# Collaboration, interdisciplinary thinking, and communication: new approaches to K–12 ecology education

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**Ecologists often engage in global-scale research through partnerships among scientists from many disciplines. Such research projects require collaboration, interdisciplinary thinking, and strong communication skills. We advocate including these three practices as an integral part of ecology education at the kindergarten through 12th grade (K–12) level, as opposed to waiting until the graduate level. Current discourse about K–12 ecology education focuses on promoting lessons in which students learn science by conducting research rather than simply reading textbooks. Here, we present five models of K–12 ecology education programs that emphasize collaboration, interdisciplinary thinking, and communication within student research projects on the ecology of drylands and other ecosystems. Such practices not only provide additional skills for future ecologists but also prepare students for success in any career as well as for ecologically literate citizenship.**

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Over the past 20 years, ecologists have challenged themselves to expand the way they think about, conduct research in, and communicate their science. They increasingly participate in interdisciplinary research on social–ecological systems (eg Collins *et al.* 2011) as they recognize that ecological systems are inextricably linked to human activities. Ecologists also engage now more than ever in large-scale studies and examine cross-scale interactions due to the global scale of many ecological issues (Peters *et al.* 2008; Soranno and Schimel 2014). Such interdisciplinary and large-scale research requires collaborative, interdisciplinary research teams (Peters *et al.* 2014). Additionally, many ecologists continue to respond to calls for active communication about their research with the general public (eg Brewer 2001; Pace *et al.* 2010; Cardelús and Middendorf 2013), with policy makers (eg Norton 1998; but see Laurenroth 2003), and with the K–12 school community (eg Metzgar *et al.* 1994).

### In a nutshell:

- Modern ecologists require a suite of practices – extensive collaboration, interdisciplinary thinking, and the ability to communicate with non-scientists about complex ecological issues – in addition to research expertise
- The foundation for these practices should be included in K–12 ecology education
- Five example programs demonstrate successful integration of these three practices into K–12 ecological research activities, an application that will benefit not only future ecologists but also students who enter other careers as ecologically literate citizens

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Because ecologists need additional skills to fulfill this new research model, ecology training must go beyond mastery of the research itself. For example, McBride *et al.* (2011) called for training graduate students as "Renaissance scientists", individuals with strong disciplinary expertise in addition to competency in three other areas: (1) strong collaboration practices, (2) a strong foundation outside their own field to facilitate work with interdisciplinary research teams, and (3) the ability to communicate effectively about science with diverse audiences outside the science community.

While educators encourage developing these practices at both the graduate and undergraduate levels (Brewer and Smith 2011), they have frequently not been included in discussions of ecology education at the K–12 level in the US. With the publication of the National Science Education Standards in 1996 (NRC 1996) and the more recent Next Generation Science Standards (NGSS; NGSS Lead States 2013), the focus of most science education reform has been on active science learning by students, encouraging a departure from teaching exclusively by textbook or having students conduct hands-on activities simply to demonstrate a principle that has already been taught to them. While we strongly support the continued promotion of research activities for K–12 ecology, we argue that this approach should be expanded to encompass the three practices required of "Renaissance scientists" (Figure 1).

This is an opportune moment to expand the K–12 concept of ecology in the US because collaboration, interdisciplinary thinking, and communication are all embedded within the newest set of education standards, the NGSS and the Common Core State Standards (CCSS) in English Language Arts and Mathematics. Collaboration and communication are included in the CCSS College

