The “Research Experiences for Undergraduates (REU) in Biodiversity Conservation” project models transdisciplinary training in conservation science, and particularly in the emerging field of conservation paleobiology (CPB), which applies geohistorical records (e.g., sediments, fossils) and approaches to solve conservation problems. We analyzed recent funding patterns in the National Science Foundation REU program (Biological Sciences and Geosciences directorates) and found that, at most REU sites, undergraduates conduct individual projects supervised by a mentor. In contrast, at the REU in Biodiversity Conservation Site, students from geology, biology, archaeology, and environmental sciences worked in transdisciplinary teams on conservation-related research using fossil, archaeological, and modern samples. The project successfully incorporated CPB approaches and taught research and soft skills useful in conservation; 85% of students subsequently pursued STEM graduate study or employment. However, because translational science partnerships with conservation practitioners were not sought, the research-implementation gap remained. We propose a new model for REU sites involving conservation practitioners and stakeholders as partners in research that includes the human dimension and meets community needs, resulting in transdisciplinary, team-focused training that yields actionable results. We recommend that the National Science Foundation encourage researchers to think beyond typical one-on-one mentorship when planning an REU, especially for conservation science projects.

KEYWORDS
conservation paleobiology, National Science Foundation, Research Experiences for Undergraduates, research-implementation gap, team science, transdisciplinary training, undergraduate education
Schwartz, 2009). Even more crucial is the development of approaches that cross the research-implementation gap (Arlettaz et al., 2010; Pietri et al., 2013; Jarvis, Borrelle, Breen, & Towns, 2015; knowledge-action boundary of Cook, Mascia, Schwartz, Possingham, & Fuller, 2013), bringing students and researchers into collaboration with managers, policy makers, and other stakeholders, to translate research results into meaningful conservation action. In other words, translational science partnerships must be developed (Briske, 2012).

These issues are even more pressing for the field of conservation paleobiology (CPB), a conservation-focused sub-discipline of paleontology allied with conservation biology (Dietl, 2016). Although CPB approaches have been used for decades, the term was introduced formally in the early 2000s, and the field has developed rapidly in the past decade (Dietl & Flessa, 2017; see Dietl & Flessa, 2017b for case studies). The CPB approach applies information derived from geohistorical records (e.g., sediments, ice cores, fossils, the archaeological record) to solve problems related to conservation and restoration of biodiversity and ecosystem services (Conservation Paleobiology Workshop, 2012; Dietl et al., 2015). Conservation scientists and managers have not recognized the full utility of geohistorical data in conservation (Savarese, 2018; Smith, Durham, & Dietl, 2018). Therefore, this emerging field has not been embraced yet by the conservation biology community, despite its potential for detecting invasive species, establishing baselines for restoration, understanding the natural variability of ecosystems and their response to perturbations, and identifying at-risk species and habitats, among many other contributions (Dietl et al., 2015; Tyler & Schneider, 2018; see Dietl & Flessa, 2017b for case studies). In addition, today’s conservation paleobiologists are mostly traditionally trained, academic paleontologists with minimal experience translating results into conservation action on the ground (Kelley, Dietl, & Visaggi, 2018). Consequently, we are poorly prepared to provide our students with the real-world experience needed to pursue conservation science careers.

Ten years ago, we embarked on the “REU in Biodiversity Conservation” (REUBC), a “Research Experiences for Undergraduates” (REU) summer training site funded by the U.S. National Science Foundation (NSF) (Principal Investigator [PI] Kelley, co-PI Dietl). At that time, CPB was not developed enough to be included in the title of our project; to our knowledge, ours was the first attempt to train undergraduate students in conservation by working across disciplines using the geohistorical record. The purpose of this paper is to present the REUBC as a case study, not only for training in CPB but also in conservation in general; CPB is not alone in needing pedagogies for training students in translational conservation science (see Brunson & Baker, 2015), although the focus is often on training at the graduate level (e.g., Schwartz et al., 2017). The REUBC can also serve as a model for training in any field that can benefit from transdisciplinary collaboration.

Why look back now? CPB has developed significantly over the past decade, providing an informed perspective from which to reflect. In addition, enough time has passed to track outcomes for student participants (see Wilson et al., 2018 for a similar approach). We are thus positioned to extract lessons from the REUBC. In this paper, we evaluate what aspects of the REUBC worked well and what we would have changed, given this matured perspective. We analyze and critique the current approach to undergraduate research supported by NSF and offer recommendations for developing training programs in conservation that provide real-world experience that matters, that is, that allow students to experience translational science.

