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COMMENTARY

Changing the culture of ecology from the ground up

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

We are two early career soil ecologists in academia who entered the field of soil ecology with the goal of studying soil-climate feedbacks to make meaningful contributions to climate change mitigation. Although our training and research extensively focused on the effects of climate change on soil ecosystems, we were not trained during our PhD nor incentivized as postdocs to work on solutions for climate change mitigation. So the question we ask here is: Given the consensus among ecologists about the urgency of the climate crisis, why is our field not promoting more solutions-oriented research in training and practice? In this commentary, we provide our perspective on (1) the way forward shown by individual soil ecologists doing solutions-oriented research, (2) some specific cultural barriers to academic institutional support, and (3) three examples promoting solutions-oriented science that improve support for early career researchers and reduce barriers to entry.

Keywords: Soil ecology, Solution-oriented, Inclusive

Introduction

We are two early career soil ecologists in academia who entered the field of soil ecology with the goal of studying soil-climate feedbacks to make meaningful contributions to climate change mitigation. When we began our PhD studies in 2015, we pursued ecology because it operates at the scale where people experience the extraordinary habitat and landscape transformations provoked by global change. And we chose soil science because soils contain more C globally than forests and the atmosphere combined (Scharlemann et al., 2014) and its degradation presents serious threats to many ecosystem services (**Figure 1**) (Joint Research Center and European Environmental Agency, 2010; Banwart, 2011). For example, air pollution from Indonesian peat fires has been estimated to result in over 35,000 premature deaths per year (Hein et al., 2022), and it is estimated that fires on drained peatlands could reduce the temperate/boreal peatland C sink by over 50% by 2050 (Wilkinson et al., 2023). In contrast, restoration of drained peatlands could mitigate negative health outcomes and increase long-term C storage (Kiely et al., 2021). Although our training and research extensively focused on the effects of climate change on soil ecosystems, we were not trained during our PhD to work on solutions for climate change mitigation. As postdocs now, we do not feel incentivized by the structure of academic science to engage in solutions-oriented research projects, nor do we feel that we have the appropriate training to dive into this area responsibly. Given the consensus among ecologists about the urgency of the climate crisis, why is our field not promoting more solutions-oriented research in training and practice?

In trying to answer this question for ourselves through discussions and by exploring the solutions-oriented research literature, we found that this deficiency does not arise from a lack of desire among soil ecologists or a lack of existing work in this area. Instead, it seems the absence of discussion around solutions-oriented research we experienced in our training stems from a culture in academic ecology that prevents it from successfully and equitably addressing the global changes we are seeing. Here, we provide the perspective from two early career researchers on (1) the way forward shown by individual soil ecologists doing solutions-oriented research, (2) some specific cultural barriers to academic institutional support, and (3) three examples promoting solutions-oriented science that improve support for early career researchers and reduce barriers to entry. Given that our opinions, perspectives, and science are heavily influenced by our backgrounds and experiences, it is worth noting that we are two white, middle-class individuals—one identifying as female and the other as non-binary.

Solutions-oriented soil ecology: A path forward paved by individual ecologists

For over a decade, our predecessors have shown that we need to rethink the scientific questions we ask with an eye to explicitly seeking environmental solutions. To do this, the scientific process must be adjusted to legitimately

