Sounding Soil: An Acoustic, Ecological & Artistic Investigation of Soil Life

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Abstract

The interdisciplinary Sounding Soil project explores the soil's soundscape and renders experienceable and investigable the activity and diversity of soil life in an artistic-acoustic observatory. The main aim is to increase soil awareness in the general population as well as among decision-makers involved in soil policies and food producers. While moving through or digging the soil matrix, the soil fauna produces noises. Moreover, some animals seem to use the soil as a communication medium, forming a complex soundscape. Land use and agricultural management may have marked effects on the soil soundscape. Thus, the (acoustic) richness of a local soil animal community may serve as an indicator of the functioning of a soil ecosystem. In the scientific module of the Sounding Soil project, we implement and test acoustic indices to assess soil biodiversity and community composition. In the art and citizen science module, several Swiss farmers and subsequently the broader public record the soundscapes of their soils with a low-cost recording device. The result is a sound art installation as a publicly accessible observatory, integrating our scientific findings with recordings by participants in the citizen science module. This article describes the character of soil soundscapes in agricultural land and forests and reports on our research design and first insights into the relations between land use, soil types, biodiversity, and soil soundscapes.

Keywords: Acoustic Ecology, Artistic Research, Bioacoustics, Ecoacoustics, Soil Ecology

Introduction

Soils mostly present themselves to us as a diverse surface while the interior remains hidden. We cannot see the manifold organisms and life processes present in soils, but we may hear them if we listen closely. Soil ecosystems are complex with closely interwoven biotic interactions. Soils are highly sensitive to disturbances, such as human farming systems or forest management. Healthy soils are of key importance because they provide indispensable ecosystem services (Haygarth and Ritz 2009; Greiner et al. 2017). Soil systems filter and regulate water, provide nutrient cycles, and deplete toxic substances (Bouma 2014; Adhikari and Hartemink, 2016). Sustainably managed soils enhance the resilience of agricultural systems and can adapt to changing climatic conditions while also contributing to the reduction of greenhouse gases in the atmosphere by carbon sequestration (Lal 2004). In contrast, soil degradation has increased in recent decades. This applies not only to its spectacular form in the tropics, with immense land loss through deforestation and erosion, but to what is directly at our front door, in the fields where our food is produced, through degradation with mineral fertilizers, pesticides, and antibiotics, as well as soil compaction by increasingly heavy machinery (Oldeman 1994; Stolte et al. 2016).

There seems to be a basic perception problem regarding these environmental issues; the pedosphere and its functions or state of health cannot easily or instantly be translated into a sensual experience. It is a black box for experts to open and interpret, and then they can convey their findings to "non-experts" (Bouma 2010). For the most part, the ground beneath our feet is not an object of our observation or contemplation; it is just there, and because it eludes


Fig. 1. What is going on below the surface?

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our direct perception, we treat it like some dead mass. Therefore, increasing awareness of soil ecosystems is crucial.

We require first-hand experience of soil life and its health. This is true not only of the consumers of agricultural products but also of the producers in the fields, wholesalers, and political decision-makers, as well as researchers seeking effective methods for exploring soil ecosystems. Accordingly, new forms of investigating and experiencing soil ecosystems are necessary; they could increase environmental awareness and influence our attitudes and behaviours towards the pedosphere as the basis of nutrition for all future generations.

There is a need for technical enhancement and facilitation of research on, and assessments of, soil health, especially for making rapid appraisals of soil biodiversity, community composition, and activity as indicators of soil ecosystem functionality (Wagg et al. 2014). Multifunctional, fertile, healthy soil provides essential nutrients for crop and plant growth, supports a diverse and active biotic community, and enables undisturbed decomposition (Mäder et al. 2002). Conversely, a community of diverse and numerous soil fauna may serve as an indicator of soil ecosystem multifunctionality (Lavelle 1996; Griffiths et al. 2016; Aksoy et al. 2017). In particular, soil invertebrate communities are "deeply affected by human activities; in most agroecosystems, they tend to disappear. Little if any mention is made of possible links between the elimination of such important regulators of soil processes and the lack of sustainability of most agricultural systems" (Lavelle 1996, 4). Measurements or estimations of soil biodiversity and activity, therefore, become increasingly important in assessments of soil ecosystem functionality, but they tend to be technically complex and time-consuming (Griffiths et al. 2016). In general, the investigator must take a soil sample and analyze it in a laboratory or conduct experiments with microcosms (Jones and Bradford 2001). Consequently, the sampling process (normally comprising digging up the soil) will either disturb or destroy the pedon or an artificial setup will detract the investigation.

An acoustic investigation and appraisal of soil fauna biodiversity and activity may offer an alternative to costly and invasive methods (Sueur et al. 2008). Almost every organism produces sound waves as its life manifestation. Be it movement activity or communication, we can potentially hear which organism does what under which circumstances on the one hand, and we may contextualize the organism's acoustic activity with the sounds of the environment on the other hand. Acoustic appraisals of the richness of local species are often much more affordable than, for example, an all-taxa biodiversity inventory (Depraetere 2011).