2 REU IN BIODIVERSITY CONSERVATION

The REUBC operated for 8 weeks each summer, 2008–2010, at the University of North Carolina Wilmington and involved nine students per year. The overall goal of the REUBC was to bring together a transdisciplinary group of undergraduate students and faculty mentors to address issues of anthropogenic biodiversity loss and ecosystem modification from a geohistorical perspective. Our immediate aim was to provide a research experience in which undergraduate students collected and compared fossil, archaeological, and modern marine samples, in order to understand the natural variability of the coastal Carolinas ecosystem, the response of species and ecosystems to environmental change, and the degree and nature of human impact. Our long-term goal was to build a diverse pool of students who were comfortable working in transdisciplinary teams and aware of issues in biodiversity conservation, and who could develop innovative approaches to addressing these issues.

2.1 Transdisciplinary participants

Issues of biodiversity conservation are best attacked through transdisciplinary collaboration (e.g., Briske, 2012; Enquist et al., 2017; Jacobson, 1990; Moslemi et al., 2009; Pooley, Mendelsohn, & Milner-Gulland, 2014; Turner II et al., 2016). Hence, we sought cohorts of students with varied academic backgrounds; the 27 students included majors in biology (including one conservation biology major), geology, environmental studies/sciences, and anthropology/archaeology. Similarly, faculty participants represented specializations in marine biology, geology (paleontology, stratigraphy, geochemistry), environmental studies, and archaeology; a faculty member from education served as project evaluator. MS students from geology and marine science assisted in the lab and field, and a PhD student in marine biology (Visaggi) assisted the PI and co-PI with all aspects of the
project. Because a primary goal of NSF’s REU program is to increase diversity in the sciences (NSF, 2018a), we also aimed for diversity in gender, race, and ethnicity (see Table 1).

### 2.2 REUBC structure and approach

At most REU sites, students work in faculty research labs on individual projects related to the mentor’s research (Wilson et al., 2018) within a unifying theme (Figure 1). Student interns typically do not work collaboratively with one another, although group activities (weekly seminars, social events, final symposia) allow students to interact with REU peers, and students may be housed together (Kelley, personal observations from REU PI meetings and listservs; see also Wilson et al., 2018). Our site also included group enrichment activities (e.g., seminars on research ethics and career/graduate school opportunities, outreach to minority middle school science camp students, a final symposium, and social events), and students were housed together. In contrast to other REUs, however, and consistent with the underlying premise that conservation training must be transdisciplinary, the REUBC was structured around research collaboration by students across disciplines (Figure 1). In other words, REUBC interns conducted team science.

“Team science,” an emerging concept with origins in the public health and medical fields (e.g., Fall-Krzesinski et al., 2010), has gained increasing attention in science as an essential framework for approaching the “big” problems impacting society (Ledford, 2015), such as global climate change, sustainability, and biodiversity conservation. Such issues require knowledge extending far beyond the structure of individual research silos. Consequently, team science goes beyond different individuals working in parallel on the same research problem; rather, teams of researchers intentionally design and drive research goals and experience the research process together. Researchers may represent vastly different disciplines (e.g., geology, sociology), and teams can include nonacademic collaborators from industry, community groups, etc.

In the REUBC, although all interns had science backgrounds, the diversity of disciplines meant that each student faced a steep learning curve on one or more aspects of the research. Therefore, at the start of each research project, faculty presented brief lectures to ensure that all students had the requisite background knowledge for the work. In addition, students were immersed in the relevant scientific literature of multiple disciplines through reading and discussion (see Pooley et al., 2014), and training was provided for completing field and laboratory work as new competencies were needed. These approaches prepared students to collaborate on projects outside their academic background.