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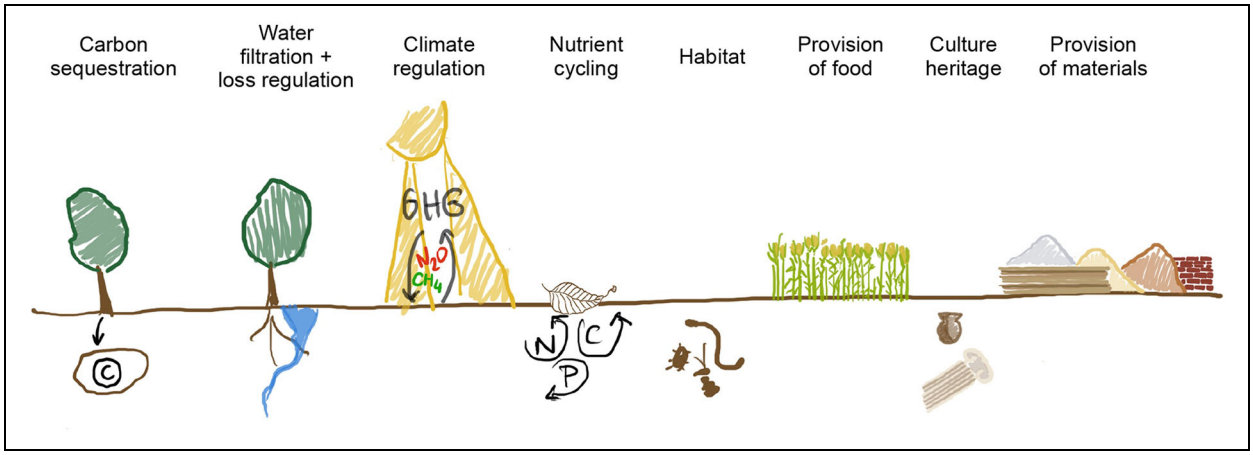

Figure 1. Ecosystem services delivered by soils. Adapted from https://www.fao.org/3/AX374E/ax374e.pdf.

incorporate input from impacted communities, land managers, and policymakers (Schlesinger, 2010; Whitmer et al., 2010; Balazs and Morello-Frosch, 2013; Méndez et al., 2013; Brunson and Baker, 2016; Enquist et al., 2017; Hansen et al., 2018; Dwivedi et al., 2022). In ecology, several terms have been used to describe solutions-oriented research. Agroecology has a long tradition of working with "participatory action research," defined as including knowledge from multiple actors and seeking to directly contribute to redirect current agro-food systems toward sustainability (Méndez et al., 2013). Whitmer et al. (2010) described the rationales, challenges, and solutions to do "engaged research" in ecology. The same year, Schlesinger (2010) introduced the concept of "translational ecology," which incentivized stakeholders, rights-holders, and environmental scientists to build partnerships aimed at solving environmental issues. Brunson and Baker (2016) and Enquist et al. (2017) followed up by proposing a framework for crafting and applying translational ecology. The need to implement these ideas has been emphasized by Halpern et al. (2023), who organized a workshop of 127 professionals that identified "diversity, equity, diversity, and justice," "human and natural systems," and "actionable and use-inspired science" as the top three priorities to help natural scientists address environmental challenges and global change.

Other disciplines adjacent to soil ecology have articulated solutions-oriented research practices (**Figure 2**). For instance, Balazs et al. (2013) demonstrate in public health two case studies of "community-based participatory research" that led to stronger science rigor, relevance, and reach. Biogeoscientists have similarly written about promoting "integrated, coordinated, open, networked science" (ICON) (Dwivedi et al., 2022). In environmental sciences, the Nunavik Research Centre in Canada is an organization comprised of Inuit and non-Inuit scientists and nonscientists that have been coproducing environmental knowledge for 40 years. Their proposed studies are evaluated not only by scientists' professional standards but by local knowledge norms and ethical requirements.

Despite using different vocabulary, those papers all agree on two ideas: that we need to conduct science that directly addresses environmental issues, and that to be successful at it we need to work in partnership from the start with impacted communities (e.g., socioeconomically marginalized) and people that have impact on it (e.g., politicians). Yet despite this clear convergence of thought these ideas are not widely included in training of ecologists, which slows their dissemination and development, and indicates a lack of full acceptance and support at the institutional level. One of very few institutional movements that have been made is that in the mid-1990s funding sources such as National Science Foundation (NSF) began to require a broader impact statement (Whitmer et al., 2010). However, because the requirements for these statements are vague, they frequently become rhetorical exercises that do not ensure true societal impact (Sarewitz, 2011; Bonaccorsi et al., 2021). This should not be surprising when most ecologists have little to no exposure in how to build direct bridges to societal impact and are not rewarded for putting in the extra work to do so. We need to promote and reward the work, both in grant applications and papers, of those who shift statements from being aspirational to practical (Amelung et al., 2020). This requires a cultural shift to encourage science that explicitly seeks climate change solutions and learn how to work directly with communities, managers, and policy experts to provide information tailored to their needs.