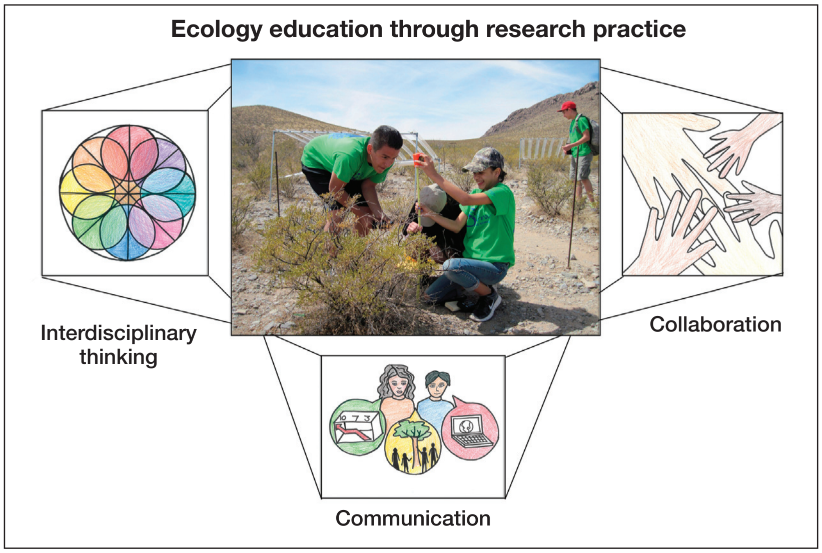


***Figure 1.*** *K–12 ecology education should reflect the full range of skills and understanding needed in modern ecology. This requires allowing students to learn and practice interdisciplinary thinking, collaboration, and communication skills as part of their research activities.*

and Career Readiness Anchor Standards for Speaking and Listening, which states that students should be encouraged to "Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively" (NGACBP 2010). Interdisciplinary thinking is encouraged in the NGSS through the organization of each standard into at least one of seven "crosscutting concepts", such as stability and change; systems and system models; and scale, proportion, and quantity. This promotes consideration of interdisciplinary connections among seemingly disparate standards. Communication is given more prominence in NGSS through its inclusion as one of the eight science and engineering practices upon which the standards are based. As K–12 schools implement NGSS and CCSS, ecologists and ecology educators need to demonstrate how a modern understanding of ecology fits within the new standards and to develop programs that integrate collaboration, interdisciplinary thinking, and communication with ecological research projects.

Here, we present five examples of programs that were developed in dryland ecosystems and exercise all of these concepts together to give students a better understanding of the collaborative, interdisciplinary nature of modern ecology. In addition, incorporating communication exercises within the framework of K–12 ecology education provides students with the necessary skills and experience to engage in public discourse about science.

## Collaboration training for students and ecologists through participatory science

Public participation in scientific research (PPSR), which includes citizen science, refers to partnerships between scientists and non-scientists to conduct scientific research on a topic of interest (Conrad and Hilchey 2011; Jordan *et al.* 2012). With the emergence of large-scale, high-impact issues such as climate change and invasive species, PPSR has received increasing attention in the peer-reviewed literature both as an educational outreach tool and as a cost-effective method for conducting research over large spatial scales (Silvertown 2009).

An additional, if less apparent, benefit of PPSR is the opportunity it provides ecologists and students to develop skills required for effective collaborations between researchers in team settings. Such cooperative efforts, the outcomes of which often surpass those achieved by individual researchers, require diversity among team members and interpersonal skills that educators do not often teach (Cheruvelil *et al.* 2014). Two examples of PPSR projects – the Melibee Project and the Global Learning and Observations to Benefit the Environment (GLOBE) Program – illustrate how PPSR can help K–12 students, educators, and ecologists build collaborative ecological research teams across disciplines and over large spatial scales.

The Melibee Project is a University of Alaska–Fairbanks PPSR project in which ecologists, students, educators, land managers, tribal government personnel, and citizens work together to understand the effects of a widespread invasive plant (sweetclover, *Melilotus albus*) on the pollination of bog blueberry (*Vaccinium uliginosum*) and mountain cranberries or lingonberries (*Vaccinium vitis-idaea*) throughout Alaska (Mulder *et al.* 2013). Volunteer participants collect data on the flowering phenology of these species to assess the degree of flowering overlap and potential for pollinator competition across Alaska's diverse biogeoclimatic zones. The collaborative approach provided by PPSR allows the Melibee Project team to gather data from a large geographic area (more than 1.5 million $km^2$) and improve both youth and adult participants' knowledge of key ecological concepts, such as phenology, invasive species, and climate change (Spellman and Mulder 2014).

In addition to achieving these research and education benefits, the Melibee Project also trains participants in facilitating successful partnerships (Figure 2). The half-day or 3-day training workshops bring together a diverse participant base, including formal and informal K–12 educators (who subsequently return home and involve their students), resource management professionals, other adults, and youth. After learning about the social and ecological aspects of the accelerating non-native plant invasions in Alaska, participants complete activities designed to improve collaborative problem solving and communication. Workshops also teach the technical

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skills required to complete standardized data collection. Upon completion of the workshops, Melibee Project educators or ecologists – when subsequently training K–12 students in schools or summer camps – relay collaborative practices to students who were unable to attend, and foster dialogue between youth, scientists, and the community at large. Those students then use a web-based portal (http://handsontheland.org/environmental-monitoring/melibee-project.html) to input their observations, analyze trends, and compare their data with those collected by other participants around Alaska.

