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Convergence, continuity, and community: a framework for enabling emerging leaders to build climate solutions in agriculture, forestry, and aquaculture

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Abstract
Many early career researchers (ECRs) have the capacity and drive to contribute to climate adaptation and mitigation solutions. Strategic investments in training and support, especially in broad-based efforts that span traditional disciplinary boundaries, can help ECRs meet this potential and become emerging leaders equipped to address pressing climate-related challenges throughout their careers. In 2018, the inaugural USDA Northeast Climate Hub's Graduate Climate Adaptation Partners (GradCAP) Program was launched to provide professional development opportunities and a platform for collaboration to graduate students studying climate resilience in agriculture, forestry, and aquaculture. This essay represents the unified voice of this consortium of emerging leaders. Here we offer perspectives, experiences, and recommendations for building capacity among ECRs, specifically with regard to interdisciplinary research, long-term research, and community engagement. We discuss these three tenants, which we term Convergence, Continuity, and Community, as essential elements in the development of successful leaders prepared for the complex challenges ahead. We encourage institutions, particularly universities and government agencies, to commit resources and pursue structural changes to provide support for mentorship and training that span these focal areas. As a result, more ECRs will have the capacity to engage in meaningful solution-oriented research and make lasting societal contributions toward the sustainable production of food and other natural resources in a changing climate.

Keywords Climate change · Interdisciplinary · Early career researchers · Adaptation · Mitigation · GradCAP

1 Introduction

In order to supply food and other renewable natural resources in the face of climate change, there is urgent need to implement ambitious mitigation efforts while simultaneously adapting to the impacts already occurring (Tilman et al. 2011; Romero-Lankao et al. 2014; Hoegh-Guldberg et al. 2018). As with all sectors affected by climate change, the scale of the challenge faced in

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sustainable food and natural resource production requires an exceptionally broad range of disciplines, skill sets, and stakeholders to be brought to bear (Shaman et al. 2013). Early career researchers (ECRs), including graduate students and postdoctoral researchers, are uniquely positioned to help fill these needs since they are actively forging their research trajectories and networks, tend to mobilize change when actively involved in decision-making processes (Ho et al. 2015), and can infuse creative and inclusive ways of thinking into discussions (Bianco et al. 2016). Today's ECRs will be expected to deliver solutions to challenges resulting from climate change that no generation before them has faced. Yet, many feel excluded from the conversation (Bianco et al. 2016) and believe that current institutional structures do not provide or incentivize the development of the broad skill sets required to effectively contribute (Hein et al. 2018). Efforts that enable emerging leaders to build on conventional knowledge, both within and beyond their primary fields of study, will lead to integrated and impactful climate adaptation and mitigation solutions. Such efforts are therefore sound investments in the future.

This essay represents the unified voice of the inaugural members of the USDA Northeast Climate Hub's Graduate Climate Adaptation Partners (GradCAP) Program (https://www.climatehubs.usda.gov/hubs/northeast/topic/gradcap). The GradCAP Program, piloted in 2018, brought together graduate students from six USDA Northeast Climate Hub partner universities ranging geographically from West Virginia to Maine. GradCAP offered opportunities for training, experiential learning, and networking, in coordination with USDA climate adaptation initiatives. The experience included virtual and face-to-face workshops with diverse leaders in state and federal government, non-profit organizations, and academia. Additionally, GradCAP offered collaborative writing workshops that were used to formulate and synthesize ideas. Although the research foci of our GradCAP cohort are diverse—spanning agriculture, forestry, and aquaculture—we are united in the objective of identifying and promoting applied management strategies that facilitate a sustainable transition to new climate reality. Based on our experience, we believe broad-based training programs like GradCAP can serve as models of how to rally diverse ECRs around a common purpose and empower their growth into leaders well equipped with the skills needed to address climate change.

