1-13-2023

The world of underground ecology in a changing environment

Elsa Abs
University of California, Irvine

Moira Hough
Michigan Technological University, mahough@mtu.edu

Follow this and additional works at: https://digitalcommons.mtu.edu/michigantech-p
Part of the Forest Sciences Commons

Abs, E, Hough, M. 2023. The world of underground ecology in a changing environment. *Elem Sci Anth*, 11: 1. DOI: https://doi.org/10.1525/elementa.2022.00139

INTRODUCTION

The world of underground ecology in a changing environment

Elsa Abs[1,]* and Moira Hough[2]

This special feature presents state-of-the-art soil ecological science and was sparked following the 2-day long online live event entitled "Ecology Underground" during the Ecological Society of America annual meeting of 2020. Here, we, the co-guest-editors of this special feature, present this body of research in context of the current state of the field. This issue highlights that we are currently in a hot time for microbial research in soil science. Specifically, we find that two themes emerge from this corpus as key next questions to answer to move the field forward. How do microbial processes scale up in space and time? And how do they respond to multiple interacting global change factors?

Keywords: Soil, Ecology, Microbiology

Not very long ago, soil ecologists debated whether or not the "black box" of microbial dynamics needed to be opened or if ecological processes in the soil could be understood without fine-tuned microbial mechanisms. It seems this debate has been put to rest. We now know, for instance, that microbes are not only the gatekeepers of decomposition in soil organic matter, but they also form stable organic composites made of microbial byproducts associated with minerals (Bradford et al., 2016). We also know that species-level understanding of the microbial community can improve earth system models (McCalley et al., 2014). Understanding microbial community dynamics is now a major frontier in the field of soil ecology. It was also a major topic of discussion when, during the online Ecological Society of America annual meeting of 2020, 3 sessions joined together to create an online event called "Ecology Underground." This event sparked lively discussion and inspired this special issue of Elementa on Ecology Underground.

So, it is perhaps no surprise that in this special feature about soil-climate feedbacks, all the articles investigated the response of ecosystems to climate change by studying belowground microbial changes. Martinez et al. (2021) investigated the localization of hotspots of microbial extracellular enzyme activity to improve predictions of soil carbon emissions. Vilonen et al. (2022) measured soil microbial respiration to characterize legacy effects of drought on C and N cycling. Jones et al. (2022) looked at whether microbial inoculation in soil could enhance crop yield. Soils are perhaps no longer a black box of microbial communities. Rather, they are a Pandora's box of deep complexity with many interacting components and clear importance for understanding ecosystems. From the complexity documented here, our authors have brought to light 2 themes that can help us frame research questions moving forward: the importance of understanding (1) spatial and temporal scales and (2) multiple interacting global change factors.

The first theme underlines our need to better understand *how belowground microbial processes scale over space and time*. For example, microbial community composition correlates strongly with soil functions like soil heterotrophic respiration between years rather than between seasons (Schimel and Schaeffer, 2012). And microbial community composition and function can differ when an environmental change is short-term (pulse) or long-term (press) (Shade et al., 2012). Vilonen et al. (2022) found significant legacy effects on C and N cycling 1 year after drought ended, but no legacy effect at all 2 years after. Romero-Olivares et al. (2022) found that volatile organic compounds (VOCs) did not change in response to warming and nitrogen addition after 1 year, but they found VOCs varied at the seasonal scale with very strong variation of specific types of VOCs at the annual scale.

Spatial scale is an important consideration because most sampling is done at the plot scale, but we know that microbial activity varies in important, but poorly understood, ways at microscales, such as between mineral soil and the rhizosphere or litter surface soil (Schimel and Schaeffer, 2012). We are only beginning to learn how soil microstructure affects microbial activity, but we know it is important to processes that control the persistence of soil C (Keiluweit et al., 2017). On this topic, Bernhardt et al.

