SOIL ORGANISMS 92 (3) · August 2019 pp. 203–212

# Society´s awareness for protection of soils, its biodiversity and function in 2030 – We need a more intrinsic approach

**Willi E.R. Xylander**[1,2]

[1] Senckenberg Museum of Natural History Görlitz, Postfach 300 154, 02806 Görlitz, Germany
[2] Internationales Hochschulinstitut Zittau, TU Dresden, Markt 23, 02763 Zittau, Germany
Email: willi.xylander@senckenberg.de

Received 19 November 2020 | Accepted 24 November 2020
Published online at www.soil-organisms.de 1 December 2020 | Printed version 15 December 2020
DOI 10.25674/so92iss3pp203

## Abstract

Decades of efforts to achieve comprehensive and sustainable soil (biodiversity) protection resulted in a moderate to limited success. The ecological arguments - the extrinsic approach - are largely formulated and known. However, it is not possible to make them sufficiently heard as they stand against the interests of lobby groups. Therefore, in order to protect the soil, its functions and biocoenoses efficiently, I plead for an extended, intrinsic, centripetal approach, which includes physical-haptic, but also digital experience, transdisciplinary networks and the establishment of sympathizers for soil biodiversity. To this end, I name best practice examples from the past and present. For the development and establishment of this 'strategy for a comprehensive sensitivity for soil (biodiversity) protection' I expect a period of 10 years.

Keywords soil biodiversity | conservation | touring exhibitions | science and art | story telling | virtual reality

## 1. Introduction

Like other non 'physically-experienceable' biocoenoses (e.g. polar or pelagic habitats of the open sea, deep sea or groundwater), the soil slides through the grid of public attention. Soil protection is not sufficiently heard by decision-makers in politics and economy - especially since the lobby of the agricultural industry, the large retail groups and others are exerting their influence on political decisions. Thus, soil biodiversity protection remains a poor relation to the perception in politics and society (Phillips et al. 2017, Cameron et al. 2019).

For more than 50 years, soil scientists and soil biodiversity researchers have been striving for sustainable protection of soils, soil biodiversity and their functions. In this effort, we often experience setbacks. For example, it was not possible to explicitly include the protection of soil biodiversity and its functions in the German Federal Soil Protection Act (Federal Ministry of Justice and Consumer Protection 2020) or to develop a European soil framework directive. This has severe implications for biodiversity, such as the rapid decline in invertebrates (e.g. Seibold et al. 2019) that live in the soil at least part of their life (Eisenhauer et al. 2019).

So, the approaches for sustainable agriculture, which the EU ratified a few weeks ago and which were praised by supporters as a first step towards a reorientation of agriculture in Europe via agricultural subsidies towards more sustainability and soil (biodiversity) protection seem to scientists and nature conservation as too little and not appropriate in view of the dramatic development of the last 70 years (see overview and demands formulated in Leopoldina et al. 2020).

Deficits and political omissions have been repeatedly criticized by scientists, but also by full-time nature conservation (in Germany Federal Environment Agency, Federal Agency for Nature Conservation). Recently, concrete demands have been made on politicians to eliminate or at least mitigate these shortcomings (see Mathews et al. 2020, Philips et al. 2020).

© Senckenberg Museum of Natural History Görlitz · 2020
**ISSN** 1864-6417 (print) · **ISSN** 2509-9523 (digital)
open access

## 2. There are enough extrinsic approximations

Experts emphasize the importance of the soil and its biodiversity for fertility, functionality and resilience, without which agricultural production would not be possible (Bardgett & van der Putten 2014, Eisenhauer et al. 2019). Soil animals significantly accelerate the recycling of nutrients; their digging activities ensure the bioturbation, aeration and loosening of the soil; crumb formation and biogenic absorption reduce the loss of nutrients and microorganisms are involved in the degradation and accumulation of pollutants (as far as the substances allow such degradation) (Wall et al. 2012). The indicator functions of soil organisms for fertility and its change, for soil quality and contamination are also services with which soil biodiversity protection can be justified (literature in e. g. Bünemann et al. 2016; Guillaume et al. 2016). Furthermore, soil is significantly involved in other processes that humans and the biosphere as a whole directly or indirectly require, such as $CO_2$ storage or water purification - to name but a few (overviews in Baer & Birgé 2018, Wall et al. 2012).

By raising public awareness, especially in the industrialized nations, of the negative effects of environmental pollution in recent years, 'healthy food' from ecological and (thus also from the point of view of soil protection) sustainable production has become more important (BMEL 2020). Many consumers are demonstrating their willingness to pay more for higher quality, resource-saving food (BÖLW 2020), and almost all supermarket chains offer products from organic farming. As gratifying as this change in thinking and willingness of broad circles of consumers is - it is countered by the continuing cheap production with dumping prices, which only works if ethical or ecological standards for nature and animal husbandry are ignored.

