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CUR Focus

Undergraduate Learning from the Ground Up: Linking Belowground and Aboveground Diversity in Costa Rica

Abstract

Through a grant from the National Science Foundation's Research Experiences for Undergraduates (NSF REU), 24 undergraduates (more than half from underrepresented demographic groups) addressed ecological and natural resource management questions within the Maquenque National Wildlife Refuge between 2013 and 2015. Students worked with faculty mentors and researched vegetation, invertebrates, primates, soil microbial community structures, or soil biogeochemical characteristics within a variety of undamaged, damaged, or at-risk habitats. This article highlights some studies conducted by students that sought to provide new ecological information to Costa Rica's Research and Monitoring Plan. Development and diversity are compared within a variety of sites, including selectively harvested forests, 10- to 30-year-old regenerating secondary forests, silviculture plots, and recent agriculture sites that were left fallow. Outcomes in student learning, scientific growth, and ability to connect personal research to that of others are presented. The research experience encouraged the students to become scientists with a global perspective in ecology and environmental sciences, and provided data that can be used for future land management and educational purposes.

Keywords: *Costa Rica, ecology, environmental science, fieldwork, lowland wet forests, nutrient dynamics, NSF REU*

Introduction

Within the ecological and environmental sciences, research is often conducted in a controlled setting, and information is presented without reference to other disciplines or to a larger socioeconomic context. Such approaches are usually not effective for students from underrepresented groups whose cultures may emphasize learning through direct engagement, a multidisciplinary perspective, and active learning (Armstrong et al. 2007, 415–420; Committee on Undergraduate Biology Education 2003, 10–14; Brewer and Smith 2011, 2–6). It is no surprise, therefore, that the people hired as ecologists and environmental scientists in the United States reflect a very low level of diversity, as indicated by the Ecological Society of America (Armstrong et al. 2007). Additionally, traditional approaches in undergraduate biology education often fail to instruct students in the practice of science, leaving majors ill-prepared to perform well early in their career (Committee on Undergraduate Biology Education 2003, 10–14; Brewer and Smith 2011, 2–6). As a response to these concerns, a program under the National Science Foundation's Research Experiences for Undergraduates (NSF REU) was designed to emphasize the development of independent, yet team-based, transdisciplinary undergraduate research within an important international conservation area.

The NSF REU programs support "meaningful participation by undergraduate students in most areas of research in science and engineering" (Beninson et al. 2011). NSF funds approximately 700 REU programs annually, with 7000 student participants in scientific disciplines at various universities each year. Sponsored sites manage cohorts of undergraduates who usually conduct summer research projects at a host university in the United States (Rorrer 2016). As reported by Beninson and colleagues (2011), few REU sites exist in international locales, and the number of these programs has decreased since 2006. A few REU programs supported by the NSF Directorate for Biological Sciences are hosted in the tropics such as those through the Organization for Tropical Studies at the La Selva Biological Station in Costa Rica (http://www.ots.ac.cr/) and the Smithsonian Tropical Research Institute in Panama (http://www.stri.si.edu/reu/english/). These programs emphasize that students reside within an academic community with many other researchers. The REU discussed here was unique in that it involved a study abroad immersive experience, with participating students and faculty members as the only researchers studying the ecology of the remote site, and the research was designed to assist in local land management decision making. Equally significant was the emphasis on community service and social activities that connected participants to the peoples of Costa Rica.

From 2013 to 2016, this REU offered 24 undergraduates the opportunity to conduct research while helping a rural community in northern Costa Rica and supplying information that can be applied to management protocols. Short-term study abroad experiences can provide undergraduate students with the chance to develop intercultural knowledge, skills, and attitudes that are essential in this age of globalization (Czerwionka et al. 2015, 80–81). Nationally, the demographic profile of students studying abroad does not match the demographic profile of U.S. undergraduates. The Institute of International Education (2016) estimates that 27 percent of students studying abroad are from a minority background:

Hispanic or Latino Americans, African Americans, Asian or Pacific Islander Americans, and Native Americans. This proportion represents a modest increase from the estimated 17 percent of students studying abroad in 2005. The REU Sites programs supported by the NSF Directorate for Biological Sciences typically engages a diverse group of undergraduates, with more than 40 percent of participants coming from underrepresented ethnic groups (around 20 percent of whom are Hispanic), and approximately 62 percent of participants across all biology REU programs are female (Beninson et al. 2011). The biology REU program discussed here had a greater proportion of underrepresented groups and women than the averages reported by Beninson et al. (2011), with women composing approximately 80 percent of participants, and Hispanic or African American individuals composing more than 65 percent of participants. Although most of the participants were sophomores or juniors when they were REU participants, more than 70 percent did not have previous research experience or had minimal exposure to research. Furthermore, 88 percent of the students had never conducted research outside of the United States.

This REU program provided a unique research opportunity that enabled the participants to become stronger scientists while developing their knowledge of tropical ecology and cultural awareness. The goals were to help REU students develop enhanced scientific creativity and critical thinking, an interdisciplinary and global perspective on the environmental-related sciences, excellent scientific skills, knowledge and technological expertise, and a better understanding of tropical rainforest conservation issues. There is arguably no greater way to understand the complexity of the rainforest than to discover it personally through immersive research. A model of undergraduate research was created in which students worked with faculty mentors to conduct field projects with potential to influence land management decisions in one of the world's most biologically diverse ecosystems. The structure and outcomes of this unique learning and research opportunity are discussed below.

This project's fieldwork provided an unparalleled opportunity to investigate environmental dynamics that occur as an ecosystem recovers following disturbance. These dynamics are extraordinarily complex in the lowland wet forests of northern Costa Rica, where 70 percent of the forests have been cleared for agriculture or pasture over the past 40 years (Schelhas and Sanchez-Azofeifa 2006). Although significant conservation efforts have been made, biodiversity loss in Costa Rica continues as forest ecosystems are converted into agricultural fields, plantations, and pastures (Shebitz and Eaton 2013; Looby and Eaton 2014). The San Juan-La Selva Biological Corridor was established in 2001 with the goal of protecting the remaining diversity. This corridor links six protected areas to form a large 1,204,812ha. unit. The Maquenque National Wildlife Refuge (MNWLR) is considered the principal conservation area within the corridor (Eaton and Chassot 2012, 187).

The study site is in one of the most remote and underdeveloped parts of Costa Rica, approximately 9 kilometers outside of the town of Boca Tapada (population approximately 250) and 20 kilometers south of the Nicaraguan border (latitude: N 10°40'13.68". longitude: W 85°45'43.15"). This area has only been accessible by land vehicles since 1970, and electricity was made available in 1994 (Marshal et al. 2011, 17). Lodging and food were provided by an eco-lodge, Laguna del Lagarto, whose staff has become close friends of the faculty and students involved with this project. The lodge's property includes 500 hectares of lowland wet forest characterized by high plant and animal diversity, set within a matrix of primary and secondary forests, grasslands recovering from grazing, and agricultural fields. William Eaton (the project's co-principal investigator) has conducted research at this location since 2002. In an effort to promote the lodge's continued use for scientific research, the owners of Laguna del Lagarto built a temperature-controlled laboratory that was used by this project.

The Structure of the REU Grant Program

To address ecological and natural resource management questions for the MNWLR, eight NSF REU students worked closely each summer with one of seven faculty mentors to research the vegetation, invertebrates, reptiles, primates, soil microbial community structures, or soil biogeochemical characteristics within a variety of undamaged, damaged, or at-risk habitats. Students were selected primarily based on their statement of purpose relating to their interest in field research and letters of recommendation that referred to the students' ability to adapt to new situations and work as part of a team. Of particular interest was participation of students from underrepresented ethnic backgrounds, and between four and eight Latino or African American students participated every year. As more than 275 students applied during the last year, deciding on eight candidates was exceptionally difficult.

The program took place over 10 weeks each summer (see Table 1), with the first two weeks of work conducted at Kean University in New Jersey where the students worked with their mentors to learn about the location in Costa Rica, develop possible research questions and methods, practice field techniques in temperate forests, and become familiar with the scientific literature. Collecting and reading scientific literature in advance were extremely important, since there is not reliable Internet access at the field site.