Cultural barriers to institutional change

Despite widespread interest in finding climate solutions, there is still a lack of institutional support for solutions-oriented science. Admittedly, major institutional change is very difficult and takes time. However, we think the hesitancy goes beyond inertia and is also derived from cultural barriers within academic science. We felt that we experienced in our training and work so far four major cultural barriers to the advancement of solutions-oriented science:

Cultural barrier 1: Hesitancy to work on actionable science before having fully understood the effects of global change

The climate crisis is progressing at an exponential rate that is out of step with the slow-paced schedule of grant writing, scientific discovery, and dissemination. While

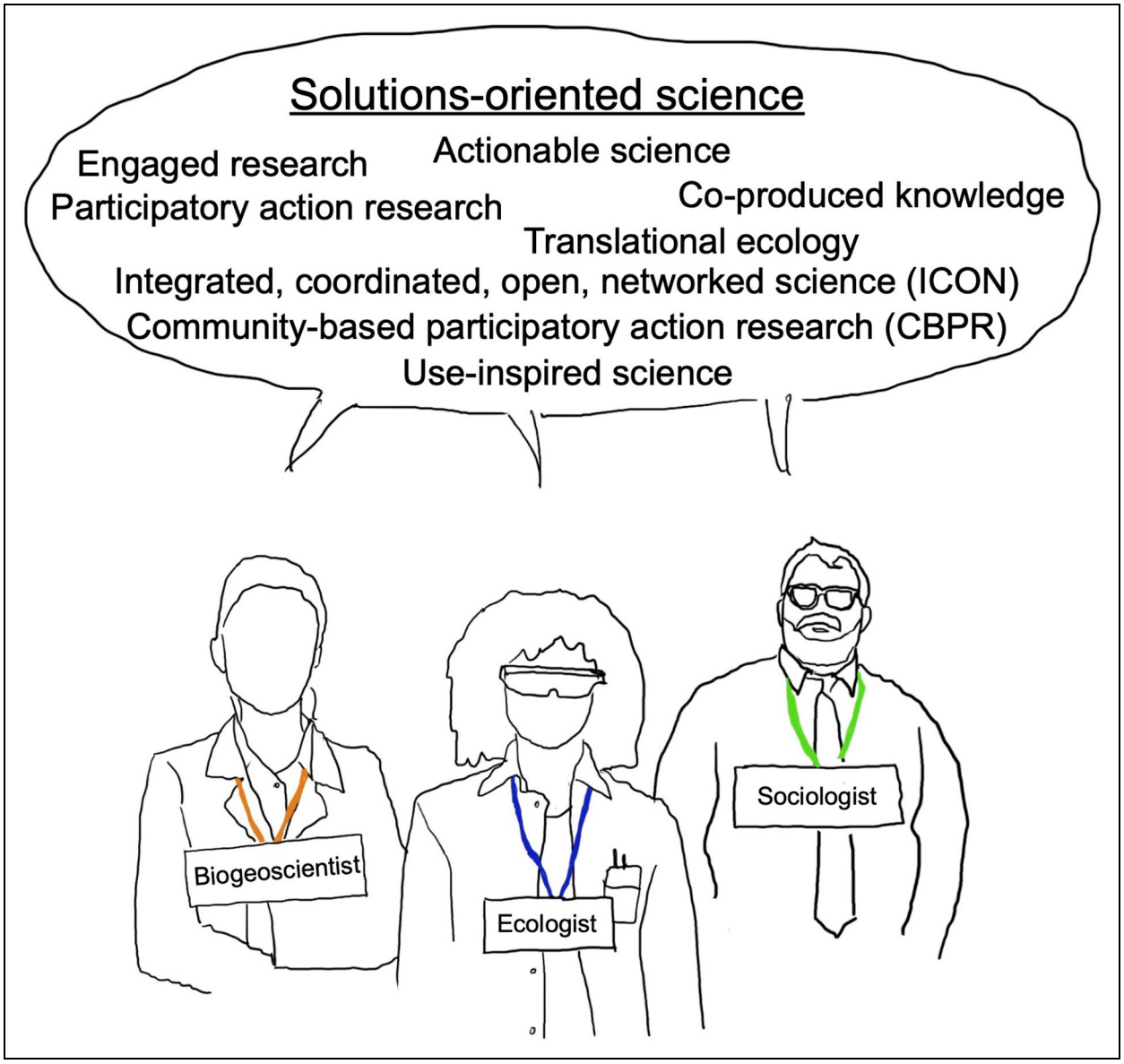

Figure 2. Different terms used across academic fields (the ones displayed are examples, not a complete representation) to describe what we call solutions-oriented science.

a deep understanding of the problems presented by climate change is certainly needed, many of them are already well-known and have been for some time. Ten years ago, Bouma and McBratney (2013) wrote "Effective framing does not need more diagnostic studies nor alarming declarations or conceptual action plans, but should focus on the presentation of specific case studies demonstrating the role of soils when confronting the major environmental issues of today." With 10 more years of research on climate change and very little progress on climate change mitigation, the current need is not more and more science to place smaller error bars on the problem (Lee, 2015). Rather, the need is for an effective way to quickly mobilize the information that we currently have. We need targeted experiments testing the effectiveness of various potential solutions for those problems so that we can begin implementing the most successful ones.

Cultural barrier 2: Perception that developing solutions is not the job of academic scientists

In the past, solutions have been left to land managers and government agencies while researchers focused on questions of basic science. The delineation between basic science and its application is a constructed dichotomy based on a particular Western mode of thought that originally served to maintain scientific independence (Stokes, 1997; Nowotny et al., 2003). The fields of conservation science and conservation social science have led the way in seeking to bridge this divide through coproduction of knowledge (e.g., Beier et al., 2017; Hastings et al., 2020; Caro et al., 2023) yet substantial chasms remain between many ecological research endeavors and their practical applications (see e.g., Toomey et al., 2017; Ferreira and Klütsch, 2022). In particular, these approaches have not yet been broadly incorporated into climate change ecology since it is still largely focused on problems rather than solutions,