But many scientists are not used to argue politically neither they have strong stakeholders. This is part of the problem. Scientific and rational access to soil protection is, therefore, far from sufficient to bring about a change in thinking on a broad basis and to enforce it in society (see Blebek et al. 2017, Philips et al. 2020). In addition, neither university nor school curricula (of all types of schools) contain mandatory content on soil and soil biodiversity beyond a few selected aspects (e.g. the earthworm). And the deficits in their academic education make it practically impossible for most teachers to give exciting and qualified lessons on soil. How is such a sensitization for soil and its importance for human survival to succeed under such conditions?

## 3. Intrinsic approach - a feeling for the soil

For the soil, as for all other habitats, biotic communities and organisms, applies what Konrad Lorenz formulated: 'Only what one knows, one loves. Only what one loves, one protects.'

Since our educational institutions provide so little knowledge about soil biodiversity, the step from knowing to loving has not yet been successful. The inclusion of an emotional level that encompasses a holistic-global view - including mankind and the soil - is missing. Professional soil (biodiversity) protection argues and informs almost consistently with academic justifications and arguments. But is necessary to create empathy for the soil and its biodiversity simultaneously to the scientific arguments (Phillips et al. 2020). Emily Brady (quoted from Toland & Wessolek 2015 a) stresses out: '... an individual's scientific knowledge can be extremely limited by educational opportunity and experience, while imagination is only limited by the mind of the observer.' How can this emotional, impressive access to the soil succeed, which is open to all and which carries the idea of protection? The centrifugal approach - which is based solely on specialist knowledge of soil protection - obviously falls short.

The well-known German zoologist Adolf Portmann already pointed out that scientific arguments, as convincing as they may be, are not enough on their own to make many people change their minds: 'The natural sciences must learn to see the facts of the human being to a much greater extent than is actually the case with the majority of their representatives. They must try to see the wealth of human experience, the breadth of spiritual needs and artistic creativity, the power of religious experience in its true extent. Many find it difficult to renounce the tactic of reduction that sifts the human being through a network of concepts and only retains what can be said in the natural sciences, to renounce this popular simplification - but the path must be taken.' (Portmann 1998, p. 115, translation by www.DeepL.com/Translator, adapted by the author).

I therefore make a plea:

- We need centripetal approaches. We need to think about soil (biodiversity) protection in a transdisciplinary way and thus bring it closer to people.
- We need a transformative change in the perception of soil: not as an inanimate structure, but as an indispensable, active basis of terrestrial life, rich in species and individuals, which - regardless of its economic value for humanity - has the right to exist.
- Whenever we want to successfully convey information to people of different education and origin, we make use of storytelling. However, we tell (almost) no stories

about the soil, its creatures and their functions. But such stories are needed.
- We have to overcome the deficit that we cannot penetrate the soil pores and layers due to our body size and experience it directly (like when walking through a forest or diving into a lake or the sea). We must and can use the new digital media to generate an immersive, haptic experience of soil and its inhabitants.
- We must succeed in describing, visualizing, formulating and transporting the strange beauty and aesthetics of the soil and its inhabitants in a way that is generally understandable; to do this, we must find suitable new formats or develop proven ones further.
- After all, we need figureheads who stand for the soil animals' community and transport it to the target groups in a striking and positively documented way. It has to become visible that soil animals are - in their own way - beautiful, fascinating and lovable.

There are first approaches for the realization of these demands. It is necessary to communicate them beyond the undoubtedly important 'event days' - such as World Soil Day (http://www.fao.org/world-soil-day/en/) or World Earthworm Day (https://www.earthwormsoc.org.uk/worldwormday) - which are insufficient for a sustainable implementation. In my reflections, I focus on examples in Germany, supplemented by selected international activities. These stand *pars pro toto* for comparable activities worldwide.

## 3.1 Experience with all senses

Rarely do we use the opportunity to physically experience soil, to absorb its smell or to surrender to the structure of broken soil. By looking at it and touching it, walking barefoot over it, kneading it, laying it and feeling it, we bring ourselves closer to the soil - its colors and patterns, its structure, its olfactory characteristics, its warmth or coldness (see also Blebek et al. 2017).

