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Deficits, needs, solution attempts and transfer formats for implementing a "Soil Biodiversity Awareness" in Germany*

Willi E. R. Xylander[1,2,a] and Frank Glante[3]

[1] Senckenberg Museum for Natural History Görlitz, P.O. Box 300 154, 02806 Görlitz, Germany
[2] Internationales Hochschulinstitut Zittau, TU Dresden, Markt 23, 02763 Zittau, Germany
Postal address: Schönbergerstr. 10, 02827 Görlitz, Germany
[3] Umweltbundesamt Dessau, Wörlitzer Platz 1, 06844 Dessau-Roßlau, Germany
Postal address: Mozartstraße 15a, 15345 Eggersdorf
[a] Corresponding author, e-mail: willi.xylander@senckenberg.de

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Abstract

Understanding of soil biodiversity and its ecological importance is limited in society. This is to some extent a consequence of an "image problem" of soil, but also due to a lack of expertise among multipliers. Therefore, targeted measures are needed to inform key communicators about this topic, such as incorporating it into teachers' theoretical and practical curricula and providing educational materials. Extracurricular learning venues such as museums can engage a wider audience through exhibitions, but also through the use of immersive digital formats (such as virtual reality animations); in this regard, the Senckenberg Museum in Görlitz which has a significant research focus on functional soil biodiversity has developed exhibitions, various other measures and formats within the last decade which are considered here. Approaches to transdisciplinary communication through music, visual arts or handicrafts, as well as interdisciplinary teaching in schools seem promising, but are only sporadically implemented in practice to date. Direct contact with soil animals, especially for children and adolescents, is an inspiring experience that raises their awareness for the topic. In the German media, there is limited awareness of the importance of soil organisms for the functioning of terrestrial ecosystems, too. It is the task of professional scientists and educational institutions to raise the societal awareness as a whole to these issues. This paper reflects the status of awareness for soil health, biodiversity, protection and ecosystem services with a major focus on the situation in Germany and summarizes initiatives and measures to increase awareness. It demands for active engagement of scientists in presenting their research and its socio-ecological relevance to a broad public.

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1. Introduction

Soil and its biodiversity are often undervalued by both adults and children, likely due to the increasing urbanization and disconnection from food production and soil's ecological role, particularly since the transition from an agricultural to an industrialized society. As a consequence, the willingness to engage with soil organisms is low despite their importance for the functioning of terrestrial ecosystems (reviews in Xylander et al. 2015, Eisenhauer 2024). In addition, soil animals are perceived as repulsive by many people: earthworms with their legless, slimy bodies and peristaltic, wobbling movements, woodlice, millipedes and spiders with their many legs and unusual movement patterns often evoke discomfort. And adults curb the curiosity of many children through their reservations (Gebhard & Scheersoi 2020).

As is so often the case, a lack of knowledge about ecological processes in the soil (e.g. decomposition, bio-physical degradation of minerals, aeration by mega- and macrofauna) results from disinterest in and rejection of many soil organisms. If parents, educators and teachers also share this reluctance and can impart little or no knowledge about or empathy for life in the soil, this deficit cannot be overcome. It is passed on to the next generation. This is because content on soils and biodiversity of soil organisms is represented in the curricula of only few of the federal states in Germany. School gardens implemented in some schools which may reflect aspects of soil health and ecosystem functions can – to our opinion – not fully compensate this deficiency if teachers have not gained information during their academic training and thus set no focus here.

In addition, the extracurricular educational programs offered by e. g. conservation centers, natural history museums and non-governmental organizations mostly tend to focus on more popular animals such as e.g. birds, mammals, amphibians, butterflies and plants. Soil animals hardly appear here, not least because materials that provide easy access to this topic are lacking or difficult to apply in educational practice. It is only in recent years that programmes for teachers, pupils and out-of-school education - including family-oriented programs - have emerged that focus on soil biodiversity and its ecosystem functions and open up a target group-specific approach.

This article reflects the situation in Germany and aims to highlight existing gaps in awareness and education. It also wants to present recent approaches and successful positive examples for the communication of soil biodiversity and its relevance for agriculture and forestry, for consumers and politics. This may help to stimulate a change in thinking and gain greater appreciation of soils, from which a sustainable use and appreciation of their biodiversity will arise. So we consider how to improve communication of soil related topics into the society and thus raise the understanding e. g. of the soil related ecosystem services. Finally, we want to motivate the scientists to engage in the communication process and acknowledge the society – beside the scientific community – as a relevant target group for addressing relevant and reliable information.