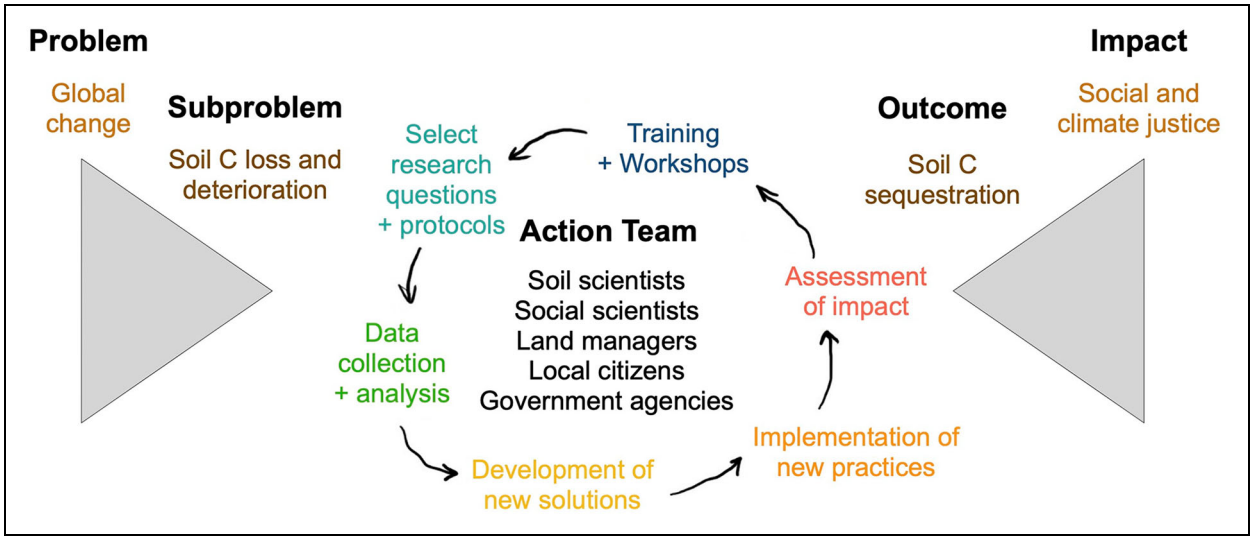

Figure 3. A representation of what solutions-oriented science could look like for soil ecology (inspired by the problems-to-action logic model [McLaughlin and Jordan, 2015]).

leaving a knowledge gap (Jarvis et al., 2020) that land managers lack the resources to address on their own (van den Hove, 2007). This is because research published in journals may not be accessible to those outside of academia (Anderson, 2014), because the questions addressed by research often don't align with the "on-the-ground" research needs and priorities of the communities most impacted (Dilling and Lemos, 2011; Anderson, 2014), and because understanding a problem is not the same as knowing how to solve it.

Instead, soil ecology research needs to encourage a focus on solutions-oriented work and to do so it must partner with more applied institutions, stakeholders, and rights-holders to enhance all of our efforts (Bouma and McBratney, 2013; Enquist et al., 2017) (**Figure 3**). Bouma and McBratney for example reported on the "Green Water" study in Kenya, where soil scientists joined stakeholders and rights-holders, as well as water and electricity companies to propose a model for soil security. Their model successfully increased water availability for crops and a reduction of erosion and siltation of reservoirs used for hydroelectricity (Kauffman et al., 2014). As this example shows, we need both scientist and community buy-in to find and successfully implement environmental solutions.

Cultural barrier 3: Inadequate support for solutions-oriented research in academic training and evaluation

To legitimately perform solutions-oriented research requires consistent training and support at all career levels. Many tools have been developed to do this type of work but they are not generally included in the training offered to students by academic departments. This leaves many students unaware of the work that already exists in this area. Even those, like us, who have read papers on solutions-oriented work are left unsure about how to practically execute it. Part of the uncertainty of how to implement it is because there is a perception that it will not be supported by funding agencies or career evaluation procedures. Grant reviewers and agencies need to place renewed emphasis on the evaluation structures of proposals to include professionals that know how to judge successful implementations of solutions-oriented research (Duffy et al., 2021). Ultimately, there needs to be a major cultural shift at the institutional level to place value on practical outcomes when evaluating promotion and job success.

Cultural barrier 4: Lack of representation and inclusion of BIPOC people in ecology

Finding solutions to climate change requires that we work to open science to a broader set of perspectives and backgrounds. Marginalized scientists and Indigenous communities have long understood the need for pluralism and the limitations of the Western developed scientific method to produce actionable science. Why such an expansion in scientific practice has yet to emerge remains an outstanding issue in our fields of practice. It is broadly acknowledged that people from historically marginalized communities are underrepresented in academia, and especially in STEM fields, as compared to the population at large (O'Brien et al., 2020; Tseng et al., 2020; Wanelik et al., 2020). Of the people who received ecology PhDs in 2015 in the United States, 85% were white, 1% were black or African American, 2.6% were Asian, 6.4% were Hispanic or Latino, and 0.5% were American Indian or Alaska Native (NSF, 2014). Add to this the additional hurdles faced by non-native English speakers (Amano et al., 2023) and lack of true collaboration between scientists from developed and developing nations (Minasny et al., 2020), and it becomes clear this problem runs deeply through academia. Training should be accessible to the people most affected by climate change (the most marginalized) and the populations most responsible for climate change (the most privileged) should be trained to work in closer partnership with them when seeking solutions. This can only happen with deep cultural shifts

within ecological departments and fields, which have historically been largely white spaces.