An ecoacoustic investigation entails placing audio recording devices with microphones or microphone arrays in a particular environment. Such a setup may be enhanced by acoustic microscopy using high-end amplifiers and highly sensitive acoustic probes that render audible the activities and processes in an ecosystem that are not normally perceptible, such as the activity of the soil meso- and macrofauna (Mankin et al. 2000; Chesmore 2008).

The Soil Soundscape

Soil acoustics

Soil acoustics differ fundamentally from atmospheric acoustics.[1] Most soils have a very heterogeneous structure consisting of organic, mineral, gassy, and fluid components. In general, soil structures show strong attenuation effects on sound waves, especially on sound frequencies above 2 KHz (Oelze et al. 2002). Attenuation of sound in soils is caused by the porous structure that scatters, reflects, breaks, and bends any sound waves travelling through the soil matrix (Bourbié et al. 1987). Moreover, the attenuation and propagation speed of sound in soils depend on the moisture content and density of the soil structure (Lu and Sabatier 2008). Therefore, the bandwidth of signals to investigate is much narrower than it would be in recordings with microphones through the air. It ranges from the infrasound spectrum (0–20 Hz) up to the lower parts of the audible domain. High frequency or even ultrasonic signals (above 20 KHz) may be detected and measured as well, but only very locally/close to the acoustic probes. These signals seem to be of physical origin and are associated with water infiltration and drainage of the soil pore system (Moebius 2013).

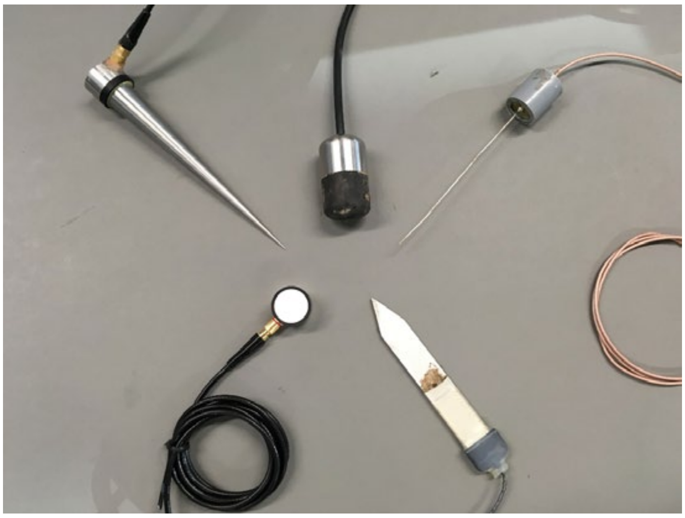

Fig. 2. Sounding Soil prestudy in summer 2016: Testing different acoustic sensors at the WSL, Birmensdorf/Switzerland.

The structure of soil soundscapes

When a soundscape is analyzed using ecoacoustic methods, it is generally separated into different groups of sound sources comprising geophonies, biophonies, and anthropophonies or technophonies (Farina 2014; Farina and Gage 2017). These acoustic components set and represent the structure and ecological interrelations of a landscape to different extents and in various degrees (see fig. 3). Sounds of an inanimate nature are subsumed under the term geophonies (e.g., the sounds of wind, rain, waves, rockfall, or rivers), while sounds of an animate nature belong to the realm of biophonies (vocal or vibratory communication of animals, acoustic emissions of plants, and all other physiological noises of organisms). Human vocalizations (language, shouting, etc.) would also constitute part of the biophonies – in contrast to the other noises that stem from human/civilization activity, such as technological sounds or traffic noise, which belong to the category of anthropophonies or technophonies, respectively.

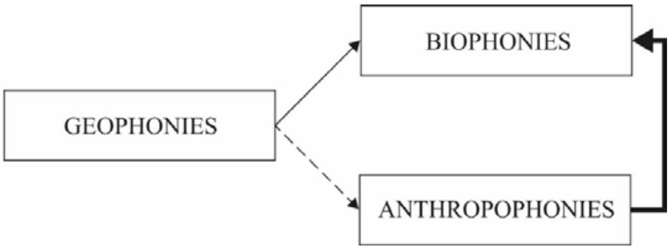

Fig. 3. Graph by Almo Farina: "Geophonies are the sonic sources that have direct influence on biophonies and secondarily on anthropophonies. Anthropophonies can strongly impact on biophonies" (Farina 2014, 11).

Geophonies

Numerous geophysical sound sources are identifiable in soil. The geo-acoustic literature predominantly focuses on the acoustic detection of movements in the earth mantle or in rock layers and on seismic investigations of soil, rock layers, or seabeds via active acoustic methods.[2] However, a few acoustical studies in soil physics exist on the movement of soil water (Flammer et al. 2000; Moebius 2013) or constantly occurring changes in the physical soil matrix, such as pore displacements (DiCarlo et al. 2003). Acoustic parameters may be used to monitor changing soil properties, such as porosity, water content, and water potential (Lu and Sabatier 2009). According to Farina's (2014) graph in fig. 3, the geophonies of soils represent the physical (re-)sources of soil life: the sounds of infiltrating, draining, and moving water and of formations of macropores by cracks or collapsing parts of the soil structure may serve as acoustical indicators of the state and dynamics of soil faunal and floral habitat conditions. The geophysical components of the soil soundscape, however, appear episodic; much more acoustic activity is to be found in the realm of biophonies.