2. Emotions - experience soil animals

The direct, hands-on interaction with various soil animals evokes emotional responses and thus enables personal experiences as a basis for sustainable learning (Xylander 2020a). Teaching units in which school classes can observe living representatives of macrofauna from leaf litter samples and mesofauna directly or from extracted soil samples under binoculars have proven successful (Fig. 1). The young participants quickly develop a tangible fascination for this unknown world – as personally experienced during many such educational units (see also Ansorge et al. 2006); this personal experience opens up approaches for in-depth studies, for example on biodiversity, ecological functionality, nutrient cycles, predator-prey relationships or soil protection. Teaching soil biodiversity furthermore can fulfill different points on school curricula at the same time as it can easily be combined with teaching scientific practices.

As part of excursions - especially with children - soil animals can be collected in the leaf litter or in deeper soil layers in order to illustrate how soil animals colonize different habitats. Handling soil animals reduces fears and fosters a connection to the organisms and their habitat. The inclusion of extracurricular teaching locations such as museum exhibitions, nature conservation centers or environmental vehicles (e.g. https://www.nua.nrw/lumbricus) make learning more interesting. Also soil nature trails that have been created in numerous places in Germany are recommended for practical work - especially with older children and young people.

For lessons in the classroom, ready-to-use materials such as the 'soil suitcase' are ideal (see e.g. http://www.bodenkoffer.de, for international references see https://ecoledusol.fr/ or https://bodenkoffer.at/). Instructions for simple experiments that can be carried out without a great deal of technical effort have been developed for pupils aged 10 and over, e.g. to introduce the behaviour and habitat requirements of soil animals, as

Figure 1. Adolescents in a course on soils, scrutinizing soil samples for meso- and macrofauna. Photo: W. Xylander

well as the cleaning and filtering functions of soil (e. g. Roch 2010). An emotional approach to the topic of soil biodiversity in the classroom, but also in print media, exhibitions and other formats, is the integration of biological facts into stories, i.e. the use of storytelling tools, as well as the visualisation of topics with powerful images (see also Ansorge et al. 2006; Beblek et al. 2017). Exhibtions such as 'The thin skin of the earth – Our soils' developed by the Senckenberg Museum für Naturkunde Görlitz, 'Mineral Resources' at the Museum in Kalkriese and the exhibitions at the Museum am Schölerberg in Osnabrück also use storytelling as a communication format.

3. Engaging key multipliers

One challenge for the successful transfer of the topic of soil protection and soil biodiversity into the classroom is the qualification of teachers: as long as teachers feel insecure about addressing soil biodiversity in the classroom, the topic will not find a sustainable place in school education. Teaching children and young people about soil biodiversity and its importance and raising their awareness for soil protection through school lessons is only possible if a) teachers are taught the relevant basics as part of their academic training and b) practical materials are available and accessible for use in the classroom for free via repositoria (e. g. https://www-lanuv-fis.nrw.de/boden-fueralle/unterrichtsmaterialien/materialien-fuer-den-unterricht?utm_source=chatgpt.com).

The implementation of the topic of soil biodiversity in society stands and falls with committed, well-informed multipliers. The basics of the soil habitat and its organisms must therefore become part of biology and geography teacher training programmes at universities and in teacher training courses. Practically relevant resources are now available that contain worksheets, simple identification keys for soil animals, information on their biology, experiment instructions, games and examples for interdisciplinary teaching (e.g. Roch 2010; Böhme 2018, further information also in https://www.umwelt-im-unterricht.de/wochenthemen/boden-ist-wertvoll?), adapted to the respective curricula, school types and class levels. The further development of such handouts, media and other formats, the use of which in lessons reduces the workload for teachers, would be a task for

the Ministries of Education and Cultural Affairs and subordinate authorities.

In addition, further training events for multipliers should be offered both at universities and in research institutions specializing in soil biodiversity. These events should combine theory and practice and focus on the transferability of content into school lessons, i.e. include target group-specific progra mmes ranging from low-threshold for kindergartens and primary schools to experimental-scientific programmes for secondary schools (e.g. Asshoff et al. 2011, Beugnon et al. 2024, Gebhard & Scheersoi 2020, Roch 2010, Xylander 2020, 2024). Visits to laboratories, experimental areas or thematically appropriate museum exhibitions can be part of the programmes.