Such experiences of the haptic handling of soil can be made, for example, in our own gardening work. Children and young people should therefore be given the opportunity to experience their own gardening or agricultural production (also as a result of soil functionality) in schools, perhaps even in kindergartens. 'School gardens' which were established in some German states at selected German schools - often on the initiative of individual teachers - a good decade ago have since often been orphaned and thus the physical experience of production from the soil has been lost. Here, a revival of the idea and its implementation sites is desirable.

**Figure 1**. Picture from the VR-animation 'Adventure Soil Life' part 'leaf litter'. By SMNG/.hapto modified after Xylander (2019).

Innovative digital media such as virtual reality make it possible to penetrate into the soil and, as part of the soil and soil biodiversity, to engage with it at eye level, to observe the organisms and their movements and to reduce resentment and fear (Baber et al. 2019). At the Senckenberg Museum für Naturkunde Görlitz, the VR 'Adventure Soil Life' was developed within the Museum 4.0 project (Xylander et al. 2018; Fig. 1. See also the list of digital material at the end of this article), which has been seen by more than 10,000 people. Here, the digital format is a mediator of experiences that compensates for the deficit of our body size in getting to know soil life and makes such an experience possible.

Also the microscopy of soil animals from the topsoil and the leaf litter under the binocular in the classroom creates sympathy, understanding and closeness (Fig. 2). With simple instructions, experiments and identification aids, children can learn to differentiate between the different soil animal groups and carry out experiments, e.g. on soil decontamination (see Asshoff et al. 2011, comprehensive materials for use in schools in Roch 2010).

Games dealing with soil animals and soil protection can also be a form of haptic exploration. The Senckenberg Museum in Görlitz has developed the card game 'Bodenbauer' (= Soil Builder; Zumkowski-Xylander 2017 b), in which 'ingredients' of soil biodiversity and soil structure have to be collected to put together a 'healthy soil'. The players can be disturbed while collecting cards by 'stop cards' (with illustrations of anthropogenic forms of intervention such as erosion, pesticides, soil compaction, Fig. 3). The playful examination of the soil as a structure and its biodiversity, but also of negative human influences, playfully promotes knowledge and an emotional approach to the soil.

## 3.2 Storytelling

'Storytelling is the basic conscious operation of creating meaning in cognition as well as in communication. Therefore, narrating is an indispensable operation which at the same time performs and reveals the intrinsic mediality of our relation to the (our) world' (Schmidt 2008).

The scientific representatives of soil science and soil biodiversity research have rarely used this option to propagate their ideas, results and admonitions. Even several well-researched and written books on soil published in recent years (Dohrn 2019, Schwinn 2019) that are aimed at a broad public are really informative but do not use the narrative sufficiently to emotionalize their concerns.

There are only a few successful, high-circulation soil animal stories to date. The best-known protagonist is probably the mole from Zdeněk Milers, who is known to three generations of children in Europe in over 60 cartoons, and later in children's books (e.g. Miler 1988, 1990). In the books and films Miler shows not only the mole, but also selected representatives of the soil arthropods (spiders, centipedes, beetles etc.). In this way, he succeeds in creating a positive-emotional approach to the representatives of this biocoenosis.

**Figure 2**. Pupils experiencing soil life in a class using dissecting microscopes. Soil samples for investigation were taken by the pupils themselves.


**Figure 3**. The card game 'Soil Builder' by Helga Zumkowski-Xylander (2017 b) (only a selection of cards is shown).

Julia Donaldson and Axel Scheffler made an earthworm (Superworm) the hero of their book of the same name in 2012, but the story is a fairy tale without a complex biological background. Due to the fame of the author through her earlier books, 'Superworm' became a commercial success. Helga Zumkowski-Xylander's book 'Klara Kugelspringer und ihre Reise' (Klara Springtail and her journey) (Zumkowski-Xylander 2017), which she wrote as accompanying material for children to the exhibition 'The Thin Skin of the Earth', not only deals with representatives of the soil mesofauna, but also describes human influence on the soil and the consequences for soil organisms (Fig. 4). The graphic artist and children's book author Rachel Ignotofsky illustrates and explains in one of her books, among other things, the importance of soil biodiversity in the carbon cycle in a remarkably vivid and child-oriented way (Ignotofsky 2018), but as a contribution in kind and not as a story.