Students collaborated in transdisciplinary teams on two large group projects, one focused on molluscan fossil

### Table 1 Numbers of student, faculty, and staff participants in the REUBC site by demographic category

| Category                          | Interns | PI | Co-PI | Senior personnel | Graduate students | Visiting scientists |
|-----------------------------------|---------|----|-------|------------------|-------------------|--------------------|
| Discipline                        |         |    |       |                  |                   |                    |
| Archaeology                       | 3       |    |       |                  |                   | 3                  |
| Biology                           | 10      | 1  | 2     | 2                |                   |                    |
| Education                         | 0       |    |       | 1                |                   |                    |
| Environmental science             | 5       |    |       | 1                |                   |                    |
| Geology                           | 9       | 1  | 6     | 2                | 1                 |                    |
| Marine science                    | 0       |    |       | 2                |                   |                    |
| Gender                            |         |    |       |                  |                   |                    |
| Female                            | 13      | 1  | 3     | 5                |                   |                    |
| Male                              | 14      | 1  | 7     | 1                | 4                 |                    |
| Race/ethnicity                    |         |    |       |                  |                   |                    |
| African American                  | 3       |    |       | 1                |                   |                    |
| Asian                             | 2       |    |       |                  |                   |                    |
| Caucasian                         | 15      | 1  | 1     | 9                | 6                 | 4                  |
| Hispanic                          | 6       |    |       |                  |                   |                    |
| Pacific Islander                  | 1       |    |       |                  |                   |                    |
| Location of intern’s institution  |         |    |       |                  |                   |                    |
| United States west coast          | 5       |    |       |                  |                   |                    |
| Midwest United States             | 5       |    |       |                  |                   |                    |
| Northeast United States           | 7       |    |       |                  |                   |                    |
| Southeast United States           | 8       |    |       |                  |                   |                    |
| Puerto Rico                       | 2       |    |       |                  |                   |                    |

*Note.* PI, principal investigator.

*Senior personnel include faculty and lab managers.

Visiting scientists from another institution who participated for <1 day.
communities and the other on modern marine communities, with the intent to understand anthropogenic ecosystem change. Concurrently with the group research, each student worked with us and additional mentors as appropriate to develop an individual research project based on fossil, archaeological, and/or modern samples. The students began their individual projects during the second month on-site, with help in the field and laboratory from other REU interns. The individual projects were completed during the subsequent academic year (e.g., as senior theses) under the supervision of REU mentors in collaboration with mentors at home institutions. Group and individual project results were presented at the annual meetings of the Southeastern Section of the Geological Society of America (GSA). The GSA meetings served as an opportunity to reunite each cohort and bring closure to the project.

2.3 Scientific focus and relation to conservation

At the beginning of the summer, we provided a list of general questions to guide transdisciplinary team research and individual projects. For example, how did past ecosystems respond to environmental perturbation? What was the range of variability in ecosystems before human impact? How did ecosystems function in the absence of human influence? How have human activities (overfishing, habitat modification, pollution) affected community structure? What are the implications of this work for ecosystem management? To answer these questions, research projects were developed using (a) the fossil and (b) archaeological records and (c) samples from the modern coastal environment, as exemplified by the following group and individual studies:

1. To better understand the response of the marine ecosystem to perturbations, the REUBC examined molluscan diversity and trophic structure during the past 4 million years, a period of multi-phased extinction in the western Atlantic with parallels to the modern biodiversity crisis in scale and causes (changes in climate, sea level, nutrients). Working in teams, students sampled 16 localities in the eastern Carolinas, extracted and identified all bivalve and gastropod fossils (>56,000 specimens), and collected and analyzed data on abundance, diversity, and life mode. We found that...
the ecosystem was resilient to change until the final extinction phase and that more latitudinal differences occurred in richness than in trophic structure.

2. An individual project used the archaeological record to explore human impact over the past 1,800 years. Average size of the hard clam *Mercenaria* in South Carolina shell middens decreased from 1,770 to 320 B.P., consistent with overharvesting by Native Americans. However, frequencies of traces of failed bird predation from oystercatchers (*Haematopus*) preserved on the shells of hard clams did not change significantly, implying that oystercatcher foraging was not affected by local overharvesting of hard clams by humans.

3. We investigated anthropogenic modification of several local environments through projects that compared the living assemblage of molluscs (representing current conditions) with dead shells (indicating past conditions) accumulated in the upper sediment levels at a site (“live-dead analysis”; Kidwelly, 2007; Figure 2). Live-dead agreement decreased with depth within several oyster reefs, suggesting that human impact (sedimentation and nutrient input) increased through time. Sea grass beds exhibited the most discordance between the live and dead assemblages, supporting significant anthropogenic change through activities such as nutrient run-off, dredging, and boat traffic.

