Transforming Ecological Science at Primarily Undergraduate Institutions through Collaborative Networks

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Ecologists at primarily undergraduate institutions (PUIs) are well positioned to form collaborative networks and make transformative contributions to the study and teaching of ecology. The spatial and temporal complexity of ecological phenomena rewards a collaborative research approach. A network of PUI ecologists can incorporate closely supervised data collection into undergraduate courses, thereby generating data across spatial gradients to answer crucial questions. These data can offer unprecedented insight into fine- and large-scale spatial processes for publications, resource management, and policy decisions. Undergraduate students benefit from the collaborative research experience as they gain experiential learning in team building, project design, implementation, data collection, and analysis. With appropriate funding, collaborative networks make excellent use of the intellectual and experiential capital of PUI faculty for the benefit of science, pedagogy, and society.

Keywords: primarily undergraduate institutions, collaborative research networks, spatiotemporal dynamics, transformative research, research efficiency

The research capacity of ecologists at primarily undergraduate institutions (PUIs) is vast but currently underutilized. Many PUI ecologists conduct their research locally, at small scales, and in isolation from other ecologists. Yet ecological science has entered an era in which collaborative research is essential for tackling important, emerging ecological questions (Carpenter 2008, Peters et al. 2008), requiring coordinated data across spatial scales and gradients (Craine et al. 2007). By building collaborative networks of PUI ecologists, the power of their intimate, local approaches can be significantly increased. The involvement of undergraduates in this research will promote scientific literacy and introduce future scientists and other professionals to the complexity and excitement of large-scale ecology.

The contributions of PUI scientists to ecological research are often overlooked as a result of the perceived dichotomy between research and teaching. Nonetheless, many PUI ecologists are active scientists who integrate research and teaching to make useful scientific contributions (Karukstis and Hensel 2010). PUI ecologists are typically more limited in the time and resources available for research compared with scientists at research universities, such that PUI research projects are frequently conducted locally, in conjunction with undergraduates, and at smaller scales. Yet ecologists at PUIs can be surprisingly productive, despite the absence of a postbaccalaureate workforce. For example, approximately 110 papers have been contributed to peer-reviewed journals in 118 cumulative years of employment by 10 of the authors of this article (admittedly not a random poll) during their employment at PUIs. This is an average of 0.9 papers per year, despite typical teaching loads of two to four courses per semester and without graduate teaching assistants, graders, laboratory technicians, graduate students, or postdoctoral fellows. Additionally, many PUI faculty, experiencing less institutional pressure to produce peer-reviewed publications, instead publish textbooks, management plans, reports, and nonrefereed articles, all of which contribute to science by directly informing decisionmakers, resource managers, and the general public. These alternative research outcomes stimulate conversation and dialogue among scientists and a more diverse group of stakeholders, and thereby help to improve national scientific literacy and popular support for the funding of scientific research.

We argue that the high-quality research and teaching currently conducted at independent undergraduate institutions can have deeper and broader impacts if collaborative research networks are established among institutions. By actively participating in a research network, faculty members can gain insight and share expertise, learn new pedagogical approaches to improve education, make more meaningful

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contributions to the scientific literature, and nurture the excitement about science that originally attracted them to this profession.

The PUI faculty position

Most of the hundreds of public and private PUIs in North America employ between one and a few PhD ecologists, many of whom are actively engaged in research at some level. As at research universities, many PUI ecologists conduct research because of intrinsic interest and a desire to remain current in their field (the authors of this article are all examples of such PUI faculty), and the tenure review process may drive research for some others. Publication requirements for tenure generally are not as stringent for PUI faculty as for faculty at research universities, partly because teaching loads are higher (varying between four and eight courses per year for the authors of this article) and also because there is a high expectation of availability to undergraduates. Nonetheless, in many PUIs, the basic tenure process is quite similar to that at research universities, and includes publication and grant requirements, anonymous outside reviewers, and research seminars. The major differences at PUIs are reduced expectations for publications and grants and higher expectations and scrutiny of teaching and pedagogy practices. Because PUI faculty are judged on both teaching and research, they may attempt to maximize quality in both of these arenas, but maximizing two variables simultaneously is not possible, and teaching is often the responsibility that cannot be delayed.