[1] Department of Ecology and Evolutionary Biology, University of California, Irvine, CA, USA

[2] Department of College of Forest Resources & Environmental Science, Michigan Technological University, Houghton, MI, USA

* Corresponding author:
Email: elsa.abs.hallet@gmail.com

(2022) found strong spatial heterogeneity and enzyme activity in large soil particles, but weak enzyme activity in soil pores and small size particles, further emphasizing the need to better understand microscale variation in soil. By knowing either the spatial or temporal scale at which an ecosystem process responds to environmental change, you can usually deduct the other as they often correlate, meaning processes that respond on short time-scales usually also respond at microscales (Schimel and Schaeffer, 2012).

The second theme brought to light by the articles in this special feature is the need to understand the effect of *multiple interacting global change factors*. Kivlin et al. (2021) investigated the simultaneous effect of wildfire and urbanization. Anthony et al. (2021) and Romero-Olivares et al. (2022) studied the simultaneous effect of warming and nitrogen addition. Romero-Olivares et al. (2022), Kivlin et al. (2021), and Jones et al. (2022) pointed out the strong interaction effect of one abiotic factor (moisture, temperature, or nitrogen) with aboveground plant identity. Martinez et al. (2021) found strong interaction effects between substrate quality and soil texture.

These efforts build on previous work showing that effects of multiple global change pressures on soil ecosystem processes may interact in nonadditive ways and are therefore essential to give realistic predictions of soil response to global change. Some recent studies have found canceling effects of multiple global change factors (Shaw et al., 2002; Yang et al., 2021), while others found more variable responses (Castro et al., 2010; Docherty et al., 2012; Torn et al., 2015). Similarly for single factors, the response to interacting global change factors is specific to the biome and to whether we look at seasonal or interannual time scales (Simon et al., 2020).

Considering multiple spatial scales, time scales and interacting factors of environmental change adds complexity to the conceptual or empirical models we create to understand soil response to global change. This complexity merits a clear conceptual framework to build the next generation of experiments on soil response to environmental change, following on a previous generation of global change experiments including Free Air CO_2 Enrichment (FACE) (Hendrey et al., 1999), warming (Melillo et al., 2017), DroughtNet (Knapp et al., 2017), and Nutnet (Borer et al., 2017). One approach to creating such a framework would be to begin with a meta-analysis of soil response to global change factors organized by soil ecosystem process, global change factor, and spatiotemporal scale. We would then study how responses compare between spatiotemporal scales: if they are similar, we can assume that the response scales up, and if not, we need to investigate with experiments and mathematical models what is the missing process or interaction effect that bridges the 2 spatiotemporal scales. We would then use the same approach to bridge responses to one versus multiple global change factors. This rigorous approach to studying complexity is a strength of the field of ecology, which needs to be mobilized to improve our understanding of such complexity.

Taking such steps is also essential for envisioning paths toward climate change mitigation. The same 2 themes identified in this special issue have also been identified as key needs for management decisions where understanding spatial scale and the interacting effects of multiple processes is critical (Banwart et al., 2014; Cameron et al., 2017). This information is also needed for research into new mitigation strategies such as microbe-mediated soil carbon sequestration. By exploring the interacting effects of different climate change responses across temporal and spatial scales, the field of underground ecology is taking big steps toward filling gaps in both how we understand our world and in how we can respond to the changes taking place in it.

Competing interests

The authors have no competing interests to declare.

References

Anthony, MA, **Knorr, M**, **Moore, JAM**, **Simpson, M**, **Frey, SD.** 2021. Fungal community and functional responses to soil warming are greater than for soil nitrogen enrichment. *Elementa: Science of the Anthropocene* **9**(1): 000059.

Banwart, S, **Black, H**, **Cai, Z**, **Gicheru, P**, **Joosten, H**, **Victoria, R**, **Milne, E**, **Noellemeyer, E**, **Pascual, U**, **Nziguheba, G**, **Vargas, R**, **Bationo, A**, **Buschiazzo, D**, **de-Brogniez, D**, **Melillo, J**, **Richter, D**, **Termansen, M**, **van Noordwijk, M**, **Goverse, T**, **Ballabio, C**, **Bhattacharyya, T**, **Goldhaber, M**, **Nikolaidis, N**, **Zhao, Y**, **Funk, R**, **Duffy, C**, **Pan, G**, **la Scala, N**, **Gottschalk, P**, **Batjes, N**, **Six, J**, **van Wesemael, B**, **Stocking, M**, **Bampa, F**, **Bernoux, M**, **Feller, C**, **Lemanceau, P**, **Montanarella, L**. 2014. Benefits of soil carbon: Report on the outcomes of an international scientific committee on problems of the environment rapid assessment workshop. *Carbon Management* **5**(2): 185–192.

