# Using Soil Invertebrates as Monitors of Soil Health: A Zoological Method for Evaluating Soil Quality

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**Abstract**

Soil invertebrates, a varied and frequently unseen component of terrestrial ecosystems, play an important role in determining soil quality and health. As living creatures that live inside the soil matrix, they are sensitive indicators of environmental conditions and overall ecosystem dynamics, making them useful sentinels in soil quality assessments. This research endeavour aims to demonstrate the vital relevance of using a zoological approach for complete soil quality assessment. The use of soil invertebrates as bioindicators allows for the evaluation of both abiotic and biotic elements that influence soil quality. Their movement helps them to adapt to changing environmental circumstances, and their tiny size makes them especially sensitive to local differences. Soil invertebrates, as agents of decomposition, nitrogen cycling, and ecosystem stability, are critical to the long-term growth of agricultural and forestry activities. The use of a zoological viewpoint in soil quality evaluation not only clarifies the complicated web of interactions within soil ecosystems, but also helps to develop sustainable agricultural and environmental practices.

**Keywords:** Health, Biotic, Bioindicators, Soil, Invertebrates, and Nutrient

## 1. Introduction

Understanding the ecological complexities of soil health evaluation is critical for effective agricultural and environmental management. Soil quality, a complex notion that includes the soil's ability to maintain biological production, protect environmental quality, and promote plant, animal, and human well-being, is dependent on the structural and functional integrity of soil ecosystems (Doran and Parkin, 1994). Soil invertebrates play an important part in these ecosystems, and recognition of their importance has grown in recent years. Soil invertebrates, which include arthropods, annelids, and other non-vertebrate animals, play an important role in the dynamic web of life that exists under our feet. Their actions have an impact on soil structure, microbial activity patterns, soil organic matter dynamics, and nutrient cycling (Stork & Eggleton, 1992; Freckman & Ettema, 1993; Parmelee et al., 1993; Linden et al., 1994). This study seeks to investigate the multidimensional function of soil invertebrates in evaluating soil quality, as well as their potential as indicators of environmental changes and the influence of management methods on soil ecosystems.

**Table 1. Common Soil Invertebrates and their Role in Soil Quality Improvement**

| Scientific Name | Family | Soil Quality Improvement Abilities |
|---|---|---|
| Enchytraeus albidus | Enchytraeidae | Contributes to nutrient cycling and influences soil organic matter decomposition |
| Porcellio scaber | Porcellionidae | Plays a role in litter decomposition, nutrient cycling, and soil aeration |
| Aphidius colemani | Braconidae | Functions as a parasitoid wasp, controlling aphid populations, which can otherwise harm plants and alter soil dynamics |
| Arachnida | Various Families | Predatory arachnids help control pest populations, promoting plant health and indirectly benefiting soil quality |
| Lumbricus terrestris | Lumbricidae | Enhances soil structure through burrowing, contributes to organic matter decomposition, and increases nutrient availability |

The soil habitat is very diverse, including a wide variety of creatures. This underground domain is essential for a variety of ecological activities, including nutrient cycling, organic matter decomposition, and soil structure preservation. These functions are critical not only for the overall health of terrestrial ecosystems, but also for their ability to provide essential ecosystem services, such as maintaining agricultural productivity and protecting environmental quality (Wallwork, 1988; Bongers, 1990; Paoletti et al., 1991). Soil invertebrates, which include a wide range of species, play an important role in these processes. Their interactions with microorganisms, plant roots, and other soil matrix components have far-reaching consequences for the overall health and productivity of soil ecosystems. The importance of soil invertebrates in soil quality assessment is not limited to their impact on soil biogeochemistry and ecological processes. Soil invertebrates respond to environmental changes and disturbances, making them useful markers of soil health. They have particular sensitivity to changes in their environment, both natural and manmade. This responsiveness enables soil invertebrates to be used as bioindicators, offering early warnings and insights into local environmental changes. Soil invertebrates respond rapidly to changes in abiotic parameters such as altitude and latitude, which have a considerable impact on the composition and organisation of invertebrate communities (Stork and Eggleton, 1992). As a result, these invertebrates can accurately reflect changes in soil ecosystems caused by both environmental factors and human activities. Furthermore, the simplicity of their body structure, combined with their abundance and diversity, makes soil invertebrates ideal candidates for studying species richness (alpha-diversity) and species turnover (beta-diversity) (Moscatelli et al., 2005; Gerlach et al., 2013). Their extremely short life cycles make them ideal as markers of soil health, allowing for the study of changing conditions over relatively short time periods. This study dives into the many functions of soil invertebrates in soil health assessment, investigating their reactions to environmental changes and their potential as sentinels of soil quality. The link between soil invertebrates and soil quality is complex and varied. Soil quality is critical for the long-term development of healthy, agriculturally significant plants (Doran & Parkin, 1994), hence the contributions of soil invertebrates to soil health must not be underestimated. This analysis will look into soil invertebrates' multidimensional function in soil quality maintenance, with a focus on their value as bioindicators for measuring soil health in agricultural and natural settings. Through this investigation, we want to get a thorough knowledge of the importance of soil invertebrates in soil health assessment, as well as shed light on their potential to act as sentinels of environmental change and sustainable soil management.