In the authors' experience, PUI professors exhibit a range of responses to the difficulty of producing excellence in both the teaching and research arenas. Some address this dichotomy by blurring the lines between the two and designing class and student research projects that contribute to scholarly data collection (e.g., Goodner et al. 2001). This tendency, combined with the common lack of graduate teaching assistants, leads PUI faculty to work very closely with undergraduates, who often occupy roles at PUIs usually reserved for graduate students at research institutions (Cech 1999). This close relationship between faculty and undergraduates often leads to coauthored, peer-reviewed publications (Withers and Detweiler-Bedell 2010). Other PUI professors measure their success in terms of service to their institutions and local communities (Mills 2000) rather than in the number of peer-reviewed publications.

Ecologists in this second group may continue to supervise undergraduate research, but their projects are often too small and disjunct to add up to significant publications. Ecologists who collect data with students at any institution may acquire rich data sets outside their area of expertise. At universities, faculty can often collaborate with a colleague or recruit a postdoc or graduate student to analyze these data and assess their importance to the field, but a single PUI ecologist may not have access to local expertise. Rigorous and appropriate data analysis and presentation in ways that are compelling and relevant to current questions in ecology can be challenging for any scientist, especially for those who have been working in isolation over long periods of time (e.g., Carlson and Pfister 1999). Among the unanalyzed data sets inherited from predecessors of the authors of this article are more than 30 years of phenological data, more than 10 years of water-quality and tree-size data, and more than 20 years of acid rain data.

The value of collaboration

Networks of PUI ecologists can use local data sets to make meaningful, career-long contributions to science while providing excellent educational research opportunities for undergraduates. The small, local, and inclusive science that is the hallmark of PUIs can be replicated across space and time to increase the power and breadth of experiments, capturing important ecological or anthropogenic gradients that are fundamental to the understanding of complex systems. The absence of the postgraduate layer between faculty and undergraduate students at PUIs becomes an advantage, presenting opportunities for closely supervised undergraduates to make authentic contributions to ecology. At PUIs, faculty members directly train students in research techniques and accompany them in the lab and field. This supervision allows for tight quality control. Thus, it is possible to design research projects to which undergraduates, even in the teaching lab, can make significant contributions.

Although collaborative research will not change institutional responsibilities, networks would help PUI faculty overcome research hurdles. Fewer data sets will be orphaned if networks of PUI scientists across academic ranks collect coordinated local data and members assist each other in data analysis. Replication would immediately add to the value of such data sets, allowing new projects to accumulate unique, publishable data more quickly. By using identical protocols at each network member's location, faculty would have the opportunity to be a part of something bigger, designing studies, collecting data, and interacting with their peers across the country or region. In doing so, they could also develop and share interactive teaching modules. The measurable scholarly outcome of these networked projects would be peer-reviewed publications or insights into management of local resources. A PUI network would not only increase the number of sampled sites but also expand the diversity of ecosystems in which data are collected. At a research university, members of a single lab might travel to sample across a spatial gradient. The PUI collaborative approach offers greater efficiency; many teams follow a common protocol on their local sites, thereby measuring the spatial gradient with reduced travel expense and temporal variability and increased familiarity with each sampling location. Because of their smaller footprint, PUIs are located in a greater variety of settings than are research universities. Field sites tend to be close to the institution and reflect this broader gradient in land uses and human population density. PUI networks may also consist of sites typical of those managed by local conservancy groups—namely, relatively small habitat patches nestled within a highly fragmented landscape. This characteristic increases the possibility of discovering useful management principles.

PUI scientists conducting long-term research at local sites are intimately familiar with their study sites and are in a position to notice important anomalies and contribute to public discourse. Working alone at a single site, one might not detect the broader ecological significance of a biological change, but there is a greater ability to identify widespread trends when the same observations are made across a wider area. By networking, PUI faculty can determine, for example, whether a specific invasive species is spreading or whether it is of only local importance. PUI networks can incorporate undergraduates who will help generate and use data sets in both research and classroom venues. The data that flow out of the networks can help managers assess the status of their properties and identify best management principles. Such management outcomes are a desired goal of ecological science beyond peer-reviewed publications.

PUI networks can also help overcome some of the challenges of intellectual isolation that an ecologist—who is often the only ecologist at his or her institution—might face (Mills 2000). Virtual lab meetings within networks could allow ecologists at PUIs to keep up with recent advances in ecological science, broaden their knowledge base, and share scholarly and pedagogical insights. Networking can also accelerate the pace of PUI research by generating collaborator excitement and accountability. These interactions will undoubtedly seed new questions, projects, and networks. The collaborative networks can also foster interrank comentoring, in which junior faculty receive traditional mentoring and senior faculty learn to use new and innovative technologies. This type of mentoring is badly needed at PUIs, where isolation can sometimes result in stagnation of skills and perspectives.