This essay describes three elements of professional training that are more important now than ever in equipping ECRs to make progress toward climate solutions: (1) convergence—facilitating involvement in integrated interdisciplinary research (i.e., "convergence research") to meaningfully address large-scale and complex problems; (2) continuity—support for participation in long-term research, including monitoring, in agriculture, forestry, and aquaculture that provide the data and tools needed to identify climate change-related trends and create data-driven management policies; and (3) community—enabling community engagement and stakeholder participation in research processes in order to identify and implement evidence-based solutions that are practical and relevant to practitioners (i.e., "co-production" or participatory research; Wall et al. 2017). This essay also includes a series of recommendations outlining ways in which universities and funding agencies can support ECRs in conducting meaningful work addressing climate change.

2 Convergence

2.1 Discipline-spanning research that enables transformative solutions

The study of climate change and its impacts is intrinsically discipline spanning (Hein et al. 2018; Deligios et al. 2019; Farmer et al. 2019) and requires integrated and team-oriented scientific approaches. A detailed understanding of the complex processes and coupled human-environment systems affected by climate change is needed to assist decision-makers who utilize research-based information to address pressing challenges related to water resources, food security, forest productivity, and biodiversity (Fig. 1). Collaboration and relationships among decision-makers and researchers across diverse fields of study are vital for the development of science-driven management and, ultimately, the successful adaptation to and mitigation of climate change.

The emerging paradigm of "convergence research" encourages a holistic approach to climate change mitigation and adaptation research (Fig. 1) and was recently identified by the National Science Foundation (NSF) as one of its 10 Big Ideas for Future NSF Investment (NSF 2019). Convergence research is related to multidisciplinary and transdisciplinary approaches; however, it is distinct in being driven by clearly defined and compelling problems. Convergence research intentionally establishes deep integration across disciplines from the early stages of problem identification and project design. Under this framework, many disciplines converge to engender progress toward a complex goal like enhanced climate resilience. The research aimed at climate resilience is inherently suited to this kind of

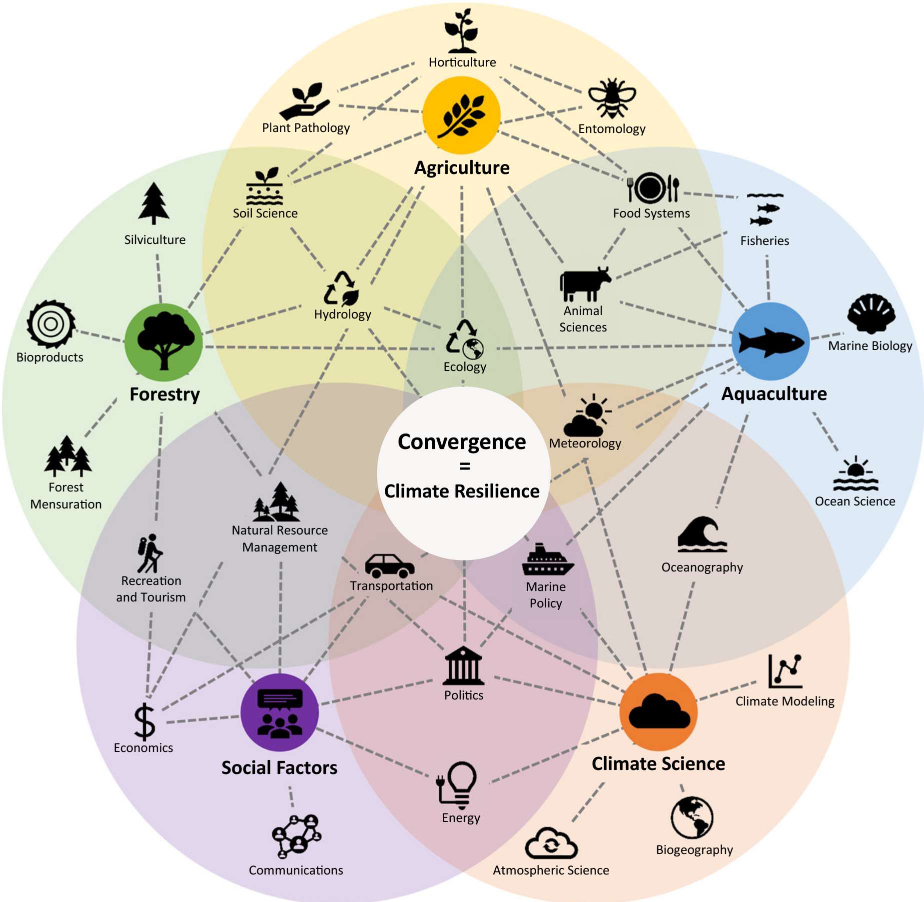

Fig. 1 Convergence research framework illustrating disciplines connected to climate resilience in agriculture, forestry, and aquaculture