Biophonies

Little is known about the acoustic activity of the soil fauna and flora. A handful of studies have been carried out to investigate soil insect infestations acoustically (Mankin and Fisher 2002; Brandhorst-Hubbard et al. 2001) and the vibrational communication of insects using the substrate as a nearfield communication medium (Virant-Doberlet and Cokl 2004; Cocroft and Rodriguez 2005). The most frequently occurring acoustic manifestations of soil animals consist of moving and feeding noises by the meso- and macrofauna.[3] The frequencies of such physiological noises (crawling, chewing, digging, etc.) vary with the body size (cf. fig. 10), morphology, and species-specific behaviour of the animals present in a pedon (Mankin et al. 2011).

Beyond that, certain animals living in the soil or on its surface communicate acoustically or seismically (vibrational communication) with each other, which makes listening to soil a surprising and fascinating experience. These signals are produced by the stridulatory apparatus (legs, mandibles, or other body parts) of soil insects (adults as well as larvae). Some studies have investigated the stridulation signals of submerged ants, signalling their position to conspecifics (Markl 1965), or signals for recruiting nestmates for food resources (Baroni-Urbani et al. 1988), while other reports may be found on the vibrational communication of grass- and leafhoppers using the substrate (plants, ground) as a communication medium for mating purposes (Heldmaier and Werner 2003).

Monica Gagliano et al. (2012) investigated the acoustic emissions of plant roots and anticipated "that plant acoustic radiation is not simply an incidental mechanical by-product attributable to cavitation [acoustic drought stress signals/indicators, the ed.] alone; recent evidence illustrates that the young roots of corn generate structured, spike-like, acoustic emissions." Whether these acoustic emissions – as Gagliano (2012) argues – have a signalling or communication purpose in and between plants remains an unanswered question.

Anthropophonies/Technophonies

Even less is known about the human impact on soil soundscapes. To the best of our knowledge, no study has investigated the ecological effects of noise pollution in soils. We may assume that anthropogenic sound and vibration emissions exert an influence on soil animal behavior as well as species composition, abundance, and interaction as they do in other elements or ecosystems (Codarin et al. 2009; Francis et al. 2012). Investigations of soil animal behaviour remain complicated and costly, as it is not possible in most cases to visually observe soil animals. Thus, observing soil animals by acoustic means is a very promising method, and it can also be useful in investigations of noise pollution effects in soils. The question is, however, what sounds of human/civilizatory origin may be heard/detected in soils. There are not only diverse vibratory emissions by streets, highways, construction, or mining sites that spread in large areas underground (Kim and Lee 1999); even airborne noise is capable of penetrating the interface between pedo- and atmosphere, especially if these emissions consist of deep frequencies/long wavelengths that are not reflected by the soil surface. One example is aircraft noise (fig. 5).