Undergraduate education is of central importance to a PUI, and all of the research benefits outlined in this article will mean little if PUI students do not profit from the networks. Fortunately, the potential benefits to undergraduates are extensive, for science students conducting independent research and for general education students participating in laboratory courses. Networking allows PUI faculty to model the collaborative process for students, who then get the best of both worlds: immersion in the milieu of collaborative big science combined with the direct faculty mentorship that is the hallmark of small colleges. Students should be more motivated to understand and carefully collect data if they know their contribution is meaningful to a larger endeavor (Olson 2000). Students would have a greater understanding of the process of science, including better preparation in study design and data analysis (Bauer and Bennett 2003, Hunter et al. 2006, Lopatto 2007). The largest impediments to rigorously demonstrating proper scientific design in a course are small sample size, little replication, and lack of independence. By sharing data among many institutions, PUI networks can counter these limitations. Students who acquire deep knowledge, demonstrate the ability to apply that knowledge, and learn to critically evaluate data in reaching evidence-based conclusions are in high demand by potential employers (Hart Research Associates 2010). By actively participating in collaborative, authentic research, students can develop these desirable outcomes regardless of their future professions.

PUI research networks: Models and templates

We envision at least two types of research networks that would allow scientists at small institutions to magnify their scientific contributions while providing unique opportunities to their students.

First, scientifically ambitious PUI researchers can develop research modules and build networks of like-minded scientists who would use their numbers, diversity, and training to ask big questions that individual scientists have not been able to ask. Their geographical spread will allow them to answer questions at regional to continental scales and across gradients. Relatively simple experiments, replicated in a network crossing any kind of gradient (latitudinal, nitrogen deposition, temperature, precipitation, urbanization, etc.), could be used to explore issues of connectivity and disjunction and to document the effects of human actions across scales. Indeed, this is the kind of approach being taken by such projects as the National Ecological Observatory Network (Keller et al. 2008) and EcoTrends (Servilla et al. 2008). PUI networks could even be organized to fill in some of the gaps in these very ambitious projects. These PUI networks would be conceived and organized by the participants, who would procure funding and publish their results as a team. Networks could be structured to allow varying levels of involvement by member scientists, from the introduction of a single lab module into a class to a commitment to spend several sampling days each year to conducting a full replicate of the experiment that comprises the majority of the scientist's research efforts. This type of network could overcome many of the challenges and criticisms of research programs at PUIs (Jones 2010) by producing meaningful research while simultaneously training a new generation of undergraduates in collaborative research with limited time, money, and institutional resources.

A good model for this first type of network can be found in the watershed study group called Collaboration through Appalachian Watershed Studies (CAWS). At a 1999 meeting with the University of Maryland's Appalachian Labs, in Frostburg, Maryland, several PUI faculty (KK, BRP, CLT) met and realized that they had a common agenda and a somewhat different set of goals from the research lab scientists. These goals were related to research in ecology, but also involved undergraduate student research and teaching opportunities. Ultimately funded by the Andrew W. Mellon Foundation, the Appalachian College Association, and the National Science Foundation (NSF), the activities of the CAWS group included workshops and collaborative meetings twice a year, the publication of an online watershed methods manual for research and teaching (Kuers and Simmons 2005), and a common research project each year, such as studying stream macroinvertebrate populations or acid deposition. These projects expanded and contracted with the availability of people and funds, but involved students and faculty from 3 to 10 undergraduate colleges in the Appalachian Mountains.

A second, alternative networking model would use PUI networks to address conservation or management goals in close collaboration with state and federal agencies and nongovernmental organizations. These projects would not always produce publications for the individual PUI researchers but would tap their training and experience; would provide opportunities for their students to participate in large-scale, applied research; and would produce relevant data sets for resource management and pedagogy. Examples of this type of research include monitoring the effects of a management action on a species of concern or performing standard bioassays on pesticides or other chemicals under investigation. The funding and structure would be determined by the organizing agency, and funding could often be incorporated into course budgets. Research protocols could be developed in conjunction with the PUI faculty scientists, and the scientists and their students would provide well-supervised, skilled labor. Data synthesis and publication would be handled by the agency in conjunction with individual PUI researchers. In this case, PUI ecologists would be "hired guns" providing labor and expertise. In return, they would gain meaningful exercises for their classes and independent research students. This network would also be an excellent way for small college ecologists who do not have the inclination or time to publish to continue to contribute to the scientific process.

