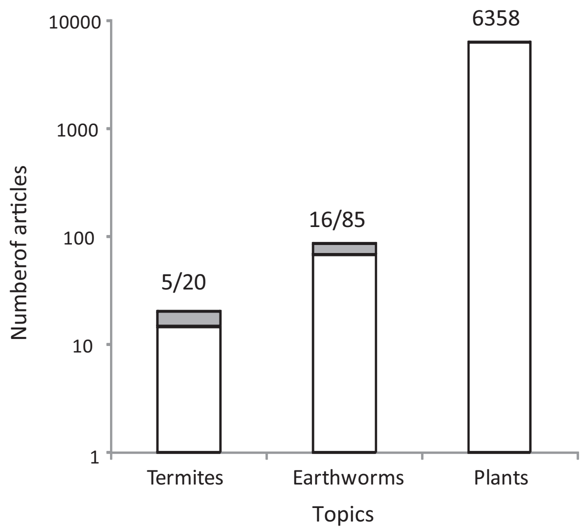

Fig. 1. Comparison between the number of articles referenced in Web of Science with the following keywords 'soils'; 'restoration' and either 'termites'; 'earthworms'; or 'plants'. In total; 20 articles have been published with termites; 85 with earthworms and 6358 with plants. However; a thorough examination of the articles reveal that the influence of soil engineers on the restoration of soil quality has only been studied in 5 and 16 articles (in grey); respectively for termites and earthworms.

2010; scarabeidae larvae, Rabary et al., 2008; ants, Majer et al., 2007; Evans et al., 2011; millipedes, Toyota et al., 2006) but their effects as ecosystem engineers remain unexplored. In addition to acting as detritivores, earthworms and termites modify resource availability to other species through the creation of biopores and biogenic aggregates. They are involved in most key soil functions, such as the decomposition of organic residues at the soil surface, the regulation of soil organic matter turnover, nutrient cycling, water infiltration and storage in the soil, soil erosion, and plant growth (Lavelle and Spain, 2001). Consequently, it is considered that soil engineers are an essential component of soil quality and their abundance and diversity have been proposed as bioindicators of ecosystem health (Muys and Granval, 1987; Paoletti, 1999; Jones et al., 2003; Ruiz et al., 2011) or to assess the level of ecosystem restoration (Dunger and Voigtländer, 2005; Majer et al., 2007; Snyder and Hendrix, 2008).

Several articles have been published in the last 20 years on the significant influence of soil engineers on key ecological functions and as a consequence on the regulation of soil bio-physicochemical properties (see the recent reviews of Jouquet et al., 2011a for termites, and Blouin et al., 2013 for earthworms). The increasing recognition of their importance in the regulation of key biogeochemical cycles has led to the suggestion that soil engineering activity could be developed as a cornerstone for the provision of agricultural and non-agricultural services, such as erosion control, water quality and supply, pollutant attenuation and degradation (De Goede and Brussaard, 2002). However, much less has been written on the possibility to use the ecological functions performed by soil engineers for the restoration of ecosystem services in degraded ecosystems (Curry, 2004; Eijsackers, 2011). Fig. 1 illustrates the quantity of articles published on the topic of soil restoration and referenced in Web of Science with the utilization of termites, earthworms and plants. Although this list is not exhaustive because it is restricted to articles that have 'soils', 'restoration' and either 'termites', 'earthworms', or 'plants' in the title or keywords, and because this method may miss relevant papers not available in Web of Science, it clearly shows how the utilization of soil engineers, earthworms and termites, has been under-explored in the approach of restoration by comparison with the classical approach of plant utilization. A review of recent studies using earthworms and termites to restore degraded ecosystems is therefore now appropriate.

In this paper, we first review the key ecological functions performed by soil engineers. We then stress the methods developed to promote their activity, and identify the obstacles hampering further research on this topic. Next, we give examples of the utilization of earthworm and termite activity for the rehabilitation of soil quality and functioning. Finally, we summarize the major obstacles hampering the utilization of soil engineer activity for the restoration of ecosystems and consider new research topics that should allow the development of sustainable practices for the rehabilitation of degraded ecosystems.

2. A functional classification of ecosystem engineers

The utilization of ecosystem engineers for the restoration of ecosystem services is supported by the knowledge of their influence on ecological functions. By contrast to other soil organisms, soil engineers are the only group impacting the four key aggregate ecosystem functions described by Kibblewhite et al. (2008). As decomposers, earthworms and termites consume litter and soil organic matter (SOM), and then contribute to the release of mineral nutrients in soil. As ecosystem engineers, they play a key role in controlling the dynamics of soil structure in addition to the regulation of the abundance and activity of subordinate organisms, from microorganisms to plants (Jouquet et al., 2006). However, different soil engineers do not influence ecosystem functioning in the same way and their influence on the four aggregated ecological functions depends on the interaction between their ecological strategy and their abiotic environment. Organisms are usually differentiated into functional groups according to their influence on specific ecological functions. These classifications can be based on both trophic and functional criteria, such as the classification of earthworms and termites into extended or intended soil engineers (Jouquet et al., 2006), the distinction between epigeic, anecic and endogeic earthworms (Bouché, 1977) or soil-feeding, litter-feeding and fungus-growing termites (Holt and Lepage, 2000; Jouquet et al., 2011a). These classifications can also be solely functional, such as in the case of the compacting and decompacting earthworm species (Blanchart et al., 1997). Obviously, it is worth noticing that soil engineers can favourably impact certain functions and others negatively. This is the case of earthworms and termites that temporarily store SOM into their casts and nests (function of C protection and service of climate regulation) but consequently reduce the release of mineral nutrients available to plants (function of nutrient cycling and service of food provisioning). It is therefore of primary importance to consider all the functions impacted by soil engineers before deciding on the species to be used in soil restoration programmes (Fig. 2).

3. Methods to promote soil engineer activity

Direct and indirect methods exist to increase soil engineer activity in the field. A direct method is simply to inoculate soil engineers in situ. This method only concerns the few earthworm species that can easily be breed since it is difficult, slow or impossible to breed termites, especially the soil-feeders and fungus-growing termite species, under laboratory conditions (Jouquet et al., 2011a). Three main methods have been described and compared to optimize earthworm breeding, inoculation and establishment of healthy populations in situ, namely the turf cutting and relaying, chemical/physical extraction with broadcasting and Earthworm Inoculation Unit (EIU) methods. The advantages and disadvantages of these methods have been discussed in several articles (Butt et al., 1995; Butt, 1999; Lowe and Butt, 2002, 2005; Butt, 2008; Eijsackers, 2011). The main obstacle hampering direct earthworm inoculation