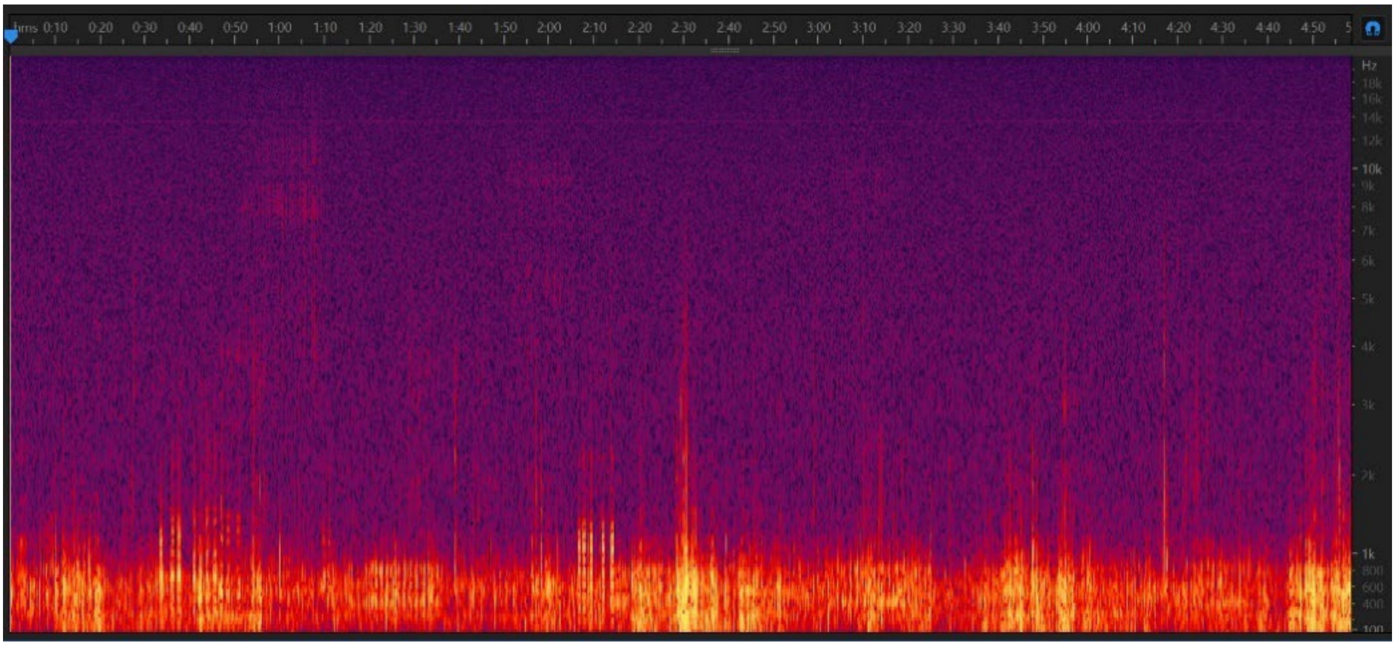

Fig. 4. Spectrogram of the acoustic activity of a soil community in a meadow, Valais, Switzerland. Some biotopes show an immense diversity of soilborne biogenic sound sources. The overlapping of movement noises, communication calls, and wind/moving vegetation makes ecoacoustic investigations of soil soundscapes a challenge.

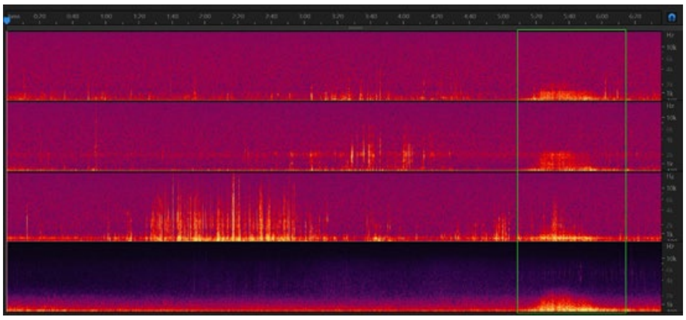

Fig. 5. Spectrogram of a 4-channel recording in forest soil (brown earth with mull humus). Channel 1 (top): acoustic sensor plugged into the soil surface; channel 2: sensor lying on the soil surface; channel 3: sensor plugged into the soil at 1 m distance to channel/sensor 1; channel 4: Electret microphone at 2 m height above soil surface. Aircraft noise (marked by the green box) appears on every channel of the recording.

Furthermore, the impact of anthropophonies and technophonies on ecosystems has become an issue in artistic investigation and production. Leah Barclay showed impressive examples of the effects of boat traffic noise on the water fauna in rivers and the sea (Bianchi and Manzo 2016) at the Sound & Environment Conference 2017. One of the goals of our Sounding Soil project in that context is to investigate and render artistically experienceable such effects in soils – not only regarding noise pollution but especially concerning the forms and intensities of land use (agricultural and forestry management) and their effects on the soil soundscape.

An Exploration of Swiss Soils

Land use and humus forms

In summer 2017, we conducted a recording and sampling procedure in 20 different soils in Switzerland at well-defined monitoring sites of the Swiss Soil Monitoring Network (Gubler et al. 2015). The sampling plots were selected along a gradient of land use (agricultural plots: from intensive to extensive or organic management) and humus forms (forest soils: from mull to mor) with three repetitions (type of land use/humus form). The sites were selected to cover a wide range of different soil types to allow for exploring possible differences in the composition of their soundscapes and investigate whether different types of agricultural management as well as forest soil humus compositions influence what may be heard below ground.

Recording and measurement techniques

As soils consist by a bigger part of solid structure, detection and measurement equipment from the physical acoustics domain is used: piezo contact sensors, geophones, accelerometers, etc. (Mankin et al. 2000). Such sensors must be physically coupled to the soil matrix by burying or plugging them into the soil. We modified self-built contact sensors developed previously for recordings in plants (Maeder 2015) to couple them with a soil area with a radius of about 30 cm and a depth of 30 cm – that is the top soil layer, which serves as the main habitat of most soil organisms.

The sensors consist of a simple piezo diaphragm (15 mm diameter), on which we soldered a gilded copper needle (1 mm thickness and 10 cm length). The housing of the sensor is made of a grey plastic tube and a backing/water sealing system consisting of epoxy resin and silicon (see fig. 6). The needle operates as a waveguide for acoustic waves to capture sound events in the soil, and then transmits these waves to the piezo element, which transforms the vibrations into electrical voltage. These signals are very weak and need to be preamplified. We modified hydrophone charge preamplifiers from Avisoft Bioacoustics, allowing us to amplify the incoming signals by a factor of 100 (+40 dB) or 1,000 (+60 dB), respectively. The preamplifiers were then connected to an Avisoft USGH 116h (one channel) or 416hb (4 channels) A/D interface, which is used in bioacoustic investigations (cf. www.avisoft.de).

The captured signals from the soil were then recorded/logged with a tablet or mini PC running the Avisoft Recorder software. The recordings were made with 50 and 25 KHz sampling rates and a bit rate of 16 bits and were then analyzed with Avisoft SAS Lab© and Adobe Audition© software, as well as custom-built Cycling74 MAX© patches. However, as this recording setup is costly (apart from the self-built sensors), we are currently developing a low-cost recording device for use in the later described citizen science part of the Sounding Soil project.

Fig. 6. Mobile recording device with preamplifier and self-built acoustic sensor.