A large group of faculty mentors and students then traveled to Costa Rica, where the undergraduate students and a PhD student mentor stayed at the field location for six weeks. The

Table 1. A Generalized Schedule for the Tropical Ecology NSF REU Project Run through Kean University

Week	Location	Focus Activity	Skill Developed
1–2	New Jersey	Literature review	Scientific reading
2	New Jersey	Develop research project concept	Developing research questions
3	Costa Rica	Introduction of field sites, methodology developed at study location	Observation and hypothesis generation
4	Costa Rica	Finalize study design and install plots/transects; initiate data collection	Experimental design
5–8	Costa Rica	Collect data in the field	Data collection
5–8	Costa Rica	Laboratory analysis for some projects (i.e., DNA extraction, plant biomass, soil chemical analysis, insect identification)	Laboratory skills specific to research area
7	Costa Rica	Work on community service project	Cultural awareness
9–10	New Jersey	Analyze data	Data analysis
10	New Jersey	Present research in a scientific format to the REU group and others	Presentation skills and scientific writing

graduate student hired through the grant started working with the principal investigator and co-principal investigator as an undergraduate participant in a 2011 REU project and was therefore very familiar with the culture and environment of the region. All faculty stayed on-site with the students for at least the first two of the six weeks of their research to assist in establishing the field study. At least one faculty member was on-site with the students throughout the project's duration. Once a week, the group assembled so that students could present updates of their research and discuss any challenges that they were facing. This scientific discourse gave the students an opportunity to assist one another in project development and facilitated connections between the different studies.

It has been established that students involved in service learning activities develop critical thinking and social awareness by reflecting upon their experiential learning with community partners (Schmidt and Brown 2016, 100–101). An important component of this project was that the students worked to benefit the people of Boca Tapada, where the blending of Nicaraguan and Costa Rican traditions, foods, medicinal plants, and histories creates a unique and vibrant community (Shebitz et al. 2013, 790). One component of this REU program was a service activity requested by the town such as cleaning the chicken coop run by the local women's association or painting the local school buildings. In addition to these activities, soccer games and canoe rides were scheduled with community residents, and members of the women's association taught the students how to prepare local dishes. These activities were not just designed to help the local community but also to enrich the cultural knowledge and sensitivity of the undergraduates.

After the students returned to New Jersey, they worked with their faculty mentor during the project's final two weeks on analyzing data and preparing presentations or publications based on their research. As a final step, the students presented their research to faculty members of Kean's School of Environmental and Sustainability Sciences, friends, and family.

A Summary of the Science

Although a Research and Monitoring Plan for the MNWLR exists that intends to provide baseline data on the condition of the lowland wet forest ecosystems, Costa Rica has not dedicated funds to implement this plan. The MNWLR offers a rare and rich opportunity for REU students to provide new ecological information to the Research and Monitoring Plan. The development and diversity were compared within a variety of sites, including selectively harvested forests, 10- to 30-year-old regenerating secondary forests, silviculture plots, and recent agriculture sites that were left fallow. One of the great opportunities in these studies is that students were making "apples to apples" comparisons, as all study sites were originally part of the same uplands primary forests in the region, with the same topography and soil types. This situation is rarely available in comparative ecosystem studies.

Student participants in the REU worked with their faculty mentors to design a research project that was possible to accomplish within the allotted time and with the field/lab equipment available. Three projects are highlighted below that sought to develop the scientific skills of the students as well as address the cultural and environmental needs of the MNWLR.

Effects of Land Management on the Availability and Ecology of Medicinal Plants. Because of its proximity to the Costa Rica-Nicaragua border, the community of Boca Tapada has a blending of the cultures of these two countries. Since a nurse or medical student only visits the village once a month, plants provide an essential and reliable source of medicine for the local population. Changes in forest cover, however, are influencing the availability of plants used to treat ailments ranging from skin and gastrointestinal infections to diabetes and cancer. Students documented commonly used medicinal plant species in the MNWLR based on interviews with local healers and began to understand the knowledge arising from Nicaraguan immigration into this remote section of Costa Rica. Many plants that are sources of medicine are found in secondary or primary forests based on their ecological re-