Bernhardt, LT, **Smith, RG**, **Grandy, AS**, **Mackay, JE**, **Warren, ND**, **Geyer, KM**, **Ernakovich, JG**. 2022. Soil microbial communities vary in composition and functional strategy across soil aggregate size class regardless of tillage. *Elementa: Science of the Anthropocene* **10**(1): 00023.

Borer, ET, **Grace, JB**, **Harpole, WS**, **MacDougall, AS**, **Seabloom, EW.** 2017. A decade of insights into grassland ecosystem responses to global environmental change. *Nature Ecology & Evolution* **1**(5): 118.

Bradford, MA, **Wieder, WR**, **Bonan, GB**, **Fierer, N**, **Raymond, PA**, **Crowther, TW.** 2016. Managing uncertainty in soil carbon feedbacks to climate change. *Nature Climate Change* **6**(8): 751–758.

Cameron, DR, **Marvin, DC**, **Remucal, JM**, **Passero, MC.** 2017. Ecosystem management and land conservation can substantially contribute to California's climate mitigation goals. *Proceedings of the National Academy of Sciences* **114**(48): 12833–12838.

Castro, HF, **Classen, AT**, **Austin, EE**, **Norby, RJ**, **Schadt, CW.** 2010. Soil microbial community responses to multiple experimental climate change drivers.

Applied and Environmental Microbiology **76**(4): 999–1007.

Docherty, KM, **Balser, TC**, **Bohannan, BJM**, **Gutknecht, JLM.** 2012. Soil microbial responses to fire and interacting global change factors in a California annual grassland. *Biogeochemistry* **109**(1): 63–83.

Hendrey, GR, **Ellsworth, DS**, **Lewin, KF**, **Nagy, J.** 1999. A free-air enrichment system for exposing tall forest vegetation to elevated atmospheric CO_2. *Global Change Biology* **5**(3): 293–309.

Jones, JM, **Boehm, EL**, **Kahmark, K**, **Lau, J**, **Evans, S.** 2022. Microbial community response to drought depends on crop. *Elementa: Science of the Anthropocene* **10**(1): 00110.

Keiluweit, M, **Wanzek, T**, **Kleber, M**, **Nico, P**, **Fendorf, S.** 2017. Anaerobic microsites have an unaccounted role in soil carbon stabilization. *Nature Communications* **8**(1): 1–10. DOI: http://dx.doi.org/10.1038/s41467-017-01406-6.

Kivlin, SN, **Harpe, VR**, **Turner, JH**, **Moore, JA**, **Moorhead, LC**, **Beals, KK**, **Hubert, MM**, **Papeş, M**, **Schweitzer, JA**. 2021. Arbuscular mycorrhizal fungal response to fire and urbanization in the Great Smoky Mountains National Park. *Elementa: Science of the Anthropocene* **9**(1): 00037.

Knapp, AK, **Avolio, ML**, **Beier, C**, **Carroll, CJW**, **Collins, SL**, **Dukes, JS**, **Fraser, LH**, **Griffin-Nolan, RJ**, **Hoover, DL**, **Jentsch, A**, **Loik, ME**, **Phillips, RP**, **Post, AK**, **Sala, OE**, **Slette, IJ**, **Yahdjian, L**, **Smith, MD.** 2017. Pushing precipitation to the extremes in distributed experiments: Recommendations for simulating wet and dry years. *Global Change Biology* **23**(5): 1774–1782.

Martinez, J, **McLaren, J**, **Tweedie, CE**, **Darrouzet-Nardi, A.** 2021. Soil enzymes are preferentially associated with larger particles in highly organic Arctic tundra soils. *Elementa: Science of the Anthropocene* **9**(1): 00020.