## 2. Taxonomy of soil invertebrates

Functional features of particular species may be classified into functional groupings. These functional groupings influence ecosystem biophysical properties by moderating interactions between ecosystems, communities, and individual species attributes (Zoeller et al., 2020). When it comes to the ecology of functional groupings of invertebrates, a range of variables impact their distribution, with abiotic factors such as altitude and latitude having the most effect. These variables shape the composition and organisation of invertebrate trophic networks.

### 2.1 Collembola

Collembola, often known as springtails, are small soil invertebrates that play an important role in improving soil quality. Their burrowing efforts assist to soil aeration and structure by allowing air and water to pass through the soil matrix (Gisin, 1960). Collembola also contribute in the decomposition of organic materials, which promotes nutrient cycling by speeding up the breakdown of dead plant material and other organic leftovers (Lavelle et al., 2006). These microscopic creatures serve as an important food source for other soil fauna, promoting biodiversity and contributing to the general health and fertility of terrestrial ecosystems (Hopkin, 1997; Coulson et al., 2002). As a result, Collembola's activities contribute significantly to soil quality improvement, influencing its physical, chemical, and biological aspects.

### 2.2 Lumbricidae

Members of the Lumbricidae family, sometimes known as earthworms, play an important role in improving soil quality via a variety of means. These soil invertebrates have a considerable impact on soil physicochemical parameters such as pH, organic matter content, water retention capacity, and structure (van der Putten et al., 2016). Their burrowing actions increase soil aeration and water penetration, which promotes nutrient mobility and root development (Scheu, 2003). Earthworms contribute significantly to the decomposition of organic matter, which enriches the soil with organic nutrients and increases soil fertility (Johnson et al., 2011). Their participation in mineralization processes, insect control, and soil porosity modification reinforces their significance in enhancing soil quality (Scheu, 2003). Lumbricidae's ecosystem services have significant significance for long-term agriculture and terrestrial ecosystem health.

**2.3 Nematoda**

Soil invertebrates, a varied collection of creatures that live in the soil, are essential for nutrient cycling and soil ecosystem function (Wardle et al., 2004). Nematodes, a phylum of tiny roundworms, stand out among soil invertebrates owing to their widespread presence and abundance in soil environments. Nematodes are recognised for their various feeding tactics, which include herbivorous, bacterivorous, and predatory behaviours (Yeates et al., 1993). These feeding preferences have a significant impact on nutrient dynamics in soil, as different nematode groups influence organic matter decomposition and the cycling of essential nutrients (Bongers et al., 1997). Nematodes play an important ecological role in nutrient cycling, particularly nitrogen cycling. Nematodes may expedite nitrogen mineralization processes in soils by feeding on microbial biomass, releasing nutrients for plant uptake (Bardgett et al., 2003). Furthermore, nematodes may alter the makeup and activity of microbial communities, affecting nutrient transformation pathways (Wasilewska, 2015). These complicated interactions highlight the significance of nematodes as nutrient drivers in soil ecosystems. Nematodes also function as bioindicators of soil health and environmental stress. The composition and abundance of nematode communities may reflect soil characteristics such as fertility and pollution (Ferris et al., 2001). Changes in nematode community structure may signal disruptions in the soil environment, making them useful indicators of soil quality and ecosystem health. Furthermore, nematodes' sensitivity to environmental stressors such heavy metals and contaminants makes them suitable sentinels for monitoring soil contamination and its ecological repercussions (Liang et al., 2015). In this context, nematodes not only help with soil nutrient cycling, but they also give important insights into the general health of soil ecosystems.