quirements. Students studied the abiotic and biotic factors that affected the growth of some of these plants (focusing primarily on the following medicinal trees that are used to treat infections: *Vismia macrophylla, Pentacelthra macroloba,* and *Simarouba amara*). In addition, some students evaluated the medicinal efficacy of plants identified in interviews based on a triplicate disc diffusion assay that tested effects of plant extracts against bacteria and fungi. By working with the local people on documenting their knowledge and uses of plants, the project sought not only to empower the elders in the community but also to inspire the youth of Boca Tapada to learn from their elders and continue to appreciate the relationships between the forest and the people in that region.

Linking Soil Chemistry to Plant Diversity in Primary and Secondary Forests. Soil composition, physical properties, and chemical nutrients in primary and secondary forests within the MNWLR were characterized and compared to understand the human impact of disturbance on the ecosystem. Students examined the role of early successional leguminous trees in recovering nutrients and enhancing the development of the soil's physical and chemical properties. Chemical analysis and soil data were used to elucidate the possible microbial reactions within the different types of the forests. Students linked the dynamics of the belowground system to changes in plant diversity and cover aboveground in disturbed and intact environments of the MNLWR and showed the importance of nitrogen (N)-fixing trees to the ecosystem recovery following disturbance in the region. This work is particularly important in documenting the role of *Pentaclethra macroloba* as the dominant N-fixing pioneer tree species in the lowland wet forests studied. Although there is increasing pressure on this species as a source of lumber in the region, it is hoped that this work highlighting the ecological importance of *P. macroloba* will be used as a call for its conservation through the MNWLR land management plan. As the students have documented, this species transforms the soil and plant communities in secondary forest and plays a pivotal role in forest recovery following agricultural clearing.

A Comparison of Soil Carbon and Nitrogen Cycle Dynamics, and Fungal and Bacterial Community Composition Associated with Different Ecosystems and Land Management Strategies. The MNWLR is one of the most important areas in the Northern Zone of Costa Rica where different land management strategies and restoration activities are attempted. This project involved comparing soil ecosystems between differently managed lands with that of the adjacent intact primary forest. Comparisons were made among primary forest, 18-year-old secondary forest, 30-year-old secondary forest, various ages of grasslands, and various ages of silvaculture plots planted with an indigenous tree (*Vochysia guatamalensis*). Also compared were the soil ecosystem communities associated with two different leguminous tree members of the family Fabaceae (*Inga edulis* and *Pentaclethra macroloba*) in some of these habitats. Soil was collected from replicate plots and tested for carbon and nitrogen cycle metrics and biomass levels. DNA was extracted and outsourced for next generation sequencing, leading to the production of millions of bacterial and fungal DNA sequences that were used to identify microbial taxa within the different habitats. Students analyzed the nutrient and biotic data to determine effects of different land management strategies and to propose biotic drivers of ecological processes in these soils. This study was designed to determine best methods of managing grasslands resulting from forest clearing in terms of carbon use efficiency and economic benefit for the land manager. The students' work showed that 12-year-old *V. guatamalensis* planted in grasslands increased the flow of CO_2 into soil, improved biomass recovery, and resulted in a soil ecosystem that was more complex than unplanted grasslands. This management strategy resulted in soil ecosystem enhancement that was similar to soils of 18-year-old secondary forests that were allowed to regenerate naturally. The local land owner is now planting all of these grasslands with *V. guatamalensis* so that sections can be harvested annually in 10–12 years. He is also encouraging other land owners in the area to do the same so that income sustainability and benefit to the environment can be accomplished. This management decision would not have been possible without evidence provided by the undergraduate researchers.

Learning Outcomes

Outcomes of the program were assessed through a survey completed by 19 of the 24 participants (79-percent response rate). The results clearly indicate that participation in this REU program inspired students, developed their skills as scientists, and helped them develop a global perspective in ecology. Part of the survey included a series of questions regarding gains made in understanding the importance of cultural dynamics and ethics when conducting international research projects. An average of 4.4 out of 5 was selected on all of the questions (see Figure 1).