integrative and participatory approach, as changes in the climate impact not only the natural world but many human dimensions. Furthermore, the challenge posed by climate change will require cooperative policymaking at the highest levels of government. Stakeholder involvement in the research process supports research outputs that fit decision-making contexts while enhancing trust in science and scientists via the process of knowledge co-production (Cash et al. 2003; Meadow et al. 2015; Dilling and Lemos 2011). Convergence thus influences the usability of research outcomes, and the capacity for research projects to concretely contribute to solutions, including through behavior changes. It is an emerging paradigm for forming sustained and productive relationships across interdisciplinary research communities.

2.2 Reflections

Many ECRs are still trained first and foremost as specialists. While this pedagogical tradition produces scientists with expert knowledge that can be helpful in working toward solutions, specialist training often fails to equip ECRs with the broader perspectives, diverse communication skills, and professional networks required for successful convergence research efforts (Holley 2017).

Through our participation in GradCAP and similar initiatives based at our home institutions, we have become involved in transdisciplinary projects and have chosen to grow our capacity for convergence research. However, branching out often represents an academic risk for ECRs. It can be simpler to succeed in academia as a specialist since each clearly defined discipline generally has a well-established roadmap for where to publish, which professional conferences to attend, and where to seek research funding. Departing from this roadmap and charting a new path can seem intimidating or detrimental to ECRs.

We believe, however, that participation in convergence research efforts will ultimately allow ECRs to be more impactful, enabling them to use their specialized skills and training in problem solving toward coordinated large-scale climate adaptation and mitigation efforts. Furthermore, many Ph.D. graduates do not stay in academia—all tenured or tenure track position account for less than one-quarter of Ph.D. holders under the age of 76 (NSF, 2017)—and participation in convergence research can in fact enhance the marketability of these scholars in non-faculty careers. As ECRs working in convergence research, we will be better equipped to study and develop solutions to complex socio-ecological problems that require working across disciplinary and academic boundaries.

2.3 Case study: transdisciplinary network collaborates to conserve water

Co-author Paul conducted her dissertation work as part of CONSERVE (COordinating Nontraditional Sustainable watER Use in Variable climatEs): A Center of Excellence at the Nexus of Sustainable Water Reuse, Food, & Health (http://conservewaterforfood.org/). This USDA-NIFA-funded project aimed to facilitate the adoption of transformative on-farm treatment solutions that enable the safe use of nontraditional irrigation water on food crops (Fig. 2). CONSERVE formed a transdisciplinary team of bioscientists, engineers, economists, social scientists, law and policy experts, extension specialists, educational media developers, and computer scientists to work together on research, extension, and education in the mid-Atlantic and southwest regions. They conducted outreach and engagement with a broad base of stakeholders including farmers, community members, educators, students, and federal, state, and local governments. As a CONSERVE scholar, Paul was provided with training, networking, and mentorship opportunities that fostered her ability to engage in convergence research.

3 Continuity

3.1 Importance of long-term data to scientific progress and climate resilience

The farms, forests, and aquaculture operations that produce our food and other natural resources are often subject to high interannual variability and exhibit varied responses to weather and climate (Vose et al. 2012; Barange et al. 2018; Wolfe et al. 2018). Thus, long-term research and monitoring in these systems are crucial to gain insights into how complex

Fig. 2 Case studies highlighting the impacts of projects that engage ECRs in convergence, long-term (continuity), and community-engaged research

functions and feedbacks are responding to climate change (Robertson et al. 2012; Thomas et al. 2019). Long-term datasets allow researchers to disentangle long-terms trends from short-term oscillations and natural variability (Franklin 1989). Unfortunately, many long-term research and monitoring programs are facing threats to, or reductions in, funding and personnel support. This, in turn, threatens long-standing collaborations and data-driven management practices as well as the opportunities that these continuous datasets provide for the advancement of environmental and natural resource management science. Continued support for long-term research and monitoring in agriculture, forestry, and aquaculture is not only necessary to understand how these systems are responding to climate change but also how they are responding to management actions (Franklin 1989).