**2.4 Chilopoda**

Soil invertebrates, especially the Chilopoda class, play an important role in improving soil quality due to their diverse contributions. Chilopods, or centipedes, are effective predators in soil ecosystems, feeding on a variety of soil-dwelling species. Their predatory efforts not only manage soil arthropod populations, but also help to break down organic matter, which speeds up nutrient cycling and decomposition (Barth, 2004). Chilopod excretion supplies soil with important nutrients, notably nitrogen, by converting prey into easily accessible organic matter (Bonkowski et al., 2000). Furthermore, their burrowing and tunnelling activities stimulate soil aeration and organic matter assimilation, hence improving soil structure and water retention capacity (Lavelle et al., 2006). Chilopods, as critical components of soil invertebrate populations, play an important role in promoting soil health and overall ecosystem function.

**2.5 Pseudoscorpions**

Pseudoscorpions, as soil invertebrates, play an important role in improving soil quality via their many ecological roles. These tiny arachnids help with nutrient cycling by feeding on soil-dwelling microbes, altering microbial community dynamics (Niedbała et al., 2018). Furthermore, they contribute to organic matter decomposition, which is necessary for nutrient release and soil structure development (Harvey & Frederick, 1990). Pseudoscorpions improve soil aeration and porosity by burrowing, resulting in greater water penetration and retention capacity (Scheu, 2003). Their presence promotes an intricate web of interactions that ultimately improves soil quality and productivity.

**3. Soil Invertebrates as Bioindicators**

The knowledge gained from natural ecosystems, which are distinguished by their rich diversity of plant and invertebrate species, emphasises the importance of sustainable agricultural practices (Mariotte et al., 2018). Bioindicators, whether taxa or functional categories, operate as environmental indicators (Manu et al., 2021). Environmental indicators are quick responders, offering early warnings of environmental changes and reflecting levels of taxonomic diversity at a site. Ecological indicators monitor specific stresses within an ecosystem.

Invertebrates frequently serve as valuable bioindicators, effectively reflecting environmental trends (Borgeset et al., 2021). Invertebrates, as bioindicators of biodiversity, may typically give more detailed information on species richness and community composition than vertebrates. This is owing to their simpler body structure, increased variety, and abundance. Their tiny size makes them sensitive to local circumstances, and their movement allows them to adapt to changing environmental conditions. Furthermore, their very brief life cycles make them suitable as bioindicators. Plant-Soil Feedback (PSF) is primarily influenced by soil microbial pathogens, herbivorous nematodes, insects, other invertebrate larvae, mycorrhizal These factors can have both direct and indirect effects on plant growth by influencing the physicochemical properties of the soil, such as pH, organic matter content, water retention capacity, soil temperature, and structure (van derPutten et al., 2016). Earthworms, for example, have a significant impact on plant growth due to the physical, chemical, and biological changes they cause. Scheu (2003) discovered that more than 75% of the studies analysed revealed an increase in plant biomass in the presence of earthworms. Their influence on plant productivity manifests through both direct effects, such as plant root feeding and seed transport, and indirect effects, which include altering soil structure, affecting mineralization processes, dispersing microorganisms, and inducing hormone-like effects (Wurstet al., 2018).

While there are numerous advantages to using invertebrates in studies that explore the plant-invertebrate relationship, Soil invertebrates have important ecological functions that impact the structure and operation of terrestrial ecosystems. Their contributions involve a wide range of critical tasks, including organic matter decomposition, nitrogen cycling, soil structure alteration, and plant community management. Soil invertebrates have an important role in driving biogeochemical processes and ecosystem dynamics. Their actions affect a wide range of trophic levels, from soil microbes to aboveground plant and animal groups. In the next discussion, we will look at the scientific basis for these ecological functions of soil invertebrates, emphasising the essential impact they have on ecosystem stability and resilience.

**4. Ecological Roles of Soil Invertebrates**

Soil invertebrates play an important role in the decomposition of organic materials. This process includes the breakdown of complex organic molecules into simpler ones, making nutrients and carbon available to plants and other organisms (Swift et al., 1979). Invertebrates like earthworms, arthropods, and nematodes are prolific decomposers, helping to change leaf litter, deadwood, and other organic debris. They accelerate the breakdown of organic waste by mechanically fragmenting and digesting it, releasing important nutrients back into the environment. Soil invertebrates support nutrient cycle by recycling components such as carbon, nitrogen, and phosphorus (van der Putten et al., 2016). This dynamic process eventually underlies primary production, promoting the development of plants and the whole food web.