Natural history exhibitions represent a special form of storytelling. They use texts, images, models, dermoplastics, films and other formats to convey biological themes to the general public (Xylander & Zumkowski-Xylander 2018, Zumkowski-Xylander et al. 2017). For example, the Senckenberg Museum für Naturkunde Görlitz has created three large travelling exhibitions on soil biodiversity in the last 25 years, which attracted more than 1.2 million visitors at over 40 locations in seven countries; the recent one ('The thin skin of the earth', see Fig. 5) was presented since 2015 at more than 10 locations in three countries till now (ongoing until at least 2023). Despite the success, only a small part of the population is of course reached with this format. In natural history museums, however, soil, its

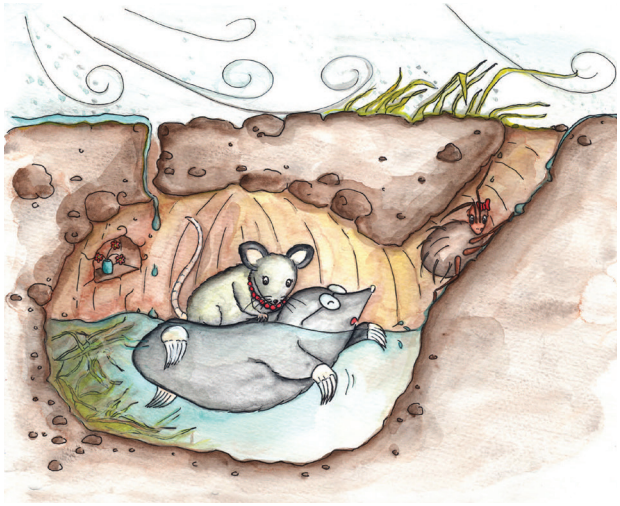

**Figure 4**. Klara Kugelspringer and her friends driven from their home by man-made erosion (from Zumkowski-Xylander 2017a)


**Figure 5**. The international touring exhibition 'The thin skin of the earth' displays units of soil biodiversity, research, heterogeneity and destruction. The exhibition had over 250.000 visitors till now.

biodiversity and functions usually play a minor role; an exception is the Museum am Schölerberg in Osnabrück, which gives the topic a wide scope in its exhibition sections 'unter.Welten' and 'Unterirdischer Zoo'.

### 3.3 Transdisciplinary approaches

The connection of music, theatre and visual arts to nature conservation has a long tradition (Meisch et al. 2020). The topic of soil has been one focus of artistic creativity, especially in recent years. The emotional approach of mediation - without claiming scientific accuracy or limits - has the chance to reach and sensitize further social groups. As Feller et al. (2015) emphasize: 'In contrast to soil scientific work, artistic work is designed to touch our emotions and provoke discussions on environmental, social, and political change. Both science and art are necessary for raising soil awareness. Only when the soil science community is more broadly based will soil protection become more relevant for the public at large and for decision makers'.

Soil scientist Gert Wessolek is looking - beyond research - for transdisciplinary approaches to soil against the background of soil protection and stresses: 'Art may serve to offer soil a new, more up-to-date image in addition to its undisputed ecological significance' (Toland & Wessolek 2015a, Wessolek 2002). Artists from his environment (e.g. Alexandra Toland) have repeatedly used soil in artworks and performances and published their intentions and results (e.g. Feller et al. 2015, Toland & Wessolek 2010 a, b; numerous examples from other countries are listed by Toland & Wessolek 2010 a). Nevertheless, the representation of soil and soil biodiversity plays a vanishing role in art or even in art lessons at school. At the same time, one's own sculptural work with (loamy) soil is a good opportunity to deal haptically with the soil and to design it in an artistic-productive way (see examples for the school in Roch 2010). Here the possibilities are far from being exhausted.

Music (e.g. the 'Bodenkantate' by Tobias Morgenstern, list of material 2) and theatrical performances (e.g. poetry slams, material 3) expand the multi-sensory spectrum of experience with soil. It does not always have to be the 'high art': Singing children's songs about soil animals ('as a social practice', see Meinsch et al. 2020) can not only provide an introduction to the topic of a school lesson, but also awaken sympathy, a sense of classes' social coherence and introduce the organisms and their lives. At the same time, the animals are made known with their names and the special features mentioned in the text. Examples of this can be found in the appendix to the materials by Roch (2010).

Some computer games thematize soil animals (such as 'Earthworm Jim': https://de.wikipedia.org/wiki/Earthworm_Jim) or have a connection to soil animals (such as 'Worms': https://de.wikipedia.org/wiki/Worms). Although they allow association and reach the 'gaming generation', they are not suitable to evoke empathy and commitment to soil biodiversity conservation.