Solutions to help institutional support

Fully and equitably addressing the impacts of climate change will require a diverse and culturally competent ecological workforce with a solid foundation in ecology, strong technical skills, and transdisciplinary expertise (Halpern et al., 2023). Other STEM disciplines like Earth sciences have already started rethinking their agenda and culture (Unlearning Racism in Geoscience [URGE], https://urgeoscience.org/), and soil ecology should do the same (National Academies of Sciences, Engineering, and Medicine, 2022). Integrating solutions-oriented science in soil ecology will require updating student education and training at all career levels, the research agenda, and the relationship between academic research and local communities, and between academic soil ecology and other academic fields. These important systemic changes cannot fall on the shoulders of individual academics; they need to be made at the institutional level (Klein, 2009; Fam et al., 2020). There are many changes that could be made to improve institutional support for solutions-oriented science. We will focus on three areas where institutions could reduce barriers to entry and increase support for early career ecologists wishing to engage in solutions-oriented research.

Develop training programs

In order to achieve this transformation, it is critical to develop and restructure existing training programs to provide the skills needed for solutions-oriented research. Currently, as undergraduate and graduate students, we are trained to develop research questions by identifying a knowledge gap in prior research. This is a fine start, but we need to also train students in how to identify knowledge gaps coming from land managers and decision makers that would help them to do their work. This requires some basic understanding of the functioning of environmental laws, policy creation, and natural resources management. Additionally, it requires specific training in how to work with communities outside of academia. The partnership between academics and communities has been found to be frustrating and possibly extractive when students attempt to engage with communities without this training (Adams et al., 2004). These skills are, for example, capacity to effectively communicate our research beyond disciplinary and academic boundaries (communication skills), ability to build strongly connected partnerships with communities (networking skills), and practice in facilitation such as collaborative consensus building (leadership skills) (Whitmer et al., 2010; Pelletier, 2020). Beier et al. (2017) made a list of seven recommended practices that should be a key part of this sort of training such as conveying the meaning of uncertainty but respecting the fact that decisions must be made, or expecting managers to challenge our science.

Developing training programs will require collaborative efforts across departments and disciplines such as between ecology, natural resources management, law, and social science (Bennett et al., 2017). A brief introduction to these elements could be incorporated into graduate level departmental seminars, with further training available in cross-departmental courses or seminar series. Universities could also promote cross-department workshops and conferences for ecologists to meet with people of other disciplines (Laursen and Rocque, 2009). Such a conference took place at University of California (UC) Irvine in April 2022, "Reimagining UCI in a climate-change world," for ecologists to discuss with geoscientists, people in law, humanities, social ecology, public health, engineering, art, how to promote solutions-oriented education and research at the university scale. These changes will also require training in how to collaborate with nonacademic groups such as land management agencies and communities through translational science (Enquist et al., 2017).

There are some examples of this training beginning to happen, but it needs to be expanded much more broadly. The NSF Research Traineeship (NRT) program is a great example of a funded program for graduate students to develop interdisciplinary skills aligned with a changing workforce, research framework, and societal needs. For example, the Ridge to Reef (R2R) NRT program (https://r2r.bio.uci.edu/ridge-reef-r2r-uc-irvine/) at University of California Irvine has funded graduate students to work with local communities to identify environmental and social challenges, as well as find innovative solutions on topics such as watershed restoration, social resilience, clean water, and sustainable agriculture. Additionally, the Transformative Research in Urban Sustainability Training (T-RUST) NRT grant funded development of a graduate program at Wayne State University to train transdisciplinary leaders in urban sustainability (Wallen et al., 2022).