There are important factors to consider in the conception and planning of acoustic recordings in soils. Periods of windy and rainy weather must be avoided or be excluded from the analysis. Raindrops may hit the sensors or their cables and produce artifacts, similar to how wind moves cables or vegetation (which produces movement noises that are transmitted via the stem and roots to the soil). Proximity to heavily used streets, highways, train tracks, or construction sites should also be avoided because the vibrations of heavy machinery may spread for hundreds of metres in soils. If the soil under investigation lies in an area where considerable animal movement is expected, the recording area must be protected with barriers or lattices.

Last but not least, the recordist and her/his recording devices should be positioned as far as possible from the sensor to avoid recording her/his own movement noises (at least a cable length of 3 m between the preamplifier and recording device, in contrast to the sensor cable, which should be as short as possible – ideally 20–30 cm). The aforementioned problems with low frequency/vibratory environmental noise may be partially solved by using high pass filters at 50–100 Hz.

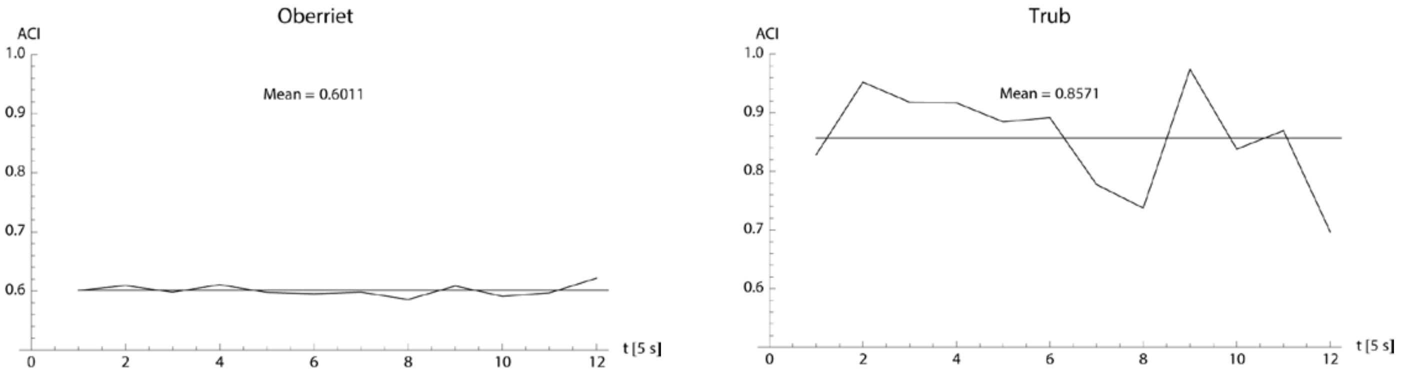

Fig. 7. Acoustic Complexity Index (ACI) measurements of two arable soils (1 min excerpts, 5 s intervals). Left: arable soil with industry potatoes and conventional agricultural management (Oberriet, Switzerland). Right: arable soil with oat, cultivated under organic agricultural management (Trub, Switzerland). The example on the right shows higher ACI rates.

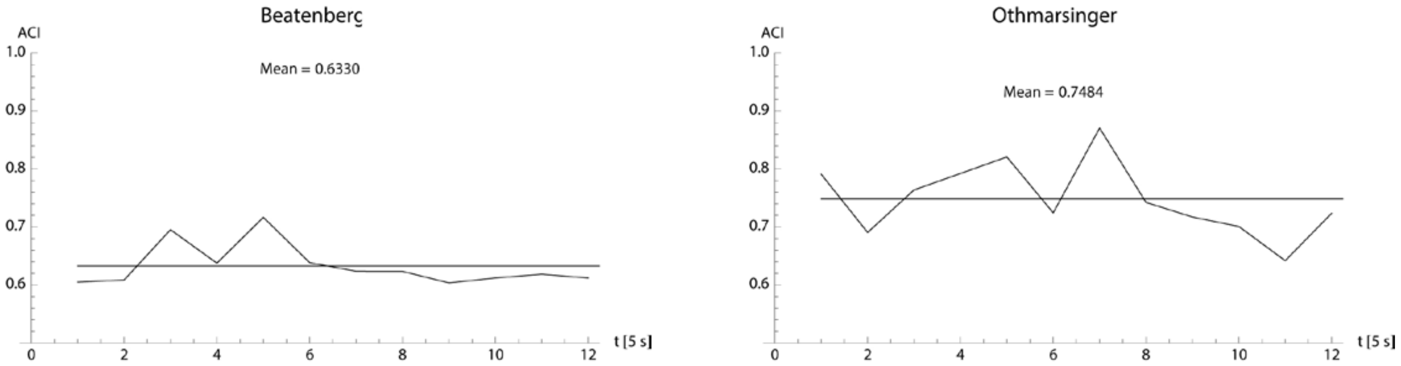

Fig. 8. ACI measurements of two forest soils with different humus layers (1 min excerpts, 5 s intervals). Left: a mor humus soil (Beatenberg, Switzerland). Right: a mull humus soil (Othmarsingen, Switzerland). The example on the right shows higher ACI rates.

Ecoacoustic investigations

Our recording and sampling in summer 2017 was aimed at investigating if gradients of human land use and humus/litter composition influence the complexity of a soil soundscape (figs. 7 and 8). Acoustic complexity has played an important role in recent ecoacoustic research (Pierretti et al. 2011). It may serve as an indicator of biodiversity in a particular sector of an ecosystem or landscape (Harris et al. 2016). The diversity and complexity of audio information in a soundscape may be measured by different acoustic indices (Sueur et al. 2014), which are applied on audio recordings.