A candidate for a conservation management–oriented PUI network can be found in the May 2009 meeting of the *Neotoma magister* Strategic Conservation Team. This group is composed of researchers and state wildlife officials who are developing a management plan for *N. magister*, the Allegheny woodrat. The range of this species has been declining for more than 40 years, and the goal of the group is to prevent listing of the species under the US Endangered Species Act. Because the exact causes of the decline are not clear, it is impossible to identify the most effective management strategies without additional research. Most relevant state wildlife agencies have the resources to perform the management actions suggested at the meeting (which include, e.g., supplemental feeding, habitat enhancement, and parasite reductions); however, they do not have the resources to monitor the impacts of these actions on woodrat populations. A network of small-college ecologists, working in concert with wildlife managers, could contribute enormously to the management of this species. Time commitments could range from modest (e.g., taking a single class for a field trip to search for woodrat sign) to extensive (e.g., spending summers with students trapping woodrats and documenting the outcomes of management efforts). Students would gain experience in the field, learning to use GPS (global positioning system) equipment, characterize habitat, and collect data. Moreover, they would contribute to a real conservation effort and would be linked to students in other PUIs doing similar work. Access to the entire woodrat database would allow them to see how their efforts fit into the larger picture and help them analyze the effectiveness of the management efforts.

Examples of PUI collaborative research and opportunities

The following four examples illustrate how ecological research typical of PUIs can benefit from research collaborations and networks, allowing PUI scientists to ask bigger questions, provide additional insight, train more undergraduates, and increase societal impacts.

An intramural network: Endangered freshwater mussels. The research program of DJH at Macalester College has an academic and conservation focus and models a large research university lab. The lab group, consisting of a single faculty member and a number of undergraduate students, investigates the biology and conservation status of endangered freshwater mussels with both management and academic publication as ultimate goals. Undergraduates have coauthored more than a dozen peer-reviewed papers in the past two decades on the physiological, population, community, ecosystem, and conservation status of these organisms. Two junior colleagues have built on the long-term data set with examinations of the population genetics and biogeography of the mussels and the hydrodynamics of the river. Again, the impact of this research could be increased by the inclusion of other PUIs near appropriate waterways. A broader geographic reach would allow scientists to determine the generality of the patterns observed and allow publication in journals that would reach a larger audience.

Opportunity lost: Bat population monitoring. A lab at Union College in New York offers an example of the potential value of data collected annually as part of a course. As an exercise in the laboratory portion of an ecology class, one of the authors (KL) brought students each year into a local cave to look for relationships between abiotic conditions and the hibernation locations of bats. This lab activity was funded internally by the course budget, but produced data that ultimately proved to be unexpectedly valuable. Designed as a fun way to collect data for use in statistics exercises, the exercise produced annual data on bat abundance and hibernation location. When students analyzed their data in the winter of 2006–2007, they found an alarming departure from the past pattern. Bat numbers had plunged, and those bats that remained in the cave were found much closer to its mouth. These quantitative observations were some of the first to show an unprecedented die-off of bats in caves of the Northeast. The data were useful to the New York State Department of Environmental Conservation's early efforts to document white-nose syndrome (WNS), which is caused by a fungal pathogen and was apparently responsible for the die-off (Veilleux 2008). Since the winter of 2006–2007, bat populations have declined more than 75%, and WNS has spread as far as Tennessee (Blehert et al. 2009, USFWS 2010). Unfortunately, cave closures to prevent the spread of WNS now make that lab exercise impossible. If a network had existed of small college ecology classes conducting the same exercise in caves near their campuses, it could have produced publishable information about bat hibernation and also might have sounded the alarm sooner, helped to elucidate the transmission pattern of the syndrome, and possibly could have aided in averting the disastrous consequences of this disease.