New observations and ideas are shared between ecologists and participants in various media and settings, including frequent email communications, follow-up visits by the scientists to classrooms or camps, a newsletter, and an end-of-season gathering. Student observations made during the Melibee Project have resulted in classroom experiments, novel questions, and a new research project comparing the phenology of native and non-native plants. These contributions demonstrate to students their essential role in the collaboration.

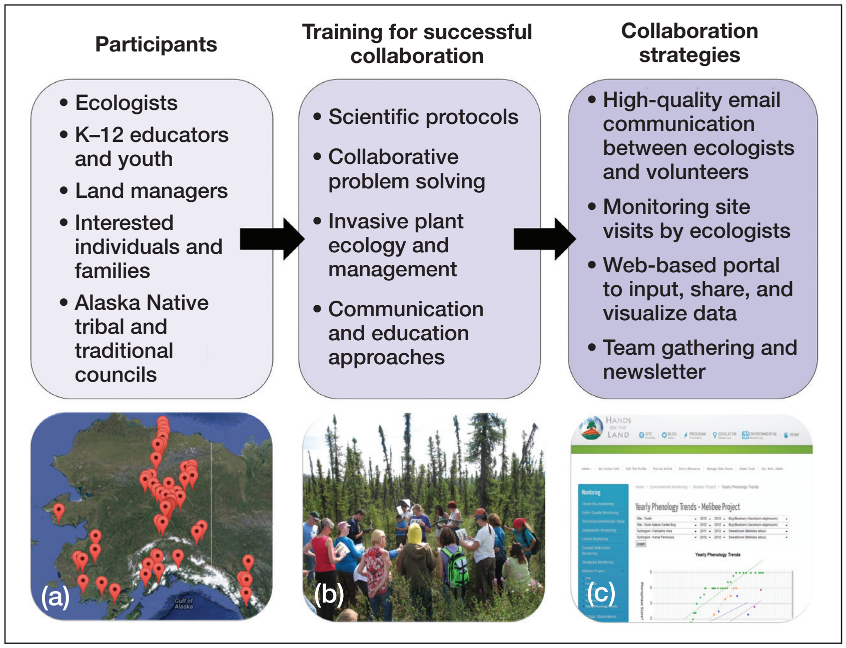


***Figure 2.*** *Model of collaboration for the Melibee Project Citizen Science program at the University of Alaska–Fairbanks and Bonanza Creek LTER project. Participants volunteer to monitor the flowering phenology of invasive plants and native berry plants across the state of Alaska (a) and are trained at in-person workshops at the Bonanza Creek LTER project (b) or through webinars. Use of a web-based citizen-science portal (c), among other strategies, facilitates collaboration across the large-scale project.*

GLOBE, another PPSR project, works at an even larger spatial scale, involving K–12 students, communities, and scientists from 112 countries in ecosystem and Earth-system science studies (www.globe.gov; Sparrow *et al.* 2013). To help teachers overcome time constraints, a major barrier to implementation (Sparrow *et al.* 2013), GLOBE protocols and learning activities are aligned with the National Science Education Standards, state education standards, and more recently with NGSS. This helps educators fit GLOBE into their existing curriculum, meeting the required standards while also involving students in valid research that highlights collaboration.

Teachers involved in Alaska's Bonanza Creek Long Term Ecological Research (LTER) project use GLOBE's standardized protocols to engage their students in research practices in their local schoolyards and also contribute to larger, collaborative projects, such as analysis of the start of the growing season of Alaskan plant species (Robin *et al.* 2008). Individual classrooms have conducted their own investigations, sharing their data and conclusions within their own school, across schools, and with other student and adult groups in the 21 countries that follow GLOBE phenology protocols (White *et al.* 2000; Gazal *et al.* 2008; Sparrow *et al.* 2013).

Involving students in local or larger scale PPSR projects has become easier thanks to web-based collaboration technologies, but major obstacles still need to be addressed. PPSR projects often require considerable amounts of instruction time, so finding a project that aligns well with grade-level content standards is crucial. Given the collaborative nature of PPSR projects and their reliance on multiple research practices already emphasized in educational standards, experienced teachers should find this barrier relatively easy to overcome. Although both of the PPSR projects outlined here involve face-to-face interactions with ecologists at universities or science agencies, this involvement is not necessary. The catalogs of PPSR projects at www.citsci.org, www.citizenscience.org, and www.scistarter.com include diverse projects involving different levels of direct interaction with project leaders. Therefore, schools without LTER sites or other research facilities nearby can still engage in PPSR programs.