### 3.4 Establishment of sympathizers

For three generations, the little mole of Miler, who digs in the earth with his spade and whom the various soil animals encounter, has been the epitome of 'the soil animal'. It is not without reason that a 1.60 m tall figure of a mole stands at the entrance of our soil exhibition 'The Thin Skin of the Earth' and is a popular motif for selfies, especially among younger visitors (Fig. 6). Nevertheless, one should think about other objects and formats of sympathy carriers than children's books and cartoons. Probably as a German analogue to Miler's main character, a mole played an important role in the 'Geschichten mit


**Figure 6**. The mole standing at the entrance of the Senckenberg exhibition is a popular motif for selfies.

der Maus' (Stories with the Mouse), which have been shown on German television for over 30 years, and thus became known to millions of children as '*the* soil animal'.

Suitable are also nature films with high-quality macro film shots, which are not made as 2-day-shoots by filmmakers who otherwise have no access to the topic. For example, David Attenborough has produced features for BBC on ground animals (material 4). In Germany, the animal filmmaker Lothar Lenz recently succeeded in shooting scenes of Sminthurid springtails (supplementary material 5), which were filmed with great attention to detail and arouse sympathy also for other mesofauna representatives. More such films should be given airtime and made available for educational purposes.

Soft toys are also available from organisms that are classic sympathizers. From the group of ground animals, only tardigrades (Fig. 7) and millipedes are known to me as such toys. Springtails are only available as custom-made products. With toys of this kind, however, stories about the animals could be told, sympathies could be aroused and antipathies could be diminished already in childhood.

So the examination of the soil life and its diversity remains difficult for the interested layman, but also for the ambitious teacher. A further disadvantage of the soil animals compared to other arthropods such as butterflies, dragonflies and beetles is that there is little illustrated material for the determination of the animals, which is easy to handle for the layman. Just recently, the Senckenberg Museum für Naturkunde Görlitz has developed an app that allows non-scientists to identify selected larger soil macroarthropods (millipedes, centipedes and terrestrial woodlice) more easily using a key (Decker et al. 2019, see also www.bodentiere.de); this key does not follow a binary path, but is based on a matrix of characteristics, which makes identification easier and faster. The find data provided by users via cell phone with GPS data and other information is checked and then released by a specialist from the respective group. They are then transferred to the online portal of our international soil animal dataware Edaphobase (see also Burkhardt et al. 2014). The fun of own research on animals in our daily environment should contribute to arouse interest and promote empathy.

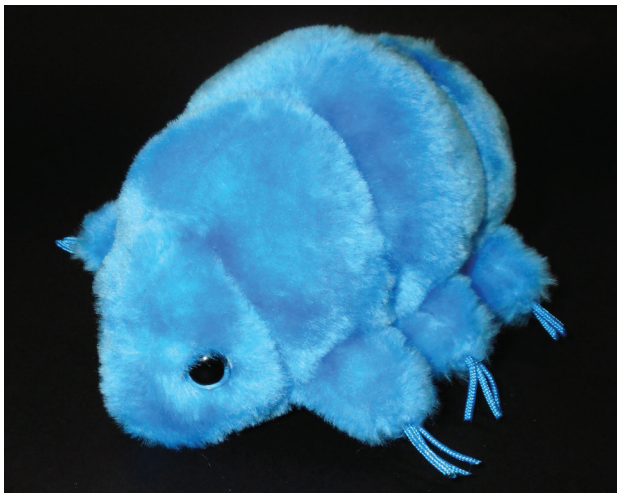

**Figure 7**. Tardigrade as a soft toy is one of few soil animals which found their way to childrens' rooms.

## 4. Conclusion and perspectives

In addition to rational extrinsic approaches to soil, soil biodiversity and soil protection based on scientific research, arguments and evaluation criteria, an intrinsic, emotional, holistic approach involving humanity and its activities is needed. Many possibilities for this approach have been outlined, but not nearly exhausted. Opening up such intrinsic potentials for soil protection in the broadest sense should be a task for the coming decade, on which didacticians, conservationists, artists, teachers and others should work together with soil scientists and soil biodiversity researchers.

If transdisciplinary cooperation is one solution to increase awareness it has to be financed. We cannot expect that additional funding sources, such as public-private-partnerships, will be able to provide sufficiently enough money. So funding for the transdisciplinarity must be a part within research projects. And scientists from the field of soil biodiversity research have to rethink their application strategies and include sums for such an approach as we need to cooperate and share our funding with experts, who are translating and transforming our scientific results into a societal message and thus into an intrinsic value that people appreciate.