More than 90 percent of the students answered that their awareness of the Costa Rican culture and their understanding the importance of ethics when working with different cultures significantly improved after completing the REU program. For example, one student wrote:

- "My worldview view has definitely changed… It was great to learn about their country and the traditions they held. It made me value the importance of learning about how others live and discovering different parts of the world."

Another student stated:

- "Working in an international community provided me

with a different perspective other than my own and broadened my horizons in numerous ways. It helped me gain a greater understanding of other cultures, particularly in regards to conservation efforts in Costa Rica and the importance of the resources located there."

The connection to Costa Rica felt by the students extended beyond the people to the environment. One participant reported:

- "The best part was just being surrounded by rainforest. This gave me a better appreciation for the land, an appreciation that can't be gained from books or shows."

One essential element of this project was that the scientific information gained can be used to preserve the very ecosystems being studied. As one participant stated:

- "[T]his research opportunity in Costa Rica was immensely impactful in that I was able to see that the research I was doing could potentially benefit the ecosystems in which I was collecting data. Furthermore, by going out into the rainforest and collecting data in the field, I gained greater appreciation for how data are collected."

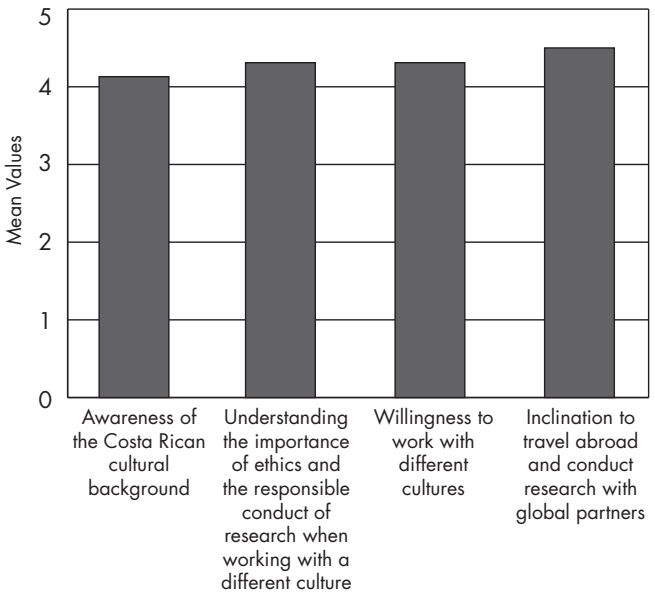
The role of the REU experience in influencing students to identify as scientists was evident throughout many survey responses. Notably, responses averaged 4.5 out of 5 (between "a great deal" and "an exceptional amount") when students were asked about the influence of the program on their appreciation of the connections between scientific disciplines. For example, a participant stated:

- "One aspect that encouraged me in my aspirations to study ecology in graduate school was witnessing the collaboration between the different disciplines of ecology; that made me particularly excited about working in a graduate school environment."

Students were asked to indicate how this experience affected their confidence as a scientist and consistently rated each of the following between 4 ("A great deal") and 5 ("An exceptional amount") in terms of how the experience affected their level of confidence, with an average of 4.3:

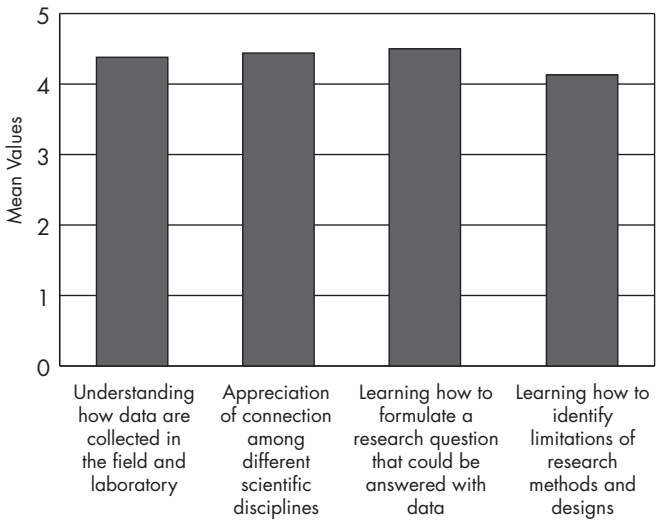
1. Knowledge of how to collect and analyze data from the field and laboratory,
2. Appreciation of the connection between scientific disciplines,
3. Ability to formulate a research question and design methods to collect data, and
4. Ability to identify limitations of research methods and designs (see Figure 2).