**Table 2. Ecological Role of Soil Invertebrates and their Impact on Soil Quality**

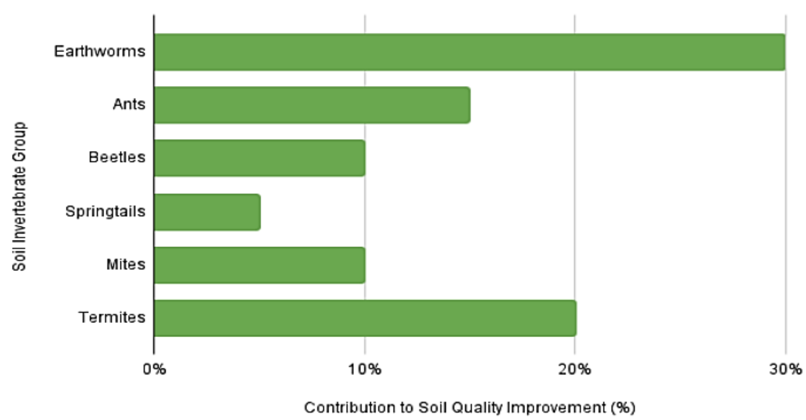
| Ecological Role | Invertebrate Example (s) | Impact on Ecosystem and Soil Quality |
|---|---|---|
| Predators | Ground Beetles, Spiders | Control pest populations, indirectly enhancing plant growth and soil health |
| Pollinators | Bees, Flies | Aid in pollination, promoting plant reproduction and diversity |
| Decomposers | Collembola, Earthworms | Facilitate organic matter decomposition and nutrient cycling |
| Soil Engineers | Ants, Termites | Modify soil structure and affect water infiltration and nutrient distribution |

In addition to their involvement in decomposition, soil invertebrates are important drivers of nitrogen cycling in ecosystems. Microbes, nematodes, and earthworms help mineralize organic matter by transforming complex organic chemicals into inorganic forms that plants can use (van der Putten et al., 2016). Soil invertebrates also form symbiotic interactions with microbes including mycorrhizal fungi and plant growth-promoting bacteria, which influences nutrient dynamics (Wurst et al., 2018). These interactions help plants absorb nutrients more efficiently, since invertebrates may increase nutrient availability and absorption via their activities (Bonkowski et al., 2009). Furthermore, soil invertebrates regulate the quantity and composition of soil microbes, influencing nutrient cycle processes (Scheu, 2003).Invertebrates also play an important ecological function by modifying soil structures. Earthworms are known for their ability to alter soil structure (Lavelle et al., 2006). Their burrowing and casting actions modify soil physical qualities, improving aeration, water infiltration, and root penetration (Blouin et al., 2013). These changes have far-reaching consequences, affecting not just soil structure but also the availability of nutrients for plants and soil microbes (Johnson et al., 2011). Furthermore, soil invertebrates indirectly influence soil compaction, lowering the risk of soil deterioration and erosion (Lavelle et al. 2006). Invertebrates shape soil structure, creating homes and niches for other creatures, which contributes to total biodiversity and ecological stability.Soil invertebrates also have an ecological function in regulating plant communities, which affects the composition, variety, and distribution of plants. Invertebrates may have a direct impact on plant communities by selectively feeding on plant elements such as roots, leaves, and seeds (Cifuentes-Croquevielle et al., 2020). These interactions affect competitive relationships among plant species, perhaps favouring some over others. Furthermore, invertebrates have an indirect impact on plant communities via their interactions with soil microbes and nitrogen cycling (Wurst et al., 2018). Changes in plant communities may have a ripple effect across the ecosystem, impacting primary production, food web structure, and overall ecosystem function (van der Putten et al., 2016). Invertebrates have important ecological functions that affect ecosystem stability and resilience.

**5. Future Directions.**

The use of soil invertebrates to improve soil health and quality offers considerable potential, as shown by the acknowledgment of their critical involvement in different ecological processes. This field's research is projected to follow many important directions. First and foremost, a thorough knowledge of the exact processes by which soil invertebrates affect soil health will be required. This includes researching further into how they affect soil structure, nitrogen cycling, and organic matter decomposition. Understanding the complex relationships between invertebrates and soil processes allows us to better exploit their potential for soil development (Schulze & Mooney, 1994; de Ruiter et al., 1994).