Figure 2. View from the bottom to the top of the 6 m model of a 30 times enlarged soil column in the stair case of the Senckenberg Museum of Natural History Görlitz with a 4,5 m *Lumbricus terrestris* and many other soil invertebrates. Photo: W. Xylander

4. Visualisation, explanation, haptic experience, change of scale: exhibitions

Natural history exhibitions in museums offer an opportunity to address specific topics to a broad public; they also often serve as a 'showcase for research'. In the past 20 years, only a few natural history exhibitions have focussed more intensively on the topic of soil and soil biodiversity.

At the Senckenberg Museum of Natural History in Görlitz, a 6-metre-high soil column illustrates the stratification of a forest floor, the distribution of soil organisms in the various soil horizons and numerous soil animals using enlarged models and a film (Fig. 2). From 2000, the Museum am Schölerberg in Osnabrück presented an exhibition on soil animals and a vivarium with living soil animals in cooperation with the Osnabrück zoo located next door. The museum's new permanent exhibition, opened in 2023, also deals with soil biodiversity and its functions, e.g. via enlarged soil animal replicas, a (mycorrhizal) fungus telephone and a whispering floor that tells the stories of an isopod and a centipede.

In contrast to these permanent exhibitions, which are usually shown unchanged for more than a decade, travelling and special exhibitions can only be seen for a limited period of time. They can present more up-to-date research findings. Travelling exhibitions generally reach a wider audience than permanent exhibitions as they are shown at many locations throughout the country (see Xylander 2020b). Since 1995 the Senckenberg Museum für Naturkunde Görlitz that has a major research focus on soil animals has therefore organised three international travelling exhibitions on the topic of soil biodiversity, seen by almost 2 million visitors at over 30 locations in Germany and abroad. The current Senckenberg travelling exhibition on soil, 'The Thin Skin of the Earth - Our Soils', presents four main themes: Soil biodiversity, soil types, soil protection and soil research (Xylander & Zumkowski-Xylander 2018, Zumkowski-Xylander et al. 2017). The scenography, provocative headlines and focussed panel texts, enlarged models of soil animals and choice of topics, as well as the level of access, which does not require any prior knowledge, appeal to different target groups, with a major focus on school classes and families.

The largest part of the exhibition is dedicated to soil biodiversity (Fig. 3). The narrative focuses on the ecosystem functions of soil organisms, especially on the organismic contribution to decomposition and nutrient recycling, and on the adaptations of predators and prey; this part is designed as a tunnel system, which is bordered by a "roof" of oversized leaves with feeding

traces covering this section of the exhibition. One model each of the macro-, meso- and microfauna visualises the size classes of soil animals, but also the sequential decomposition of leaf litter. Hands-on stations allow visitors to try out the functioning of the different mouthparts of soil animals or to visualise the incredible numbers of organisms under one square metre of a decidious forest floor. Numerous films and digital media such as the animation 'Let's talk about soil' developed by the RIFS (Forschungsinstitut für Nachhaltigkeit am GFZ) and a unique virtual reality presentation complement the exhibition (Wesenberg et al. 2019, Westermann et al. 2018, Xylander 2019). Since October 2015, about one million visitors have visited 'The Thin Skin of the Earth' at 15 locations in three countries.

There are only few research paper dealing with visitors´ reception of exhibitions on soil and soil biodiversity (e. g. Baber et al. 2019 using questionaires of more than 1.000 users of the VR "Adenture Soil Life"; the unpublished B.Sc. thesis of Sandy Nagy who interviewed 121 children between 5 and 14 years of age in the Senckenberg travelling exhibition "Below our feet" (Nagy, S. (2011) "*Wie beeinflusst die mediale Präsentation die inhaltliche Perzeption in naturkundlichen Ausstellungen*", B.Sc. thesis, University of Leipzig, mentioned in Xylander & Zumkowski-Xylander 2018). So there is still a need for future investigations to evaluate the perception efficiency and improvement capacity for natural history museum exhibitions, other presentation as well as new educational formats.

5. Popular science publications

While many popular science publications and games for different target groups have been developed for other environmental topics, these were lacking for soil for a long time in German-speaking countries. In recent years, however, a number of well-researched, in-depth popular science publications on the topic of soil and soil ecology have been published (e.g. in erman: Dohrn 2019; Schwinn 2019). There are also books on the topic for children and young people with different formats and narratives, e.g. the brochure "Fridolin – the Earthworm", the most successful publication for kids of the German Environmental Agency (UBA) or the booklet "Klara Springtail" by Zumkowski-Xylander (2017a) and others (Guillain et al. 2018; BMBF 2021). Publications for kids also in other languages were provided by Jochum et al. (see https://kids.frontiersin.org/collections/11796/soil-biodiversity) or by the FAO (https://openknowledge.fao.org/handle/20.500.14283/i7957en).