In our first analysis, we used two different acoustic indices and compared them: the Acoustic Complexity Index (ACI) and the Acoustic Entropy Index (AEI). Since the AEI is very sensitive to background noise in the environment, we decided to use the ACI for our field recordings[4] – these had a standardized length of 15 minutes in total, and we selected a 1-minute excerpt of each recording for our analysis (a segment of the recording with the fewest background noise). The excerpts were filtered with a lowpass filter at 2 KHz and then analyzed with the ACI algorithm in 5-second steps and an FFT window size of 1,024.

On the same plot where we took the audio recordings, samples from the top soil layer were taken with a Kempson corer of 30 cm diameter and 20 cm length, suggested as a suitable method for assessing soil fauna in the frame of a Rapid Ecosystem Function Assessment (Meyer et al. 2017). The litter layer was separately collected in plastic bags. The samples were brought to the laboratory and the soil/litter animals were extracted using the Berlese/Winkler methods (Sabu et al. 2009; Meyer et al. 2017). The collected animals were identified, mostly on the level of taxonomic orders, and counted (Dunger 1983).We then compared/correlated our ACI measurements with the taxonomic countings (fig. 9).

We found significant differences in acoustic complexity between different land-use types, with the highest values in extensively managed grasslands and lowest in arable fields (fig. 9). Intensively managed grasslands and forests had intermediate values. The high variability within grasslands may be explained by the farmers' different treatment methods within the management schemes – some manage their land more sustainably than others, and in the case of

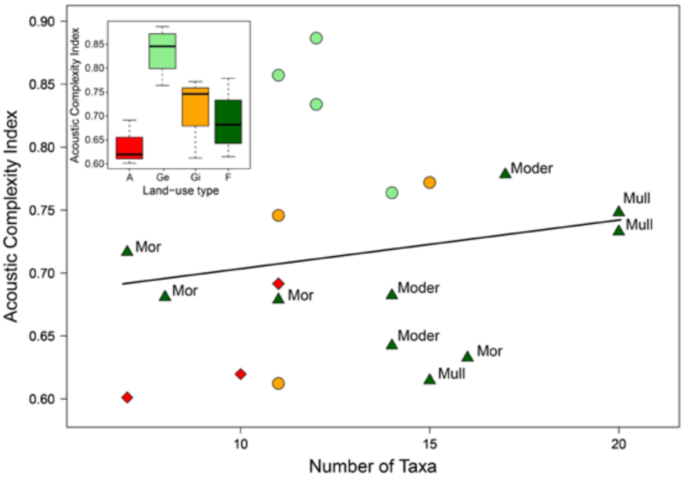

Fig. 9. The ACI as a function of the richness of soil taxa assessed by Berlese incubation of soil cores (Kempson method). Different land-use types are indicated by different colors and symbols. A = arable field, G = grassland (I = intensively managed, e = extensively managed), F = forest (respective humus forms are indicated by the labels). The black line shows a linear regression across all sites.

a declaration of intensive management with regard to fertilization plans, grazing, and moving patterns. The high variability within forests can be explained by the different activity in different soil types.

The results show an overall weak, positive relationship between acoustic complexity and higher taxa diversity (total 26 taxa), assessed by traditional methods (fig. 9). In arable fields and grasslands, we expected decreasing management intensity results in an increase in the diversity of the soil fauna and consequently in high acoustic complexity. In forests, we expected a corresponding gradient in our ACI measurements according to the qualification of different humus forms as worse or better habitats for soil organisms (a gradient from mor/worse over moder up to mull/better). The weak observed correlation in open land-use types as well as in forests might have been due to the low taxonomic resolution, or the abundance of particular taxa might not well reflect their activity during the recordings. We will study this in more detail in the next step.

By analyzing the composition of acoustic signals (i.e., their peak frequencies) and soil fauna, we found a good indication that low- and high-frequency sound signals are associated with an abundance of particular soil dwelling taxa (fig. 10). While low-frequency signals seem to be associated with an abundance of taxa with a large body size (e.g., Diplopoda, Isopoda, Chilopoda), high-frequency signals seems to reflect taxa with a small body size (e.g. Collembola, Enchytraeidae, Diptera larvae). This provides a first indication that an acoustic signal at a particular frequency may be able to detect the occurrence of particular taxa.