## ■ Interdisciplinary training through K–12 urban ecology projects

More than half of the world's population lives in urban areas, a fraction that is expected to increase over the next 50 years. It will therefore be increasingly important to find ways to create livable urban environments for both humans and the other organisms that share the space. Solving urban sustainability problems requires an interdisciplinary approach linking a wide variety of stakeholders, including natural and social scientists, city planners, and local citizens.

Research on the causes and consequences of the urban

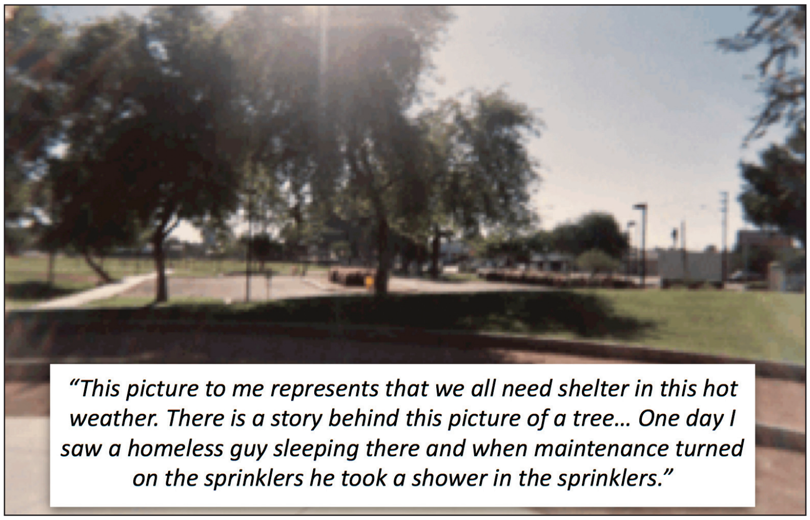


***Figure 3.*** *As a culminating activity in the urban heat island (UHI) unit, Elizabeth Matlock, a 7th-grade student in Arizona, took this photo and explained a personal connection with the UHI effect. This activity often shows students' understanding of the interdisciplinary implications of complex ecological topics.*

heat island (UHI) phenomenon provides a model for teaching students about the environment as a social–ecological system. The UHI begins when cities grow and transform the natural environment from native vegetation into a diverse assemblage of built structures and artificial surfaces. Heat stored during the day in concrete and asphalt slowly radiates back into the environment at night. Local changes in climate, such as those caused by UHI effects, may outpace the top-down influence of global climate change on cities (Grimm *et al.* 2008). In addition, the net effect of the UHI in naturally hot climates can be detrimental to human well-being. Social–ecological research can provide new information on how these changing urban climates interact with human–natural systems across socioeconomic boundaries and racial/ethnic groups; for example, the urban poor are more vulnerable to extreme heat (Dybas 2013).

While social and natural scientists work together to address urban and sustainability science questions, classroom content and teaching typically separate these disciplines (Duschel 2008). To illustrate an interdisciplinary approach to solving urban sustainability problems, the education team at the Central Arizona–Phoenix LTER program partnered with environmental scientists, social scientists, and engineers to develop and implement a UHI unit for middle-school students. In this interdisciplinary unit, students investigate the causes and consequences of UHI by collecting data about the built and natural environment through various field studies and activities. Using a participatory technique called Photovoice (Buck and Cook 2010), students share their own UHI experiences through photography and build on their new understanding of the problem to progress toward solutions and action. Students also discuss their motivations and reactions to the images they have taken (Figure 3), which may reveal themes of environmental justice. Finally, students are challenged to engineer a thermally efficient house. The UHI unit's ultimate objective is to engage others in the community through public exhibits and projects.

Our challenge in sharing this unit with teachers has been to find a place where it fits into the current curriculum, a common problem encountered with interdisciplinary studies of the environment (Ramsey *et al.* 1992). One solution is engaging a multidisciplinary team of teachers to cooperate on the unit, as discussed by a teacher who wrote on behalf of her team of six (two science, two social studies, one language arts, one mathematics) teachers: "The [UHI] project influenced not only our students' understanding of a real-world problem, but also our ability as teachers to work together to provide a powerful, inquiry-based learning experience that was enjoyed by all students" (MM Elser, pers comm).