The card game 'The Soil Builder' ("Der Bodenbauer" by Helga Zumkowski-Xylander 2017b) constitutes a playful approach to the topic of soil and soil protection (see Xylander 2020a). Here, players have to collect the elements of healthy soil (e. g. soil animals, microorganisms, humus, mineral components, air and water) and are hindered by 'disturbance cards' (erosion, soil compaction, pesticide use).

Figure 3. View into the "Chamber of Life" of the international Senckenberg touring exhibition "The thin skin of the earth – Our soils". Photo: W. Xylander

6. Citizen Science

In the past, citizen science activities have not only proven to be a valuable source of data for biodiversity monitoring, but also a basis for a deeper understanding of ecological relationships and societal empowerment (e. g. Burton & Cameron 2021, Walker et al. 2021). Thus, promoting citizen science is a suitable approach for increasing awareness of soil biodiversity. However, the vast majority of soil animals are very small and cannot be identified without a longtime taxonomic experience, special literature, reference collections and high-quality microscopes. On the other hand, for some larger soil animals such as earthworms conventional determination keys are available and the majority of relevant characters (in most European species) are accessible using a normal magnification glass. So for some groups of larger soil animals (e. g. Carabidae, Lumbricidae) there are communities of active citizen scientists involved in monitoring and ecological surveys – often with a scientific background by institutes or organizations via funded projects (such as earthworm watch or SoilRise https://www.citizen-science.at/projekte/soilrise; https://www.uni-goettingen.de/de/soilrise/688271.html) - providing data stored in databases and repositories for scientific evaluation.

The Senckenberg Museum has developed an app that makes it easier for citizen scientists to identify three other prominent groups of soil macrofauna: centipedes (Chilopoda), millipedes (Diplopoda) and isopods (Isopoda) (Decker et al. 2019). For these taxa only conventional determination keys were available which were hard to use for taxonomic beginners. The app and the training courses were funded by the project museum4punkt0. During a test phase, numerous introductory courses were offered to interested users, which significantly increased the quality of identification and also the willingness to collect and provide data in the future (Neu et al. 2022).

7. Art and soil biodiversity

A promising approach to raising awareness of environmental issues lies in a combination with artistic formats (see Feller et al. 2015) and so the topic of soil has also arrrived in art. However, there are only a few such transdisciplinary formats that have a focus on soil biodiversity whereas there are numerous collaborations between artists and soil science: Painters use different soils, soil particles and structure or deal with soil in a more metaphoric approach to create images or video installations (Toland & Wessolek 2010). Obviously, art has more difficulties visualizing soil biodiversity than inorganic soil as a substratum and matrix. Soil animals (such as millipedes, spiders, or woodlice) or their ecology receive less attention and - if they are the subject of artwork at all - often remain merely an accessory in still lifes; however, recently commercial art on soil animals became available (e.g. https://smartwork.bigcartel.com).

In recent years, the ‘Theatre of the Anthropocene’ in Berlin under the direction of Frank Raddatz has staged and performed the revue ‘Critters’ on soil biodiversity and vulnerability. The production highlights and visualizes the subsoil life and its importance for mankind and loss through various artistic elements such as performances, dance, poetry, and music (Fig. 4).

8. Innovative, immersive formats of communication - opportunities by technology

A digital additional offer for the exhibition ‘The thin skin of the earth’ is the globally unique VR animation ‘Adventure Soil Life’, which the Senckenberg Museum developed together with the company .hapto from Cologne as part of the museum4punkt0 project network (see short presentation at https://vimeo.com/channels/hapto/333094945). Using HTC Vive glasses, visitors are shrunk to the size of an isopod (1 cm in size) and encounter lifelike animated soil animals in the leaf litter, in the soil pores a few centimetres below ground and in water films around soil particles or in tiny soil spaces (see Wesenberg et al. 2019; Westermann et al. 2018; Xylander 2024 a). A large screen at the setting allows companions (e.g. family members or classmates) to observe in real time what the users experience in the goggles and interact with them (Fig. 5). This digital format enables immersion in a world otherwise inaccessible to humans and a scale-modified unique experience of soil life. In a study based on 1,500 questionnaires from users of the VR (during a 2 weeks presentation in the Senckenberg museum in Görlitz), over 70% stated that they had developed a deeper understanding of soil animals after the virtual experience. 88% of children and 44% of adults reported an increased interest in the soil animals (Baber et al. 2019). The VR travels with the exhibition to the presentation locations if the partner museums have capacities (personnel and/or space) to present it.