**Fig 1. Contribution of Invertebrates in Soil Quality Improvement**



The incorporation of soil invertebrates into sustainable farming operations is an interesting area for future study. Designing and executing agroecological systems that capitalise on invertebrates' natural activities may assist minimise dependency on chemical inputs while also promoting environmentally friendly agricultural practices. The function of invertebrates in agroecosystems will be studied closely, notably in terms of pest management, soil fertility, and crop yield improvement (Lal et al., 2015; Gurr et al., 2016).

Furthermore, as global environmental changes continue to occur, it will be critical to understand how soil invertebrates adapt to and affect these changes. Climate change, land-use changes, and habitat loss all provide substantial challenges to soil ecosystems. Research studying soil invertebrate populations' flexibility and resilience in the face of these stresses is critical for anticipating the long-term consequences on soil health and quality (Wardleet al., 2004; van der Putten et al., 2013).The future of soil invertebrate research will place a greater focus on the interaction of above- and below-ground activities. Soil invertebrates communicate in a sophisticated network that extends beyond the soil. An developing field is the study of the relationships between invertebrates, plants, and above-ground animals, as well as how these interactions affect soil health and ecosystem functioning. Advances in molecular methods and omics approaches will help to light the black box of soil invertebrate contributions to soil health. We may acquire insights into the precise features and processes that cause their beneficial effects on soil quality by unravelling the genetic and molecular foundations of their activities (Moretti et al., 2016; Wilschut & Kleunen, 2021).Finally, future research on soil invertebrates must prioritise long-term monitoring and global-scale evaluations to fully understand their contributions to soil health and quality. Large-scale, cross-continental research is required to determine the generalizability of their activities across various environments. International cooperation and data exchange will be required to collect comprehensive datasets that can support evidence-based management methods (Bongers, 1990; Parmelee et al., 1993).In conclusion, the future of soil invertebrates as contributors to soil health and quality requires a multifaceted strategy. Understanding the mechanisms that underpin their roles, incorporating them into sustainable agriculture, addressing their responses to environmental changes, investigating above- and below-ground interactions, leveraging advanced molecular techniques, and fostering large-scale, global research collaborations are the key avenues that will propel this field forward. By going further into these study areas, we may realise the full potential of soil invertebrates as partners in the fight for better soil health and ecosystem sustainability.

**Conclusion**

In conclusion, this thorough analysis has shed light on the critical function of soil invertebrates as sentinel creatures in detecting soil quality. A better knowledge of their importance in soil ecosystems has arisen as a result of an investigation into their usage as bioindicators, the ecological roles they perform, their taxonomy, and future research opportunities. Soil invertebrates serve as bioindicators, providing vital insights into the status of the ecosystem and accurately reflecting environmental changes. Their different functional categories react to a wide range of abiotic and human influences, contributing to the complex dynamics of soil ecosystems. As this review has shown, invertebrates have the capacity to alter plant community structure and composition, nitrogen cycling, and ecosystem successional trajectories. Their sensitivity to local circumstances, short life cycles, and simplicity of collecting make them excellent subjects for investigations on species diversity and community dynamics.

Furthermore, the taxonomy of soil invertebrates is critical to their effectiveness as bioindicators. As research progresses, a more sophisticated knowledge of the many invertebrate species is essential. By going further into taxonomic complexities, researchers may find certain invertebrate groups that are especially suggestive of soil health, resulting in more precise soil evaluations. Taxonomy serves as the key in this setting, allowing for exact categorization and identification of invertebrates as well as reliable monitoring of population dynamics. Looking forward, the study of soil invertebrates promises to broaden horizons. The developing discipline of molecular ecology has the potential to advance our understanding of soil invertebrate groups.

Molecular approaches enable researchers to dive into the deep genetic basis of invertebrate-soil connections. This line of study provides insights into the genetic basis of plant-soil interactions, offering light on the development of plants and soil biota. The combination of molecular technologies and classic ecological methodologies may give a comprehensive perspective of soil health and open up new areas for future research. Furthermore, in the next years, there will be a greater acknowledgment of the need of an integrated approach to soil health evaluation. An integrated framework that includes soil invertebrates, microorganisms, and plants may provide a thorough knowledge of soil ecosystems. This comprehensive approach will reveal the complicated web of interactions that influence soil health and give a more nuanced understanding of the function of invertebrates in these systems.