Long-term data has demonstrable utility in enabling science-informed policy priorities, establishing baseline conditions essential in a time of rapid change, and informing future research priorities (Sutherland et al. 2004). Hughes et al. (2017) found that long-term ecological research was cited disproportionately more in policy documents as compared with more common studies of short duration (less than 4 years), stressing the value of historical knowledge to make well-informed decisions today about the distant future. Federal agencies, such as the USDA and NOAA, support many long-term datasets that provide invaluable information to policymakers and stakeholders (Online Resource 1). The comprehensive, system-level understanding gained from long-term research and adaptive monitoring can help inform natural resource managers and other stakeholders, enabling them to prepare for predicted changes in the climate over the next century (Lindenmayer and Likens 2009).

3.2 Reflections

Several of the authors of this essay have benefited from access to long-term data and, through this work, have come to recognize both the strengths and limitations (e.g., lack of precision and consistency) to the current networks and programs of long-term data collection and monitoring.

With access to high-quality long-term data and technical training in data science fields, graduate students can address large-scale natural resource problems and make robust conclusions despite the relatively short duration of graduate studies. At a management-relevant timescale, long-term data can act as a guide to develop more impactful and informative research questions and management strategies than would be possible with typical short-term (3–5 years) experiments. Despite the utility and availability of datasets from long-term studies and monitoring programs, some of which have been in operation for over a century (Kleinman et al. 2018), it is our impression that few ECRs utilize these data. Lack of knowledge and barriers to finding and gaining access may limit their use by ECRs who do not happen to be in a lab group focused on long-term projects.

In addition to data continuity through time, continuity over space through common measurements from a diversity of natural or managed systems can allow ECRs to better place their work into the broad context of climate change as it variably impacts local, regional, and global scales. Emerging "big data" frameworks and technologies may facilitate the integration of spatially explicit climatic and ecological information with long-term continuous agricultural, economic, and social data in order to capture patterns at local to global scales (Fig. 1). The Socio-Environmental Synthesis Center (SESYNC) and the National Ecological Observatory Network (NEON) are examples of some interdisciplinary synthesis networks that seek to train ECRs in synthesizing "big data" across space, time, and different disciplines; to make data publicly available; and to ultimately advance scientific discovery and climate solutions through these efforts (www.sesync.org; www.neonscience.org). Furthermore, the increasingly fine spatial and temporal resolution of data can enable detailed local and regional analyses to aid resilience efforts. Given this potential, a greater prioritization of long-term research and large-scale data collection (appropriately standardized to be directly comparable across regions) would likely increase opportunities for ECRs to contribute effectively to vital regional vulnerability assessments and resilience planning efforts.

3.3 Case study: long-term forest service data reveal the impacts of chronic acid rain

Co-author Eastman is conducting research in the Fernow Experimental Forest, West Virginia (https://www.nrs.fs.fed.us/ef/locations/wv/fernow/), to understand the impact of long-term nitrogen deposition from decades of acid rain on carbon storage in Central Appalachian forests (Fig. 2). Whole-watershed studies across the Eastern US, including the Fernow Experimental Forest, were instrumental in the implementation and success stories behind the Clean Air Act Amendments that reduced air and water pollutants across the Eastern US (Sullivan et al. 2018). Long-term tree growth, litterfall, and streamwater data from the site have allowed Eastman to determine the mechanisms behind the ecosystem-scale increase in carbon storage due to simulated acid rain (Eastman et al., unpublished data). There is a need for additional government funding to continue support for these long-term datasets, as continued ecosystem monitoring may help inform management strategies that keep soils productive while storing more carbon on forested lands.