A world first among the digital applications is a device that generates holograms of soil animals, based

Figure 4. Dancer Liv Frenkel – dancing the life of an ant – during a performance of "Critters" for the Humboldt University, a production of the Theatre of the Anthropocene Berlin. Photo: H. Zumkowski-Xylander

on an invention by the Voxon company and developed to museums´ application demands by .hapto. It allows the three-dimensional, holographic presentation of about 10 different soil animals. With the help of an artificial intelligence hand control device, the user can rotate, enlarge or reduce the holograms (Fig. 6). The possibility of interacting 'pseudo-haptically' with the virtual animals encourages the user to engage with the morphology of the animals and helps to reduce resentment.

Figure 5. Setting of the virtual reality animation "Adventure Soil Life", user interacts with habitat and organisms with a controller, accompanying persons can watch via a large screen. In the situation shown the user has virtually picked a springtail from the litter layer with the controller and is able to turn it around to look at it from various directions. The surroundings show the ground of a deciduous forest covered with litter and mushrooms. Photo: J. Gitschmann, Senckenberg

9. Media presence

A major challenge in raising awareness of soil biodiversity is its low media presence. Soil enjoys nationwide attention in Germany once a year: at the beginning of December when the 'Soil of the Year' is announced; this date coincides with the World Soil Day where also in other countries there are activities on soil, soil protection, types and biodiversity. Television programmes, radio productions or the print media, on the other hand, hardly ever address soil biodiversity and its functions (apart from a few exceptions such as 'Löwenzahn', 'Planet Wissen' or 'Im Reich des Regenwurms - Der Boden unter unseren Füßen' on ARD and Arte). This is not least due to the fact that the small, at first glance unspectacular soil creatures do not attract a mass audience. A rising audience for journals about gardening, sustainability, and recreation in nature, however, offer an opportunity to raise awareness for and gain better understanding about soil biodiversity.

Even more noticeable is the near-total absence of this topic on social media channels. Only certain scientific organisations (such as the German Soil Association or the German Soil Science Society) and a few ambitious photographers who post macro images e. g. of springtails, mites and other soil animals use these formats to communicate aspects and present representatives of soil biodiversity.

The low media presence is the result of a vicious circle: a lack of knowledge about soil biodiversity results in a lack of interest in this topic among media consumers. As media producers are focussed on topics of general interest, soil biodiversity hardly generates any attention in the editorial offices. As a result, the media coverage of this topic remains limited (Beblek et al. 2017).

Figure 6. Interactive hologram presentation of a moss scorpion – one out of 10 soil animals visible in the presentation. Photo: J. Gitschmann, Senckenberg

10. Soil biologists are in charge – leave the ivory tower!

In the past, scientists from universities, other research organisations or conservation institutions (with a focus on soil biodiversity) have repeatedly pointed out gaps, called for changes and proposed solutions (e.g. Eisenhauer et al. 2024, Leopoldina 2020, Mathews et al. 2020, Xylander 2024 b), but with little response if the criterion for success is consistent and comprehensive implementation in practice.

Therefore, there is a need for committed and intensified public relations work by soil biodiversity researchers and their institutions, which - in addition to other target groups - address political decision-makers, describe the status and current trends, identify drivers and propose specific solutions. At least in an initial phase, the research institutes, scientists and public relations officers should prepare and make available target group and topic-specific press releases, events, printed materials, high-quality, free-to-use films, animations and other formats for the media. Such media must be adapted to an easy use for e.g. teachers, children and NGOs. They should be made available free of any charge in as many languages as possible. The initiatives "Translating Soil Biodiversity" (Beugnon et al. 2024) and LOESS (https://loess-project.eu/, last checked March 2025) provide promising international measures in an interdisciplinary and transnational approach addressing teachers as well as school children.

Furthermore, scientists should be open for presentation of their results to a broader public by writing and popular lectures of their work – parallely to addressing their work to the scientific community – as authors of easy to understand articles, being interview partners for the public media or by posting contributions in the social media. Scientists should even actively demand for medial publicity for their field of work and the socio-ecological consequences of the loss of biodiversity and ESS.

The soil chapter as part of the "Faktencheck Artenvielfalt" (Eisenhauer et al. 2024), the condensed version summary for societal decision making (Wirth et al. 2024, 2025) and other publications on Faktencheck (Guerra et al. 2024, Kleemann et al. 2025, Ristok et al. 2025) provide a basis and orientation for possible relevant topics and content.

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