## 5. Acknowledgement

I would like to thank the Federal Minister for Culture and Media for the opportunity to participate in the Museum4Punkt0 project and to develop the above mentioned immersive VR formats on soil life, and the Federal Ministry of Education and Research for supporting the development of the soil exhibition 'The Thin Skin of the Earth'. I would like to thank the teams 'M5' from Museum4Punkt0 and the soil exhibition team at the Senckenberg Museum in Görlitz as well as Lutz Westermann from .hapto, Cologne for the successful cooperation on the VR animations. I would

like to thank my friend Gert Wessolek for inspiring discussions and impulses to connect art and soil. I would also like to thank Mrs. Elisabeth Pohl, my co-worker, for editing the manuscript. I would like to thank the animal filmmaker Lothar Lenz for generously providing films on Sminthurids as supplementary material. My colleague Nico Eisenhauer kindly supplemented the text with numerous relevant notes. Posthumously, a special, heartfelt thanks goes to my predecessor, the great soil zoologist Prof. Dr. Wolfram Dunger.

## 6. References

Asshoff, R., A. Fricke & N. Eisenhauer (2011): Regenwurm ist nicht gleich Regenwurm – Ein Experiment zur Verdeutlichung der unterschiedlichen Ökologie von Regenwürmern. – Biologie in der Schule **60** (1): 20–24.

Baber, K., J. Wesenberg & W. E. R. Xylander (2019): Perzeption und Evaluierung von Virtual Reality(VR)-Formaten im Naturkundemuseum. – Natur im Museum **9**: 37–39.

Baer, S.G. & H. E. Birgé (2018): Soil ecosystem services: An overview. In: Managing soil health for sustainable agriculture. Vol. 1: Fundamentals. Don Reicosky (ed.). – Burleigh Dodds Science Publishing, Cambridge: 1–22 [http://dx.doi.org/10.19103/AS.2017.0033.0].

Bardgett, R. & W. van der Putten (2014): Belowground biodiversity and ecosystem functioning. – Nature **515**: 505–511 [https://doi.org/10.1038/nature13855].

Beblek, A., K. Diehl, S. Kühlberg, L. Lahaye, M. Luckas, F. Makeschin, K. Schmidt & H. Wiggering (2017): Boden eine Sprache geben – 10 Thesen für die Kommunikation von Bodenthemen. – UBA (ed.), Dessau-Rosslau: 1–22 [https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/180104_uba_fb_bodenkommunikation_10_thesen_bf.pdf].

BMEL (2020): Ökologischer Landbau in Deutschland. Stand: Februar 2020. – BMEL (ed.): 1–32 [https://www.bmel.de/SharedDocs/Downloads/DE/Broschueren/OekolandbauDeutschland.pdf?__blob=publicationFile&v=6]

BÖLW (2020): Branchenreport 2020 Ökologische Lebensmittelwirtschaft. – Bundesverband Ökologische Lebensmittelwirtschaft (ed.): 1–42 [https://www.boelw.de/fileadmin/user_upload/Dokumente/Zahlen_und_Fakten/Brosch%C3%BCre_2020/B%C3%96LW_Branchenreport_2020_web.pdf].

Bundesministeriums der Justiz und für Verbraucherschutz (2020): „Bundes-Bodenschutzgesetz vom 17. März 1998 (BGBl. I S. 502), das zuletzt durch Artikel 3 Absatz 3 derVerordnung vom 27. September 2017 (BGBl. I S. 3465) geändert worden ist" [version downloaded on Nov., 9th, 2020 via https://www.gesetze-im-internet.de/bbodschg/BBodSchG.pdf].

Bünemann, E. K., P. Mäder, J. Wohlfahrt, L. Brussaard, G. Bongiorno, R. de Goede, V. Geissen, L. Fleskens, W. Sukkel, Z. Bai & T. Caspari (2016): Concepts and indicators of soil quality – A review [https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5ae63cb0e&appId=PPGMS].

Burkhardt, U., D. J. Russell, R. Buryn, P. Decker, M. Döhler, H. Höfer, S. Lesch, S. Rick, J. Römbke, C. Trog, J. Vorwald, E. Wurst & W. E. R Xylander (2014): The Edaphobase Project of GBIF-Germany – A new online soil-zoological data warehouse. – Applied Soil Ecology **83**: 3–12.

Guillaume, T., D. Maranguit, K. Murtilaksono & Y. Kuzyakov (2016): Sensitivity and resistance of soil fertility indicators to land-use changes: New concept and examples from conversion of Indonesian rainforest to plantations. – Ecological Indicators **67**: 49–57 [https://doi.org/10.1016/j.ecolind.2016.02.039].