Figure 1. Student Learning Outcomes Assessing to the Effect of the REU on Student Understanding of the Value of Cultural Dynamics and Ethics in Conducting International Field Research Projects



Note: For the Y-axis scale, 0 = Not at all, 1= A little, 3 = A lot, 4 = A great deal, 5 = An exceptional amount

Figure 2. Student Learning Outcomes Assessing to What Extent the REU Experience Affected Student Confidence and Skills as a Scientist



Note: For the Y-axis scale, 0 = Not at all, 1= A little, 3 = A lot, 4 = A great deal, 5 = An exceptional amount

Throughout the 10 weeks, students were able to experience an entire project from creation to completion, and many of them continued to work throughout the rest of the year to present their information at conferences or write manuscripts for peer-reviewed journals. As one student stated:

- "Conducting research is complex. There is a crucial balance between big picture thinking and analysis and detail driven data collection. Teamwork is also very important. My hands-on experience taught me the challenges and rewards of conducting research—insights most scientists don't get until graduate school."

More than 70 percent of participants indicated that the research experience that they gained during the program increased their interest in ecology and encouraged them to apply for a scientific graduate program. In fact, 10 of the REU participants (seven of whom are from underrepresented ethnic groups) have started a science-based graduate program or have indicated a plan to pursue a graduate career in the next two years. One of the Hispanic REU participants who would like to gain experience before entering a graduate program mentioned:

- "I plan on joining the Peace Corps and then working towards a graduate degree in ecology. Throughout my future, I will continue to share lessons I learned through the REU with those from diverse ethnic groups so that I can inspire people of various backgrounds to pursue careers in the environmental sciences."

Another REU participant from an underrepresented ethnic group explained:

- "My research experience made me confirm that science is the field for me. I gained so much from the process of coming up with a research question, troubleshooting issues along the way, feeding off of others' ideas, and working long, exhausting hours. It was all so worth it. I felt so accomplished at the end of the REU program and knew that I had grown so much. I was pushed outside of my comfort zone and made to think deeper and harder. For that, I am so very grateful. This program made me realize exactly what the field of science has to offer. With research, there is still room to ask questions that fascinate you and work hard to get answers. It is that sense of passion that I felt while at REU that has propelled me toward my future goals."

The REU program also gave participants an opportunity to significantly improve their interpersonal and professional skills. They were asked about their current level of comfort working in groups, and they all responded they either feel good (4 out of 5) or excellent (5 out of 5) working with a team and local community members after completing the REU program. In fact, when asked about the best part of the experience, 10 students answered in terms of their connections with the team of their peers, their mentor, and the locals. For example, one student responded:

- "The best part of the REU was the friendships I made along the way, both with the other members of our research team and the locals we meet."

Another student replied:

- "Working with my peers and professors throughout this experience was hugely rewarding, and I have referred back to our group dynamic as an example of a hugely positive work experience many times since."

Conclusion

An essential part of this REU program was the international scientific experience for students. This critical educational component helped the undergraduates develop a deeper understanding of the global nature of environmental science and an appreciation of different cultures. This type of life-changing event is often missing in the education of U.S. students. According to the Commission on the Abraham Lincoln Study Abroad Fellowship Program (2005, ii), "What nations don't know can hurt them. The stakes involved in study abroad are that simple, that straightforward, and that important. For their own future and that of the nation, college graduates today must be internationally competent." The authors believe that every student, regardless of economic or ethnic background, should be encouraged to study abroad and that taking part in international field research provides an unparalleled opportunity for young adults to develop a truly ecological and cultural worldview. It was hoped that this part of the REU program would serve as a "tipping point" experience to inspire these students to pursue the ecological sciences, as they experienced its value to the scientific and public communities and realized that it was part of an attainable career—all critical factors in attracting students from underrepresented groups into environmental science.

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