Mirroring the situation in modern ecology, tackling large, interdisciplinary ecological questions at the K–12 level requires new ways of thinking as well as multidisciplinary collaboration.

## Communications training through near-peer teaching

In near-peer teaching, a student at a slightly more advanced school level teaches a less-advanced student (Campolo *et al.* 2013). This strategy is used widely in medical schools and other health professions, as it has been found to benefit both the learner and the teacher (Ten Cate and Durning 2007; Ten Cate *et al.* 2012). Near-peer teachers report a more thorough understanding of the content material and improved leadership and communication skills, especially if they received adequate training in the subject matter and teaching strategies (Campolo *et al.* 2013). Lockspeiser *et al.* (2008) attributed the effectiveness of near-peer teaching to near-peer teachers having a similar knowledge base as the near-peer learners, resulting in less cognitive distance between teacher and student.

"Science Interns", an ecology education model developed by the Asombro Institute for Science Education, uses near-peer teaching as a form of science communication in elementary schools in New Mexico (Figure 4). Fifth-grade teachers choose from three modules (desert biome; seasons and climate; and matter and energy), each aligned with New Mexico 5th-grade education standards in science and CCSS in language arts and mathematics. The 5th-grade students engage in hands-on research activities with Asombro educators to learn about the topic; by discussing teaching strategies with the students, with a special emphasis on how to communicate difficult

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concepts coherently and accurately to younger students, educators then challenge their students to become near-peer teachers. Subsequently, 5th-grade students prepare and practice age-appropriate, hands-on activities, which they then teach to kindergarteners through 3rd graders at their schools. Each class repeats the process with another module later in the school year, thereby providing a second opportunity to learn, practice, and teach.

Asombro staff, teachers, and school administrators report considerable benefits to both the near-peer teachers and learners. One teacher reflected on her students' growth in Science Interns: "Planning for and taking part in the teaching made our science curriculum real and purposeful. The collaboration and problem solving skills that were needed to prepare and teach showcased their learning and leadership. All 5th graders will remember this teaching day as one of the highlights of their 5th-grade year!"

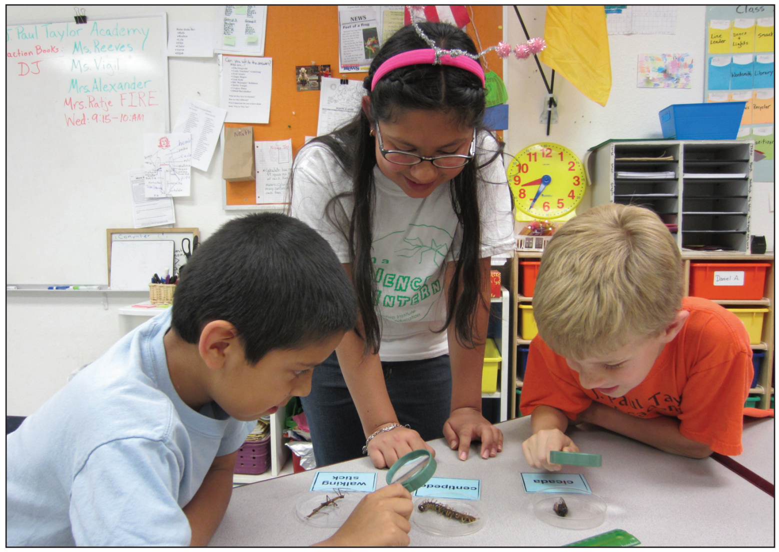

***Figure 4.*** *Through the Science Interns project in New Mexico, 5th graders learn about ecology through research projects and then teach younger students at their school using hands-on activities. Fifth graders gain science communication skills, a sense of leadership, and mastery of the subject. Younger students engage in science lessons and gain science role models.*

Fifth-grade near-peer teachers gain communication skills, master lesson content, gain a sense of leadership, and begin to appreciate their own teachers' challenges and rewards. Near-peer learners gain opportunities to participate in hands-on science, currently an important benefit considering that – due to the standardized-testing-driven focus on language arts and mathematics – only one-in-five kindergarten through 3rd-grade classes receive science instruction daily (Banilower *et al.* 2013).

Another benefit of near-peer teaching within K–12 education is the opportunity to provide science role models with backgrounds similar to those of the learners. While communicating and teaching ecology to younger students, the 5th-grade near-peer teachers implicitly and explicitly begin to break down stereotyping associated with ecologists and to demonstrate the value of education and leadership. In southern New Mexico, where 83% of students are Hispanic – a group severely underrepresented in ecology (Ortega *et al.* 2006) – the value of providing Hispanic science role models cannot be overemphasized.