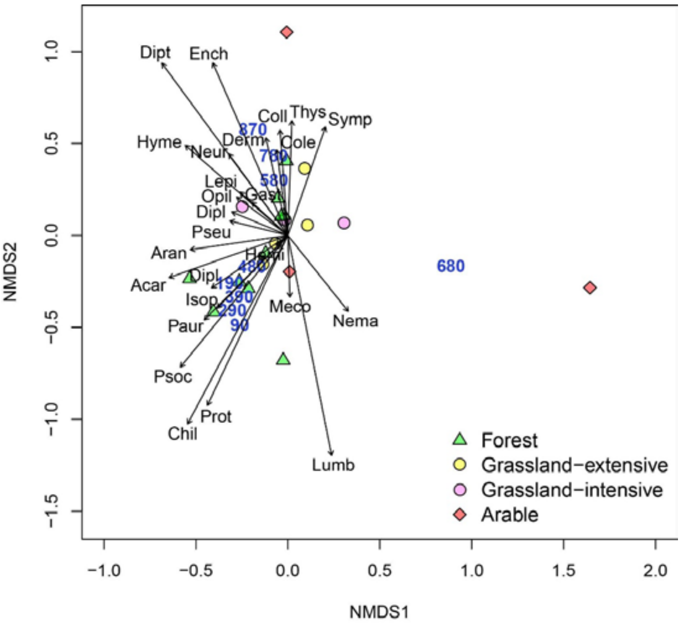

Fig. 10. Ordination diagram (Bray-Curtis distance, k = 3, Stress = 0.04) showing the differences in acoustic composition in terms of the recorded frequencies (Hz; blue numbers) among all 20 sites (symbols). The arrows illustrate how different soundscapes are correlated with the abundance of particular soil-dwelling taxa (Acar = Acari, Aran = Araneae, Chil = Chilopoda, Cole = Coleoptera, Coll = Collembola, Derm = Dermaptera, Dipl = Diplopoda, Dipl = Diplura, Dipt = Diptera, Ench = Enchytraeidae, Gast = Gastropoda, Hemi = Hemiptera, Hyme = Hymenoptera, Isop = Isopoda, Lepi = Lepidoptera, Lumb = Lumbricidae, Meco = Mecoptera, Nema = Nematoda, Neur = Neuroptera, Opil = Opiliones, Paur = Pauropoda, Prot = Protura, Pseu = Pseudoscorpiones, Psoc = Psocoptera, Symp = Symphyla, Thys = Thysanoptera).

The recordings and information regarding soil type that we gathered during the 2017 campaign are being used in the artistic and citizen science part of the Sounding Soil project. We developed a sound art installation/an acoustic observatory that includes the soil recordings and renders our investigations and findings accessible and perceptible for a broader audience.

Art and Citizen Science

Enhancing soil awareness: Situated environmental experiences

Approaches in cognitive sciences and environmental education that are linked to embodiment theories interpret human learning and knowledge as a product of interactions between body/mind and the environment (Csordas 1994; Kiefer and Trumpp 2012). Philipp Payne (1997) suggested using the body as a "localized" site for understanding, explaining, and acting on environmental problems as a strategy for overcoming the gap between theory and practice as well as between expert knowledge and "naïve," first-hand experience. Instead of lifting learners out of their everyday lives and their communities of practice and alienating them in abstract environmental learning circumstances, Payne proposed taking a closer look at what constitutes "lived" experience (fig. 11) – in other words, how new, different, and situated experiences can make self-evident one's own responsibility and accountability for environmental problems and also install a critical ecological ontology.

Sound as an intimate sensory impression that triggers emotion (Bachorowski and Owren 2003) is a substantial part of almost everyone's daily experiences and social interactions (Martin 1996). Sound, and especially sound art as a reflective "sound practice," seems to be the investigation and intermediation instrument of choice for situated environmental experiences (Maeder 2014, 2017). Situated experiences constitute what pedagogy recognizes as situated learning (Anderson et al. 1996), where agency and learning are embedded in social, cultural, and biological contexts. A situated experience is a physical experience (through the body senses) that emerges in a dialogical engagement in a specific problem-solving context (Frie 2011). As a theoretical concept, it not only describes something trivial, like "learning by doing," but may also serve as the theoretical background of the experience and learning process in citizen science projects as well as participatory artworks.

Listen to your soil

The Sounding Soil project, especially its artistic module, is conveyed through a citizen science part, where, first, a specific group (farmers of the NABO network) and, later, the general population are invited to contribute to the project with their own soil recordings and observations. The citizen science project (starting in summer 2019) will be accompanied by interviews documenting involvement processes and describing the effects that our project had on the participants' and the general public's perceptions of soils.

Sounding Soil is an open research and art system (Busch 2009) with several interfaces for involving the public in scientific and artistic explorations of soil ecosystems. This structure comprises a participatory art installation, where participants contribute to the project with their own soil recordings, which will be integrated into the installation's playback console. The soil recordings may be made with a low-cost recording device that will be developed for public use (standalone recorder with probes, remote control via mobile phone app, and uploaded to an online sound map) and that may be borrowed for a certain period.

An artistic-acoustic soil observatory

The artistic research component consists of experiments with stagings of soil sounds and their ecological meaning. Of interest is how to adequately describe soil sounds and implement them in

Fig. 11. Soil listening session at Zentrum Paul Klee, Bern, June 2018.