4 Community

4.1 Prioritizing people: meaningfully engaging stakeholders and boundary organizations

Stakeholder engagement is widely acknowledged as crucial to the transfer of knowledge into action, creating climate science knowledge usable and salient for adaptation efforts (Meadow et al. 2015; Klenk et al. 2017; Prokopy et al. 2017). Participatory research is a framework in which local stakeholders are involved in the scientific process, from conceptualization to the dissemination and use of findings. This framework is mutually beneficial to stakeholder groups and the scientific community. Participatory research benefits stakeholders by allowing them to influence the direction of climate change research so that it becomes more aligned with their specific needs. In natural resource fields such as agriculture, forestry, and aquaculture, this often means conducting applied research that addresses a specific challenge that climate change poses to production. Furthermore, participatory research benefits scientists by providing access to local knowledge, bolstering convergence research efforts, and facilitating the transfer of research outputs to end users. Notably, research approaches that engage key stakeholders can effectively address barriers associated with the complexity and politicization of climate change science (Hoffman 2015). Likewise, effective participatory research can generate outcomes that are more trusted by the community and support evidence-based decision-making processes (Prokopy et al. 2017).

Despite broad advocacy for participatory research approaches, scientists who engage with community partners in climate change research face numerous challenges (Cvitanovic et al.

2019). Participatory research requires extensive time, coordination, and resources, as well as skills in communication, facilitation, and interfacing across disciplines (Kirchhoff et al. 2013; Méndez et al. 2017). However, these skills are not universally emphasized in graduate training programs (Dedeurwaerdere 2013). Building trust and stakeholder buy-in can be a lengthy process (Reed et al. 2014). Best practices for community-engaged research may include incorporation of multiple perspectives into stakeholder groups, carefully choosing stakeholders with a strong willingness to participate, and establishing formalized participatory mechanisms that enable researchers and stakeholders to coordinate their efforts (Cvitanovic et al. 2019). Academic mentors and institutions aiming to encourage ECRs in participatory research should be mindful of these best practices, which can ensure a higher likelihood of success.

4.2 Reflections

Our observations and experiences as ECRs support the need for community-engaged research. In our experience, stakeholder participation in the scientific process has enhanced the practical impact of our research. As frontline researchers that often communicate and work directly with community members, ECRs can play an important role in knowledge exchange between academics and community stakeholders. Therefore, the relationships ECRs build with community members can influence the success and impact of a project. As ECRs studying agriculture, forestry, and aquaculture, we often look to Cooperative Extension staff as exemplary facilitators of a community partnership between universities and practitioners. In recent interviews conducted by co-author White, Vermont Extension staff highlight the importance of building trust with community partners, having good communication skills, and following through on commitments to successfully co-produce knowledge that has value to both the community and researchers (White, unpublished data).

The community partners we engage with include citizens, businesses, non-governmental organizations, and government entities. If research processes and outputs are not accessible and targeted to the needs of these end users, even research being conducted to specifically address a problem of interest can fail to translate into meaningful action (Wyborn and Leith 2018). In order for participatory research to succeed, stakeholders and researchers alike must have the time, funding, and capacity to participate. Understanding the obstacles to stakeholder participation in research is therefore vital to successful community engagement. For example, one Vermont farmer highlighted the role personal financial capacity plays in research participation during a recent focus group, stating, "I have to hire help to leave the farm and come to this meeting" (White, unpublished data). Resource brokers—organizations and individuals that provide research funding and capacity-building—can be crucial for facilitating community-engaged research by funding projects that divide resources equitably between researchers and the community partners with which they collaborate.

4.3 Case study: SEANET connects researchers and stakeholders

The Sustainable Ecological Aquaculture Network (SEANET; https://umaine.edu/aquaculture/seanet/) was developed to help grow the state of Maine's coastal economy through a community-focused interdisciplinary marine aquaculture research and development effort (Fig. 2). Co-author Zhu is part of this network, which draws together researchers from 11 institutions in Maine, with expertise ranging from engineering to the biophysical and social sciences. A framework based on Elinor Ostrom's social-ecological system framework (SESF, Ostrom 2009) was used to guide SEANET's interdisciplinary research process (Johnson et al. 2019). Notably, SEANET explicitly set stakeholder engagement as a goal, creating a Stakeholder Advisory Board to facilitate knowledge exchange. Stakeholders have been included as key partners in research projects including citizen science initiatives (Fig. 2; Spicer et al. 2019) and studies to explore the resilience of Maine's coastal communities (Bricknell et al. 2020). Through participation in SEANET, Zhu has gained a deep knowledge and appreciation for the value of community-focused research.