Furthermore, the advent of multidisciplinary research initiatives, such as the combination of soil science, ecology, and genetics, offers promise for a more comprehensive knowledge of soil health evaluation. Finally, soil invertebrates serve as sentinels of soil health, demonstrating the complex and dynamic character of soil ecosystems. Their position as bioindicators, ecological roles, classification, and research paths all contribute to a better understanding of their importance. The evaluation of soil health, as noted in this study, goes well beyond conventional bounds, including genetics, ecology, and the complex interactions between biota and abiotic variables. As we go forward, the complex world of soil invertebrates will continue to be a source of scientific inquiry, giving important insights on the health and vitality of our soil ecosystems.

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**References**

1. Blouin, M., Hodson, M. E., Delgado, E. A., Baker, G., Brussaard, L., Butt, K. R., ... & Brun, J.-J. (2013). A review of earthworm impact on soil function and ecosystem services. European Journal of Soil Science, 64(2), 161–182. doi:10.1111/ejss.12025
2. Bonkowski, M., Griffiths, B., & Ritz, K. (2009). Food-web complexity affects soil community responses to drought. Microbial Ecology, 58(2), 280–286.
3. Cifuentes-Croquevielle, A., Goenaga, R., Ruzzante, D. E., Leiva, J. C., & Carmona, M. (2020). Changes in mite species density and composition affect soil organic matter transformation rate and fertility. Applied Soil Ecology, 156, 103671.
4. Johnson, D., Vandenkoornhuyse, P. J., Leake, J. R., Gilbert, L., Booth, R. E., Grime, J. P., & Young, J. P. (2011). Plant communities affect arbuscular mycorrhizal fungal diversity and community composition in grassland microcosms. New Phytologist, 189(2), 257–265
5. Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., ... & Toutain, F. (2006). Soil functions in a changing world: The role of invertebrate ecosystem engineers. European Journal of Soil Biology, 42, S23–S25.
6. Scheu, S. (2003). Effects of earthworms on plant growth: Patterns and perspectives The 7th international symposium on earthworm ecology · Cardiff · Wales · 2002. Pedobiologia, 47(5–6), 846–856. doi:10.1016/S0031-4056(04)70279-6
7. Swift, M. J., Heal, O. W., & Anderson, J. M. (1979). Decomposition in terrestrial ecosystems. University of California Press.
8. van der Putten, W. H., Bardgett, R. D., Bever, J. D., Bezemer, T. M., Casper, B. B., Fukami, T., ... & Wardle, D. A. (2013). Plant–soil feedback: The past, the present and future challenges. Journal of Ecology, 101(2), 265–276. doi:10.1111/1365-2745.12054
9. van der Putten, W. H., Bradford, M. A., Brinkman, E. P., van de Voorde, T. F., Veen, G. F., Bailey, J. K., ... & Olff, H. (2016). Where, when and how plant–soil feedback matters in a changing world. Functional Ecology, 30(7), 1109–1121.
10. Wurst, S., & Ohgushi, T. (2018). Do soil organisms affect plant–herbivore interactions? Soil Biology and Biochemistry, 116, 180–186. –Bardgett, R. D. (2018). The biology of soil: A

community and ecosystem approach. Oxford: Oxford University Press.

11. Bongers, T. (1990). The maturity index: An ecological measure of environmental disturbance based on nematode species composition. Oecologia, 83(1), 14–19. doi:10.1007/BF00324627

12. Gurr, G. M., Wratten, S. D., Landis, D. A., & You, M. (2017). Habitat management to suppress pest populations: Progress and prospects. Annual Review of Entomology, 62, 91–109. doi:10.1146/annurev-ento-031616-035050

13. Lal, R., Follett, R. F., & Stewart, B. A. (2015). Soil management and greenhouse effect. Boca Raton, FL: CRC Press.

14. Moretti, M., Dias, A. T. C., de Bello, F., Altermatt, F., Chown, S. L., Azcárate, F. M., ... & Dinnage, R. (2017). Handbook of protocols for standardized measurement of terrestrial invertebrate functional traits. Functional Ecology, 31(3), 558–567.

15. Parmelee, R. W., Wentsel, R., & Checkai, R. (1993). Earthworms and the vertical distribution of organic matter in a sugar maple forest. Soil Biology and Biochemistry, 25(5), 689–692.

16. Schulze, E. D., & Mooney, H. A. (1994). Biodiversity and ecosystem function. Berlin: Springer