Cameron, E. K., I. S. Martins, P. Lavelle, J. Mathieu, L. Tedersoo, M. Bahram, F. Gottschall, C. A. Guerra, J. Hines, G. Patoine, J. Siebert, M. Winter, S. Cesarz, O. Ferlian, H. Kreft, T. E. Lovejoy, L. Montanarella, A. Orgiazzi, H. M. Pereira, H. R. P. Phillips, J.Settele, D. H. Wall & N. Eisenhauer (2019): Global mismatches in aboveground and belowground biodiversity. – Conservation Biology **33** (5): 1187–1193 [https://doi.org/10.1111/cobi.13311].

Decker, P., J. Wesenberg & W. Xylander (2019): Bodentierhoch4 – Mit dem Smartphone in den Boden abtauchen. – Natur Forschung Museum **149** (7-9): 119–122.

Dohrn, S. (2019): Der Boden - Bedrohter Helfer gegen den Klimawandel. – Christoph Links-Verlag: 1–240.

Donaldsen, J. & A. Scheffler (2012): Superworm. – Verlag Scholastic. **32** (ISBN 9781407132044).

Eisenhauer, N., A. Bonn & C. A. Guerra (2019): Recognizing the quiet extinction of invertebrates. – Nature Communication **10**: 50 [https://doi.org/10.1038/s41467-018-07916-1].

Feller, C. E. R. Landa, A. Toland & G. Wessolek (2015): Case studies of soil in art. – SOIL **1**: 543–559.

Ignotofsky, R. (2018): The wondrous working of Planet Earth – Understanding our world and its ecosystems. – Ten Speed Press: 128 pp. (ISBN 9780399580420).

Leopoldina et al. (ed.) (2020): Biodiversität und Management von Agrarlandschaften – Umfassendes Handeln ist jetzt wichtig. – Nationale Akademie der Wissenschaften Leopoldina, Deutsche Akademie der Technikwissenschaften, Union der deutschen Akademien der Wissenschaften (eds.): 1–76.

Mathews, J., F. Glante, M. Berger, G. Broll, U. Eser, A. Faensen-Thiebes, N. Feldwisch, W. König, N. Patzel, R. Sommer & W. E. R. Xylander (2020): Soil and biodiversity – Demands on politics. – Soil Organisms **92** (2): 95–98 [DOI 10.25674/so92iss2pp95]

Meisch, S.P., T. Potthast, L. Fischer, R. Piechocki, L. Voget-Kleschin & N. Wiersbinski (2020): Vilmer Thesen (2017): Natur(schutz) und Musik. – Natur und Landschaft **95** (11): 500–504.

Miler, Z. (1988): Wie der Maulwurf zur Hose kam. – VEB Domowina Verlag Bautzen.

Miler, Z. (1990): Der Maulwurf hilft der Maus. – Pestalozzi-Verlag, Erlangen.

Phillips, H., E. K. Cameron, O. Ferlian, M. Türke, M. Winter & N. Eisenhauer (2017): Red list of a black box. – Nature Ecology & Evolution **1**: 0103 [https://doi.org/10.1038/s41559-017-0103]

Phillips, H. R. P., L. Beaumelle, N. Eisenhauer, J. Hines & L.C. Smith (2020): Lessons from the WBF2020: extrinsic and intrinsic value of soil organisms. – Soil Organisms **92** (2): 121–127 [https://doi.org/10.25674/so92iss2pp121].

Portmann, A. (1998): Biologie und Geist. 3rd Edition. Edition Nereide, Burgdorf-Verlag, Göttingen: 1–336.

Roch, K. (2010): Schutz der Böden. Eine Lehrerhandreichung. – Open access materials for school teachers developed by Senckenberg as part of a DBU-project [https://museumgoerlitz.senckenberg.de/en/bildungsangebote/schulen-und-kitas/lehrmaterialien/].

Schmidt, S. J. (2008): Telling stories about storytelling, In: Storytelling – Reflections in the Age of Digitalization. – Innsbruck University Press: 17–28

Schwinn, F. (2019): Rettet den Boden! Warum wir um das Leben unter unseren Füßen kämpfen müssen. – Westend-Verlag, Frankfurt: 1–272.

Seibold, S., M. M. Gossner, N. K. Simons, N. Blüthgen, J. Müller, D. Ambarlı, C. Ammer, J. Bauhus, M. Fischer, J. C. Habel, K. E. Linsenmair, T. Nauss, C. Penone, D. Prati, P. Schall, E.-D. Schulze, J. Vogt, S. Wöllauer & W. W. Weisser (2019): Arthropod decline in grasslands and forests is associated with landscape-level drivers. – Nature **574**: 671–674 [https://doi.org/10.1038/s41586-019-1684-3].