PUI and stakeholder collaboration: The Smith Mountain Lake water quality program. The Smith Mountain Lake long-term water-quality monitoring project is a prime example of PUI scientists' ability to conduct long-term research, engage the public, and play an important role in the management of natural resources. For the past 23 years, this collaboration among faculty at Ferrum College in Virginia (including CLT and BRP), the Smith Mountain Lake Association (a nonprofit lake resident group), and the Virginia Department of Environmental Quality (VA-DEQ) has worked to evaluate the nutrient dynamics; depth profiles; and bacterial, algal, and invasive weed populations in Smith Mountain Lake, Virginia. Students, local residents, and faculty scientists have been collecting and analyzing samples, writing reports, and changing land-use decisions each year since 1987. Ferrum College students gain experience by doing tier III level–certified (the highest quality recognized by VA-DEQ for nonagency data) laboratory analyses and field collection of samples. Faculty scientists train students and other citizen scientists to interpret the results and make recommendations to protect the water quality at Smith Mountain Lake (Thomas and Johnson 2008, Thomas et al. 2008). The primary goal of this project is one of resource management rather than publication in academic journals, and it demonstrates how PUI scientists can remain engaged and productive without having peer-reviewed publications as an outcome or even a goal. Expanding this project through a network that includes other lakes and other PUIs could not only improve the management of other freshwater systems but could also create an adaptive management framework to test new techniques and provide valuable information on our freshwater resources.

A new model: The Ecological Research as Education Network. A new prototype for PUI networks is the Ecological Research as Education Network (EREN), recently funded by an NSF Research Collaborative Network (RCN) grant. EREN (*http://erenweb.org*) focuses on developing collaborative research projects among PUIs at regional to continental scales. The authors of this article are members of this new network; our goal is to design projects to maximize student engagement in authentic science while generating transformative data. The initial focus of EREN is to collect data with well-supervised students in laboratory exercises coordinated across institutions, with future opportunities for student and faculty summer research to further develop research projects. We began with a small collaborative grant from the NSF for a single workshop. At that workshop we outlined three potential pilot collaborative research projects, two position papers (Anderson et al. 2009 and this article), and the central ideas for the NSF RCN proposal. Potentially more important, we initiated invigorating new relationships with other PUI ecologists at various career stages, from new hires to those with more than three decades of experience.

Funding, building, and maintaining a PUI network

There is no single framework or road map for a successful collaborative network, but networks that do not combine at least a few critical elements tend to be more ephemeral. Essential elements include frequent communication, shared research focus or enthusiasm, transparent structure for rewards and data access, strong leadership and organization, and funding. The aforementioned examples cover a broad range of collaborations, both actualized and potential. The Macalester collaboration around endangered mussels has been very successful, as it contains all of these elements. Funding has come from a variety of sources, including national and local governmental agencies (NSF, Army Corps of Engineers, National Park Service, Wisconsin and Minnesota state governments), private foundations (The Blandin Foundation, Mellon Foundation, Pew Charitable Trust), and internal college funds. Although not a "network" by our strict definition (because all scientists are at the same institution), their reward structure, communication, funding success, and shared research focus highlight the elements necessary for a network of colleagues at other PUIs around the country.

The success of the Smith Mountain Lake project also demonstrates the importance of the elements listed above. Like the Macalester research, all the Smith Mountain Lake faculty participants were at one college, making frequent communication among academic collaborators uncomplicated. Funding came from local agencies and nonprofit groups interested in the results. The founders' collaborative experience at Smith Mountain Lake informed their successful attempt to create CAWS, which they assembled around a group of PUI faculty with shared interests. Crucial to their success was a schedule of regular face-to-face meetings to maintain communication and foster camaraderie. These meetings and the research were made possible by funding from the Mellon Foundation (the former Conservation and the Environment division) and the NSF (Curriculum Course and Lab Improvement, which has been supplanted by the Transforming Undergraduate Education in Science [TUES] program). Another key to their success was the designation of a pair of strong, flexible leaders (CLT and BRP), who were responsive to the collaborative desires of the entire group, but who also made crucial decisions and shouldered the administrative burden.

The EREN project builds on the successes of these networks to bring undergraduate-focused research to an even larger scale. The founders came together because of a shared enthusiasm for continental-scale ecological research rather than a single driving ecological question, and they have stayed together because meetings made possible by grant funding have produced stimulating scientific interactions. A central key to success has been a very strong leadership team. One member (LA) has been the driving force behind EREN: She set up the initial interactions that generated the collaborative research ideas, took on the administrative tasks and spearheaded the proposals for funding. She and seven other members wrote and received the NSF RCN grant one year after the first workshop. This grant has funded further meetings, the creation of a database and Web site, and one pilot research project. A different member or small team of members are responsible for each activity. EREN members recently outlined a clear authorship and participation policy and a strategy for tiered involvement that allows members to focus on particular ecological questions, with a clear sense of responsibilities and payoffs (more details can be found at *http://erenweb.org*). They can propose projects for which they will develop the research protocols and pedagogical materials and serve as lead scientists and authors. We anticipate that the EREN Web site will ultimately serve as a clearinghouse to help PUI scientists find collaborators with similar research interests. The group plans to pursue funding for specific projects through such sources as NSF TUES, the NSF Research at Undergraduate Institutions program, and other appropriate public or private organizations. With the network structure already in place, these more modest grants will provide appropriate summer salaries, student stipends, and equipment and materials not covered by course budgets.