There are an increasing number of resources to support equity in science both in the form of publications (https://education.umd.edu/sites/default/files/uploads/inline-files/Equity-Minded-Faculty-Evaluation-Reform.pdf) and in the form of initiatives such as the Research for Justice Datacenter (https://www.datacenter.org/services-offered/research-justice/). These efforts need to be greatly expanded and more broadly incorporated into graduate training programs so that trainees everywhere (not just in these few specific programs) can learn these approaches. Additional opportunities are needed to help postdocs and professors who did not have access to such training during their graduate studies learn how to practice solutions-oriented science.

Support for building long-term relationships with stakeholders and rights-holders

Universities can provide support for community-based research in three key areas: in helping researchers to make connections with communities, in maintaining those connections, and in valuing the time and effort it takes for researchers to do this even if it does not result in as many academic papers.

Currently, it is up to individual ecologists to establish connections with actors outside academia (be they communities, public, rights-holders or private stakeholders) (Haddaway et al., 2017). One way to help researchers to

form initial connections with communities is to facilitate a long-standing series of workshops with other departments and nonacademic stakeholders and rights-holders (Gossa et al., 2015). The goals of such workshops could be to: (1) facilitate and build networks that cut across academic and nonacademic sectors, and doing this with intention to bring in historically excluded groups such as community-based organizations, and (2) identify a preliminary list of priority topic areas for moving forward with the collaboration. One of these topic areas could be important logistical aspects such as how to ensure combined sources of funding and fair distribution of funding. Such workshops could serve as an initial seed of introduction between researchers, stakeholders, and rights-holders. Faculty could be supported in organizing such a long-standing series of workshops by getting paid honorariums or by counting this as research productivity (similar to writing a paper or receiving grant) in tenure track positions. They could also be provided with clerical help by their departments/campuses to help with organizational and administrative aspects.

Once connections have been made, universities can help to maintain them in the long term by hiring permanent staff as part of a university research center. University research centers can play pivotal roles in communities by collaborating with community organizations to form long-term coalitions working on broad problems (Weiner and McDonald, 2013). Long-term staff can be hired to maintain the relationships with community partners beyond a single workshop or grant cycle or graduate thesis (D'Alonzo, 2010). These staff can also provide training for students and help manage expectations of students, community partners, and academics if there is a long-term relationship. Creating these long-term relationships with the institution rather than individual students who are only there for short periods of time would help to avoid redundant requests for input from community members who have limited time and energy.

The additional labor coming with coproducing knowledge is seldom supported or properly rewarded by the individual's home institution (O'Meara et al., 2019). For example, Caro et al. (2023) showed that scientists and managers should work together in the field to ensure feedback in real time or conduct research at multiple sites as it broadens manager's abilities to reach multiple stakeholders and right holders. As a consequence, few ecologists are incentivized to do solutions-oriented science, and some may even feel penalized if it comes at a cost to their publication rate (Klein, 2009; Klein and Falk-Krzesinski, 2017; Fam et al., 2020). Universities should recognize this work when considering promotion and retention.

Promote inclusiveness through funding and group support

Promoting equity involves both improving collaboration with communities and improving access to scientific training to facilitate people from minoritized communities becoming leaders in seeking environmental solutions. There are an increasing number of publications in the literature providing guidance from BIPOC on ways that institutions can increase equity and diversity. Some issues of particular relevance to early career soil ecologists are decolonization of curricula (Schell et al., 2020) and implementation of fieldwork safety practices that focus on the additional risks faced by minoritized individuals (e.g., Demery and Pipkin, 2021).