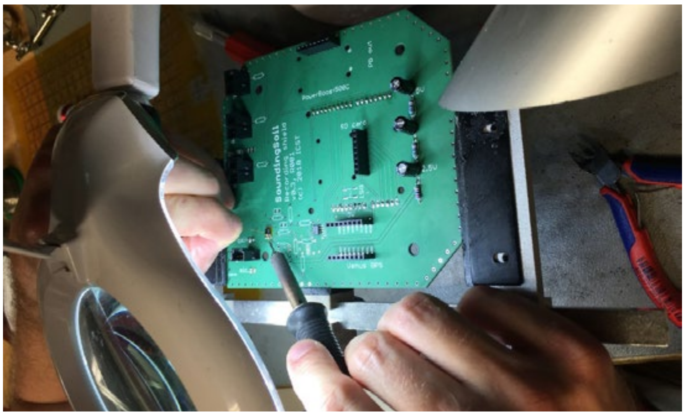

Fig. 12. Development of a low-cost recording device for the citizen science module of the Sounding Soil project at the Institute for Computer Music and Sound Technology, Zurich University of the Arts ZHdK.

terms of eco-cultural meaning (Schafer 1993; Hinton et al. 2006), and how shifting/intensifying meanings of sound could influence the attitudes and behaviours of the project contributors. Beyond that, research on the aesthetic implications and conditions in ecology and environmentalism has found its discipline in eco-aesthetics (Miles 2014); new art forms, such as eco-art, environmental art, and bioart, have emerged in the past few years (Weintraub 2012). These genres use and transform scientific methods to produce artworks that often integrate ecocriticism and environmental–aesthetic questions. They also possess the potential to introduce and integrate new and aesthetic research methods in the natural sciences (Maeder 2017).

The Sounding Soil installation (unveiled in October 2018 at Zentrum Paul Klee, Bern/Switzerland) consists of a modified ship container, which carries a soil receptacle on its roof. In the dark interior, visitors may listen to our soil recordings and the recordings of the citizen science project participants. The single recordings may be selected in a sound map on a touch screen console and be played back spatially – that is, the four channels of our recordings are placed at different levels/parts of the spatial audio speaker system. The channel containing the aerial microphone recording, for instance, is placed on the top/ceiling of the container, while the soil surface channel is placed slightly lower and the soil channel is mapped on the lower half of the speaker system.

The spatial distribution of the sound sources and the dark environment with minimal light falling in through small tubes in the ceiling/soil receptacle (simulating soil pores) provide an immersive experience and create the impression of being within the soil. Additionally, information about the recording plots, some soil science basics, as well as sustainable soil treatment and consumer behaviour are available on the console of the installation.

Conclusions

Our study is among the first to explore the soundscapes in soils and their relationships to land-use and habitat characteristics as well as biodiversity. The first results of our scientific investigations showed that variability in the acoustic complexity of soil soundscapes among sites can be related strongly to land-use intensity in open land, increasing from arable land to intensively to extensively used grasslands and between humus forms in forests. Moreover, we found good indications that differences in the acoustic complexity and composition of soil soundscapes can inform us about the diversity and composition of animal communities in soils. The further development of easily applicable devices for recording and analyzing soil soundscapes, thus, opens new avenues for evaluating soils in terms of nature conservation issues that can also be used in the frame of citizen science.

Our current approach is biased by punctual recordings without considering temporal variation in the activity of soil organisms. In our next step, we will conduct longer measurement and recording series to obtain further insights into the temporal and spatial dynamics of the acoustic and biological diversity in soils.

Based on our experience and results, we will evaluate the use of the art installation by measuring accesses and interactions at the console in different public settings (museums, agricultural fairs, science nights, etc.). We will also explore in which context our project will have the biggest impact in terms of ludic engagement (Morrison et al. 2007), learning effects, and environmental concern. Furthermore, we will collect information about the socio-geographical backgrounds of the citizen science participants. These surveys and measurements will help us develop and improve our artistic-scientific observatory, its presentation forms, and concomitant communication. As such, we aim to initiate higher sensitization to the fascinating and fragile soil ecosystems – not only among the general public but also, and most importantly, on the part of political decision-makers and agricultural producers and their lobbies.

Up-to-date information about the undertaking of this project may be obtained at **www.soundingsoil.ch**. The console/sound map of the console in the Sounding Soil container is reachable under **www.soundmap.soundingsoil.ch**.

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Endnotes

1 Like in ecology, soils may also acoustically be understood as an interface between the atmosphere and lithosphere. On the one hand, sound from the atmosphere at least partially penetrates the soil structure (Chang and Li 2007), and seismic/geo-acoustic events spread in the soil space (Belyakov 2004). On the other hand, the pedosphere possesses its own complex acoustic characteristics, which clearly differ from atmospheric and geo-acoustics, because of their mixed structure and dead and living organic matter contents.

2 For example, it is possible to emit sound wave pulses into the soil and measure the returning reflections. This technique is used in the mining and oil industries and in landmine eviction and archeology.

3 The meso- and macrofauna consist mainly of insects (mites, collembolans and arthropods, etc.), but also other invertebrates, such as worms and Enchytraeidae.

4 The recording setup consisted of a 4-channel recording system with components by Avisoft Bioacoustics and a Microsoft© Surface Tablet PC running Avisoft Recorder© Software. The recordings were led with a sampling rate of 50 KHz, 16-bit. Channel assignments: 1 – acoustic sensor plugged into the soil, 2 – sensor placed on the soil surface, 3 – sensor plugged into the soil at 1 m distance from sensor 1, 4 – electret microphone on a stand at 2 m above ground. Sensor 1 was protected with a windshield case, which also prevented insects present on the ground and close to the sensor from escaping the sampling area.

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Fig. 13. The Sounding Soil installation at Zentrum Paul Klee.

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