Making research more efficient is especially important in the current economic environment. The state of the economy and the national deficit suggest that levels of research funding will decrease in the near future from record highs at the beginning of the new century (Jones 2010). Therefore, the academic scientific community needs to explore new venues to achieve transformative research results. Collaborative PUI networks promise to provide multiple advantages, including benefits to PUI faculty from increased collaboration, cross-rank mentoring, time-saving and pedagogically sound laboratory modules, and the ability to participate in large-scale ecological research. Benefits to students include the opportunity to participate in real science using well-tested, inquiry-based labs that provide the ability to interact and share insights with collaborating students at other institutions. Data sets will be geographically broad and may lead to landscape- and regional-level insights not available from current data sets or data collection methods, promoting the potential for transformative insights. This approach also promises to be economically efficient. By incorporating the protocols into lab sections, we should be able to assemble these data sets relatively cheaply using course budgets for data collection and some equipment. Other grant or foundation funding can then be reserved for administrative costs, meetings, student stipends for summer research, and faculty summer salaries for set up, analysis, and writing. Finally, networking allows scientifically ambitious PUI faculty an opportunity to collaboratively ask some of the big questions in ecology and gives the opportunity to make contributions beyond the relatively small sphere of their own local research. This system, with closely supervised undergraduates following a carefully developed protocol to collect data, offers the advantages of citizen science with pedagogical benefits from the student involvement in analysis, the opportunity to contribute to management, and additional benefits for faculty.

These networks are potentially more efficient than the single investigator approach, but will still require funding to be developed and maintained. The costs are real and are sufficiently diverse to make funding difficult. To make this idea sustainable will require innovative grant writing, since currently no one source exists to fund this type of multilayered project. The NSF RCN program funds the construction of the network, including collaborative workshops and faculty professional development, but does not fund the research itself. The NSF Research at Undergraduate Institutions program offers research funds, but these grants are typically for a single or small number of institutions, not a large collaboration (although this may change in the future). EREN has secured funding to develop a prototype network and a small-scale pilot project, but not to conduct the ambitious, long-term research that will make this approach transformative. Nevertheless, we believe that this concept is highly fundable. In addition to the federal agencies that typically fund ecological research (the NSF, US Fish and Wildlife Service, National Park Service, and US Environmental Protection Agency), PUI faculty in the aforementioned examples have received support from state and local government agencies; private foundations, both large and small; local and regional corporations, such as power companies; and their own colleges. Many of these funding sources would be especially supportive of the "two-for-one" advantage of simultaneously stimulating excellent teaching and excellent research.

Ideally, ecologists in the United States will someday see the development of a new funding source that offers smaller allotments of funding to conduct research within these preformed, efficient networks. This approach would offer data storage and sharing efficiencies but would be flexible enough to change data collection protocols to meet new research agendas and answer cutting-edge questions. We suggest funding for equipment, supplies, virtual lab meetings, occasional travel for faculty and student researchers to interact and present their results, administrative and technical support, and limited summer salaries. Summer research students will need stipends, but much of the material costs and labor can be covered by institutional course budgets in cases in which data are collected by students in a course. We assert that PUI networks can increase efficiency in our system and simultaneously benefit PUI faculty and students.

Conclusion

The time is right to advance ecological science, enhance undergraduate science education, and unlock the talents of PUI ecologists through the creation of hybrid research-teaching networks. By fostering collaborative networks, individual faculty could become more productive scientists and more effective teachers. Undergraduate students could engage in authentic, meaningful research as they learn ecological concepts and the value of collaboration. Granting agencies stand to yield a greater return on their investments as collaborative ecological research at PUIs may yield more high-quality publications and resource management insights. Societal benefits include a better-educated and more collaborative workforce, answers to crucial environmental questions, and efficient use of public funds. Collaborative ecological networks have enormous potential to (a) provide students a better understanding of the collaborative scientific process, (b) give faculty enriching and productive scientific interactions, and (c) bestow society with real progress on important ecological questions and problems.

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