5 Recommendations

As members of the USDA Northeast Climate Hub's GradCAP Program, we represent an interdisciplinary group of ECRs with a shared goal of contributing to climate solutions in agriculture, forestry, and aquaculture. In our view, cooperation across disciplines and institutions, coordination over time and space, and meaningful communication with boundary organizations and end users are crucial for achieving this goal (Fig. 3). We propose three

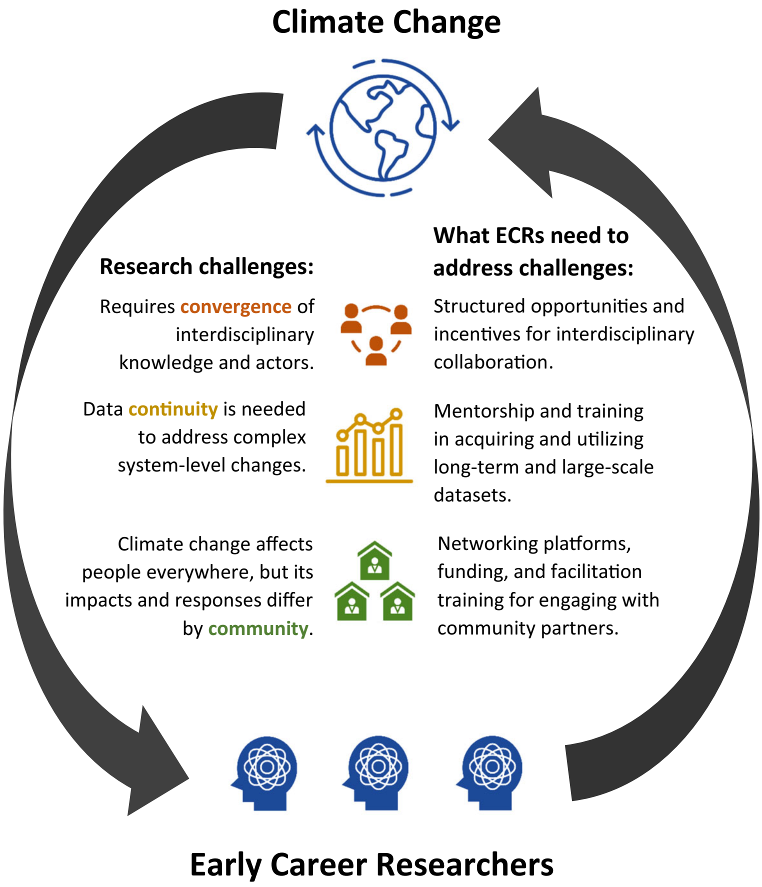

Fig. 3 Research challenges and factors that can enable success among early career researchers (ECRs) seeking to address climate change in agriculture, forestry, and aquaculture

recommended pathways through which institutions can help ECRs like us develop the skills and professional networks needed to meaningfully engage in high-impact research: (1) formal training, (2) scholarly incentives, and (3) mentorship.

5.1 Formal training

Investment in formal training for ECRs has the potential to break down barriers associated with convergence, long-term, and community-driven research. Training in the use, management, and applicability of long-term datasets can enable ECRs to ask questions proportional to the scale of the challenges we face in a changing climate. Additionally, training in social science research methods, communication and facilitation, and effective management of collaborative projects are necessary to address current and future challenges to sustainable agriculture, forestry, and aquaculture. Furthermore, these skills may help ECRs better understand the management implications of climate adaptation and mitigation strategies, as well as the challenges and processes required for implementation.