Toland A. & G. Wessolek (2010 a): Merging Horizons—Soil Science and Soil Art. – In: Landa E. & Feller C. (eds): Soil and Culture. – Springer, Dordrecht: 45–66 [https://doi.org/10.1007/978-90-481-2960-7_4]

Toland A. & G. Wessolek (2010b) Core Samples of the Sublime - On the Aesthetics of Dirt. – In: Landa E. & C. Feller (eds): Soil and Culture: 239–257. – Springer, Dordrecht [https://doi.org/10.1007/978-90-481-2960-7_15].

Wall, D. H., R. D. Bargett, V. Behan-Pelletier, J. E. Herrick, H. Jones, K. Ritz, , J. Six, D. R. Strong & W. H. van der Putten (2012): Soil Ecology and Ecosystem Services. –Oxford University Press.

Wessolek, G. (2002): Art and soil. – Newsletter of the Committee on the History, Philosophy, and Sociology of Soil Science of (International Union of Soil Sciences) No. **10**: 14–16 [available at http://www.iuss.org/].

Westermann, L., K. Baber, J. Wesenberg & W. Xylander (2018): „Abenteuer Bodenleben“ - Virtual Reality (VR) zur digitalen Wissenschaftsvermittlung im Museum. – In: Bienert, A., A. Börner, E. Emenlauer-Blömers & J. Hemsley (eds): Proceedings EVA, Berlin 2018: 7–33.

Xylander, W. E. R (2019): Nicht nur, weil wir es können - Reflexionen zu Kriterien für den Einsatz von Virtual Reality in Naturkundemuseen. – Museumskunde 2019: 148–155.

Xylander, W. E. R & H. Zumkowski-Xylander (2018): Increasing awareness for soil biodiversity and protection - The international touring exhibition “The Thin Skin of the Earth”. – Soil Organisms **90** (2): 79–94. [https://doi.org/10.25674/KKY5-A011].

Xylander, W. E. R., H. Zumkowski-Xylander, J. Wesenberg, P. Havlik & B. Herkner (2018): Fast wie im Leben - Senckenberg testet virtuelle Realitäten. – NaturForschungMuseum **148** (1-3): 28–30.

Zumkowski-Xylander, H., M. Pilz, A. Paczos, A. Christian & W. Xylander (2017): The thin skin of the earth – Our soils. – Exhibition guide through the touring exhibition of the Senckenberg Museum für Naturkunde Görlitz (English version): 1–84.

Zumkowski-Xylander, H. (2017a): Klara Kugelspringers und ihre Reise. Booklet for children. With drawings by Jana Pelenus. – Senckenberg Museum für Naturkunde Görlitz (ed.): 32 pp.

Zumkowski-Xylander, H. (2017b): Bodenbauer (Engl. Soil Builder). – Card game for the international touring exhibition „The thin skin of the earth“. With drawings by Jana Pelenus, Layout Ekkehardt Mättig. 70 Cards [Available via post-gr@senckenberg.de].

**Digital material mentioned**

(1) Presentations by .hapto, Cologne and Senckenberg on the interactive virtual reality animation “Adventure Soil Life”
https://vimeo.com/247731074
https://vimeo.com/333094945

(2) “Bodenkantate” by Tobias Morgenstern, Movement 1, 2 and 3
https://www.youtube.com/watch?v=nzEkQZzgPic&list=PLd2kshRyXxRRKr_AvJ-TmrGk
https://www.youtube.com/watch?v=iFAO7sX-Io4&list=PLd2kshRyXxRRKr_AvJ-TmrGkurE0AqFUf&index=2urE0AqFUf
https://www.youtube.com/watch?v=qXdTj_iHGio&list=PLd2kshRyXxRRKr_AvJ-TmrGkurE0AqFUf&index=3

(3) Poetry slam on “Wadden sea soil”
https://www.facebook.com/BundesverbandBoden/videos/poetry-slam-zum-thema-boden-und-naturschutz-preisverleihung-am-weltbodentag-f%C3%BCr-/440102346906868/

(4) Films by David Attenborough on earthworms and springtails on youtube:
https://www.youtube.com/watch?v=bFpblBf1dfE
https://www.youtube.com/watch?v=OwOL-MHcQ1w

(5) Films by Lothar Lenz on Smithurid springtails on youtube:
https://www.youtube.com/watch?v=NwTOiS29Xro
https://www.youtube.com/watch?v=7VNvm71RUxM
https://www.youtube.com/watch?v=7VNvm71RUxM
https://www.youtube.com/watch?v=CnDvRjWLQec
(6) Animations on soil protections
https://www.youtube.com/watch?v=AOefA-bSduM
https://www.youtube.com/watch?v=pSQxO43CRsk