While Science Interns was developed for implementation by a non-profit science education organization, the concept of near-peer teaching could easily be adapted for use by individual teachers with their own classes. However, the model requires time for teachers to collaborate with each other to schedule near-peer-teaching time and discuss the science content to be covered.

## ■ Communication training through the "Data Jam" competition

Large, complex datasets present a particular challenge within science communication. Ecologists acquire and use large datasets in multiple ways, often to answer questions about changes in environmental systems (Soranno and Schimel 2014). However, these large datasets can be intimidating for many people. Skilled communicators such as data artists – who create infographics and other visual tools to help people understand complex data – are key for extracting meaning from large datasets and communicating the related "story" to others (Frankel and Reid 2008).

With these challenges in mind, the Jornada Basin LTER created the "Data Jam", a competition that encourages high-school students to apply non-traditional formats to communicate trends in long-term datasets to non-scientist audiences. Since the Data Jam began in New Mexico in 2011, students have used ecological and social data from EcoTrends (www.ecotrends.info) to create songs, dance routines, physical models, infographics, games, and animated videos (eg Figure 5). Ecology educators in Florida, Maryland, and New York replicated the Jornada Basin LTER Data Jam model for the first time in 2014, accessing data on EcoTrends from their own region.

In the first 3 years of the Data Jam, the biggest challenge that student participants face is finding a creative way to present data trends, as this is often the first time high-school students have used data to create something other than a graph. Jornada Basin LTER educators encourage students to use their other talents in this process: as a result, ballet dancers have used dance to represent data, musicians have written and recorded songs, and students skilled in woodworking have created physical models. Once students have succeeded in confronting this first challenge, even those who do not believe themselves to be gifted in science often begin to understand how they can contribute to the field.

Teachers participating in the competition report that their students gain confidence as well as skills in data


***Figure 5.*** *"Cottontailopoly" was a prize-winning project in the 2013 Data Jam. This board game allows players to interact with data and answer questions about population trends of desert cottontail rabbits (*Sylvilagus audubonii*) based on a Jornada Basin LTER dataset accessed from the EcoTrends website (www.ecotrends.info).*

interpretation, science communication, technical reading and writing, and computer literacy. Students in the Data Jam are also required to include a section reflecting on their projects' challenges and successes, and they routinely report that the most demanding and ultimately rewarding part of their respective projects was understanding – and finding creative ways of illustrating – the data trends. More formal, quantitative assessments of changes in communication skills through the Data Jam have been difficult to develop because of the variety of project types created by the students.

## Conclusions

The quest for an ecologically literate public requires that ecologists and science educators accurately portray ecological concepts, practices, and thinking during the period when most people receive their formal ecology education. More than 41% of the US population 25 years and older have not attended college (US Census Bureau 2013), so waiting to fully explain ecology until students enter college excludes a large fraction of the populace. Achieving ecological literacy on a large scale requires an earlier start.

Ecologists have discussed the importance of collaboration, interdisciplinary thinking, and communication for an ecologically literate population (Jordan *et al.* 2009). For example, Berkowitz *et al.* (2005) detailed three dimensions of ecological literacy: knowledge of key ecological systems, understanding the nature of ecological science and how it interfaces with society, and ecological thinking skills. Within this third dimension, the authors include the ability to link knowledge from other disciplines, which requires the ability to collaborate.

To create the contemporary ecologist – one able to grapple with complex, interdisciplinary questions at multiple scales and then actively engage the public in participating in and understanding their science – we need to create a precollege culture where these practices are an integral part of what it means to be an ecologist. Early training allows students to recognize the range of skills that are important in the field of ecology. This might encourage more students, and particularly students from groups currently underrepresented in ecology, to consider the discipline as a possible career choice.

Ecologists must advocate for this suite of practices in K–12 ecology education. While the programs highlighted here were developed in dryland ecosystems, these models can be, and in some cases already have been, expanded to other ecosystems. Throughout the US, most K–12 teachers are challenged by implementation of new education standards from CCSS and NGSS, and fewer than half of elementary teachers believe themselves well prepared to teach science (Banilower *et al.* 2013). Therefore, ecologists, and those working at the interface of ecology and K–12 education, must take the lead by implementing projects that encourage authentic ecological research while promoting collaboration, interdisciplinary thinking, and communication.

## Acknowledgements

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