Several examples of classes, workshops, and social learning opportunities (such as GradCAP) that train young professionals in skills related to convergence, continuity, and community already exist and can serve as templates for other institutions. For example, the National Ecological Observatory Network (NEON, www.neonscience.org) is a recently established source for standardized ecological data across many sites in the USA. NEON not only allows for consistent and standardized monitoring data acquisition but it also offers tutorials, workshops, and other training opportunities to make it easy for researchers to use its vast datasets. Other institutions (such as USDA) that acquire long-term data can similarly provide workshops and training to expand the use and impact of these invaluable data. Another example, the NSF Research Traineeship (NRT) program, emphasizes convergence research and supports bold, new, and transformative models of graduate education training. The NRT program incorporates formal coursework in communication, opportunities to engage with faculty across disciplines, and classes that engage groups of students in collaborative projects. We believe that expanding these types of training programs across other institutions and increasing their accessibility to a broader range of ECRs is a prudent investment for adapting natural resource management strategies to the climate crisis.

5.2 Scholarly incentives

Codifying broad training and community engagement in academic curricula at both undergraduate and graduate levels will help prepare future leaders to adopt solution-based approaches and increase their capacity to meaningfully address climate change. Universities are often the institutions that are most capable of supporting innovative and creative research. By rewarding and valuing research outputs beyond “timely” traditional peer-reviewed journal articles and lucrative grant awards, universities can help ensure that ECRs will not shy away from tackling the most important and intractable problems facing society. Especially, greater emphasis should be placed on community engagement and effective transfer of knowledge to stakeholders who may be affected by research outcomes or may use the information or products to implement actionable changes.

The establishment of formal boundary-spanning organizations within universities, for example, “super-departments” such as the Rutgers Climate Institute (RCI) and the University of Maine’s Climate Change Institute (CCI), can aid in the growth of convergence research approaches (Fig. 1). RCI connects graduate students with numerous external internships and scholarship opportunities (https://climatechange.rutgers.edu/). RCI also offers several student support funds, fellowships, and scholars programs to facilitate research in this field and to effectively communicate this information to stakeholders. Similarly, CCI at the University of Maine provides research assistantships, as well as an exploration award and a service award to support and recognize excellence in the field of climate science. By facilitating collaborations across disciplines and supporting the development of relationships between ECRs and wider communities, these professional development programs contribute to both the success of ECRs—preparing them to pursue impactful work both in and outside academia—and the resilience of communities facing challenges associated with climate change.

5.3 Mentorship

Investment in strong mentorship, through advisor training and opportunities for off-campus or transdisciplinary mentorship programs, can increase the capacity of ECRs to engage in interdisciplinary and participatory research approaches. Mentors provide necessary resources, informal training, experience-based advice, and moral support (Van Bavel et al. 2019). Connecting with mentors at various career stages, from near peers to senior scientists, can provide ECRs with a wide breadth of perspectives on potential career trajectories. Linking ECRs with mentors who are outreach professionals and resource brokers can provide training to young professionals in strategies and pitfalls of community-engaged research and facilitate introductions and information-sharing with stakeholders and other key end users.

One example of an institution emphasizing the importance of mentorship is in the Department of Agriculture and Natural Resources at Rutgers University. This department provides new faculty members with a mentoring committee to support their efforts to effectively communicate science-based information to various stakeholder groups including farmers, policymakers, industry groups, NGOs, researchers, students, and the general public. The personal relationships new faculty form with stakeholders, which are essential for meaningful dialogue, are greatly strengthened by the experience of the mentoring faculty members as well as their long-standing relationships within these various communities.

Mentors who are invested in the professional growth of their mentees and their communities are essential for retaining talent and investing in the future. In our experience, the best mentors are often those who are cognizant of the challenges inherent to interdisciplinary, long-term, and participatory research and willing to provide their mentees with individualized support in pursuing these high-impact areas of research.

6 Conclusions

Ensuring sustainable production of food and other natural resources in a rapidly changing climate is among the most pressing challenges facing humanity. We and emerging leaders like us have the capacity and enthusiasm to address difficult challenges posed by climate change. However, more must be done to prepare and equip ECRs like us for this work. We believe that ECRs must become better acquainted with the transformative process of convergence research, have opportunities to engage with long-term monitoring projects and the invaluable datasets they provide, and be encouraged to translate knowledge into action by engaging with stakeholder communities at all stages of the research process. We recommend that institutions, such as universities and funding agencies, invest in ECRs by funding formal educational programming and networking opportunities, altering academic incentive systems, and prioritizing mentorship that will help equip us for the challenges ahead.

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