A key point is that these efforts must go well beyond increasing representation through hiring decisions (which is badly needed, Miriti, 2020) and also increase *retention* through changes to the work environment (Sealey et al., 2020). For example, departments can ensure that they reward activities that increase inclusivity and that the burden of these efforts does not rest excessively on underrepresented faculty (Jimenez et al., 2019). Increasing inclusivity is partly about creating a supportive work environment that takes into account the particular needs of different groups of people (Maas et al., 2020) as well as the particular challenges faced by those with intersectional identities (Miriti, 2020). One approach could include creation of employee resource groups (ERGs), also called affinity groups, through funding and coordination (Welbourne et al., 2017). These collectives can provide a sense of belonging, career opportunities, and connection with broader groups such as the Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS), Women of Color in EEB (WOCinEEB), and topic-specific groups like Black microbiologists. These types of structures can also serve as advisory councils, so that management is encouraged/required to consult with ERGs on matters that may affect that group. Many of these solutions have been initiated on an individual basis by ecologists around the United States; we would like those initiatives to be normalized, promoted, and implemented in all ecology departments.

A key aspect of increasing inclusiveness in training is for institutions to make graduate study more financially accessible to a broader array of people. The current graduate system in the United States compensates people for at most 20 h per week of their time despite the fact that they are generally doing work that is essential to moving the field forward for far more than 40 h per week. Stipends often barely cover or do not cover cost of living, and may lack access to health care coverage, making graduate school difficult or inaccessible to people who lack family support in these areas let alone those who are themselves responsible for supporting their family. Those issues are at the roots of the strikes that happened in all the UC campuses and that gathered 48,000 graduate and postdoctoral strikers. We cannot hope to increase diversity in academia without making the training financially accessible to students coming from marginalized backgrounds (Duc Bo Massey et al., 2021; Emery et al., 2021).

Conclusion

We believe that many early career soil ecologists, like us, are craving a more inclusive and meaningful practice of ecological research in academia. We recognize that soil ecology potentially holds many solutions to environmental problems, particularly in terms of climate change mitigation. We want to be trained to produce

research that provides some of these solutions, and to do it with communities most impacted by climate change, with academics from other disciplines and with rights-holders and stakeholders outside of academia. As global change is progressing, solutions-oriented science will only become more of a priority, and as such, will determine funding and hiring. Some schools (e.g., Columbia, Stanford) and departments (e.g., Earth System Science at UCI funded by the NSF's Cultural Transformation in the Geoscience Community program [https://new.nsf.gov/funding/opportunities/cultural-transformation-geoscience-community-ctgc]) have already started to build inclusive cross-discipline climate solutions-focused science, proving the need for institutional level restructuring.

We recognize that trying to do solutions-oriented science is a shift from the traditional academic approach to ecology and as such is going to require substantial work. However, it will also bring substantial benefits to academia that make the difficulty worthwhile. First, a shift toward solutions-oriented science will aid academic fields that are trying to fix the barriers that prevent their faculty from being more representative of the local and undergraduate populations (Bingham and Torres, 2008; Cid and Bowser, 2015; Wallace and York, 2020; Duffy et al., 2021; Graves et al., 2022). It has been shown that younger generations of scientists, and in particular minoritized students (Miriti et al., 2021), are looking for research disciplines that are directly connected to environmental justice and the needs of their communities (Carter et al., 2021; Schusler et al., 2021). Thus, rewarding solutions-oriented ecology will help increase recruitment and retention of diverse individuals (Hansen et al., 2018; Duc Bo Massey et al., 2021). Additionally, support for solutions-oriented science could help to reduce mental health problems of students and early career ecologists (Gin et al., 2021). Working daily on the destructive effects of global change can fuel eco-anxiety (Pihkala, 2020), which may be reduced by focusing on solutions to the problems. Additionally, creating stronger networks with more applied, solutions-oriented groups (such as management agencies) would also help to provide a much needed expansion of career opportunities available to PhDs beyond academia (Cyranoski et al., 2011; Hansen et al., 2018). As for society, such a change will help train a workforce more capable of solving the challenges raised by global environmental and social crises.

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Competing interests

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Author contributions

EA and MH both conceptualized, wrote, reviewed, and edited equally.

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