McCalley, CK, **Woodcroft, BJ**, **Hodgkins, SB**, **Wehr, RA**, **Kim, E-H**, **Mondav, R**, **Crill, PM**, **Chanton, JP**, **Rich, VI**, **Tyson, GW**, **Saleska, SR.** 2014. Methane dynamics regulated by microbial community response to permafrost thaw. *Nature* **514**(7523): 478–481.

Melillo, JM, **Frey, SD**, **DeAngelis, KM**, **Werner, WJ**, **Bernard, MJ**, **Bowles, FP**, **Pold, G**, **Knorr, MA**, **Grandy, AS.** 2017. Long-term pattern and magnitude of soil carbon feedback to the climate system in a warming world. *Science* **358**(6359): 101–105.

Romero-Olivares, AL, **Davie-Martin, CL**, **Kramshøj, M**, **Rinnan, R**, **Frey, SD.** 2022. Soil volatile organic compound emissions in response to soil warming and nitrogen deposition. *Elementa: Science of the Anthropocene* **10**(1): 00065.

Schimel, JP, **Schaeffer, SM.** 2012. Microbial control over carbon cycling in soil. *Frontiers in Microbiology* **3**: 348.

Shade, A, **Peter, H**, **Allison, SD**, **Baho, DL**, **Berga, M**, **Bürgmann, H**, **Huber, DH**, **Langenheder, S**, **Lennon, JT**, **Martiny, JBH**, **Matulich, KL**, **Schmidt, TM**, **Handelsman, J.** 2012. Fundamentals of microbial community resistance and resilience. *Frontiers in Microbiology* **3**: 417.

Shaw, MR, **Zavaleta, ES**, **Chiariello, NR**, **Cleland, EE**, **Mooney, HA**, **Field, CB.** 2002. Grassland responses to global environmental changes suppressed by elevated CO_2. *Science* **298**(5600): 1987–1990.

Simon, E, **Canarini, A**, **Martin, V**, **Séneca, J**, **Böckle, T**, **Reinthaler, D**, **Pötsch, EM**, **Piepho, H-P**, **Bahn, M**, **Wanek, W**, **Richter, A.** 2020. Microbial growth and carbon use efficiency show seasonal responses in a multifactorial climate change experiment. *Communications Biology* **3**: 584. DOI: http://doi.org/10.1038/s42003-020-01317-1.

Torn, MS, **Chabbi, A**, **Crill, P**, **Hanson, PJ**, **Janssens, IA**, **Luo, Y**, **Pries, CH**, **Rumpel, C**, **Schmidt, MWI**, **Six, J**, **Schrumpf, M**, **Zhu, B.** 2015. A call for international soil experiment networks for studying, predicting, and managing global change impacts. *SOIL Discussions* **2**(1): 133–151.

Vilonen, LL, **Blair, J**, **Trivedi, P**, **Zeglin, L**, **Smith, MD.** 2022. Limited legacy effects of extreme multiyear drought on carbon and nitrogen cycling in a mesic grassland. *Elementa: Science of the Anthropocene* **10**(1): 000093.

Yang, Y, **Li, T**, **Wang, Y**, **Cheng, H**, **Chang, SX**, **Liang, C**, **An, S.** 2021. Negative effects of multiple global change factors on soil microbial diversity. *Soil Biology and Biochemistry* **156**: 108229.

How to cite this article: Abs, E, Hough, M. 2023. The world of underground ecology in a changing environment. *Elementa: Science of the Anthropocene* 11(1). DOI: https://doi.org/10.1525/elementa.2022.00139

Domain Editor-in-Chief: Steven Allison, University of California, Irvine, CA, USA

Associate Editor: Peter Homyak, University of California, Riverside, CA, USA

Knowledge Domain: Ecology and Earth Systems

Part of an Elementa Special Feature: The World of Underground Ecology in a Changing Environment

Published: January 13, 2023 **Accepted:** December 12, 2022 **Submitted:** November 08, 2022

ELEMENTA Science of the Anthropocene

Elem Sci Anth is a peer-reviewed open access journal published by University of California Press.

OPEN ACCESS