These studies all used geohistorical data to draw inferences that we thought would be useful in management decisions. At the time of the REUBC, we understood our role as providing information that policy makers and managers could find and use in decision making (a “trickle-down” or “loading dock” approach; see Enquist et al., 2017; Dietl & Flessa, 2018). However, we now realize that the research-implementation gap (or space; see Toomey, Knight, & Barlow, 2017) is rarely crossed when a policy maker accidentally stumbles on research results; rather, intentional connections are needed between researchers and practitioners (Enquist et al., 2017), as discussed below. Information flow must be multidirectional within translational science partnerships (Briske, 2012; Cook et al., 2013; Enquist et al., 2017).

2.4 | Project successes

The REUBC was a unique undergraduate research experience in incorporating the perspective of the emerging field of CPB and consisting of work by transdisciplinary teams of students. In contrast, most other conservation (and other!) REUs are strongly disciplinary, with students working one-on-one with mentors. We downloaded an Excel spreadsheet from the NSF REU website (NSF, 2018b) that provided information on 211 recent REU site awards (start dates within the past 5 years) in the Biological Sciences (BIO) and Geosciences (GEO) directorates (see Supporting Information). Of the 211 REU sites, 57 mentioned collaborative research in program titles or abstracts, but in most cases the collaboration was between individual students and mentors, or between institutions (Figure 3a). Based on award abstracts, only two sites definitely involved REU students collaborating with one another; abstract wording was ambiguous for four others that may have involved intern collaborations. A search for the word “team” found 13 awards in which interns worked in teams (6% of the 211 awards; Figure 3b). Twenty-three awards mentioned “biodiversity” and/or “conservation” in their title or abstract; none of these appears to involve cross-disciplinary team projects (Figure 3c), though at one site (funded twice during this period) each student worked with two mentors from different fields.

Team research may be infrequent among recent BIO and GEO REU projects in part because, as noted by Pooley et al. (2014), collaborations involving multiple disciplines are challenging to orchestrate. Not only did content knowledge vary among REUBC participants, but they were also unfamiliar with the language, methods, and perspectives of other disciplines. Was our site successful in implementing team science? A multifaceted evaluation process included participant focus groups, pre- and end-project self-assessments by students, post-project online final surveys of students and faculty, and analysis of student research portfolios and other products. Formative and summative assessments were used to modify the project during each summer and from year to year, respectively (Figure 1). The evaluation indicated that the REUBC met its goals. Based on focus groups and the online final survey (78% response rate), interns indicated satisfaction with all aspects of the project. Three students from early cohorts returned in subsequent summers at their own expense to mentor new interns informally and continue their research, and one returned on a “Research Experiences for Teachers” supplement, indicating their engagement in the project. Students agreed that they learned the importance of geohistorical data in conservation biology; many methods and tools useful in addressing conservation issues; and soft skills such as reading the literature,
For instance, 78–83% of respondents reported large or very large gains in research skills (e.g., formulating a question, making observations, analyzing data), ability to collaborate (89%), and communication skills (78%). Students reflected:

**This REU helps you to grow as researcher but also as a person. It will help you to trust yourself and develop skills you never thought you knew you had.**

This research experience helped to confirm my interest and excitement for scientific research into anthropogenic change.

The knowledge and experience that I gained as well as the guidance and support provided by faculty and my fellow interns assisted me in developing an interdisciplinary research study and methodology suitable for publication as well as my honors thesis research project. Each ... assisted me in my evolutionary process, moving from the role of student to that of professional.

This REU has provided me with opportunities and experiences I thought I would not receive until after graduating college. Being able to apply to graduate school with a possible publication is a huge help. While at this REU I have also been able to combine many different disciplines and learn how they are all intertwined. Not only was [I] able to expand my knowledge of paleontology, I was also able to incorporate biology, geology, and archeology to have a more complete understanding of how our environment and the organisms in it changes. This REU has allowed me to begin a project and see it out until the end, mainly on my own, which has given me the confidence I needed for a career in the scientific world.

The evaluator reported to NSF that fulfillment of “the goal of the program to recruit a diverse group of students and engage them in multidisciplinary experiences was evident in the interview data” and that “all of the students were satisfied with the research experiences, diversity of participants and faculty, and are in the process of presenting and publishing their research findings.” In total, 26 of 27 students prepared posters for one or more GSA meetings, and 25 students attended and presented their work (one was absent due to studying abroad). To date, nearly 80 abstracts and five peer-reviewed papers related to this work have been published, with more in preparation. All participants indicated an interest in pursuing graduate study and 20 (74%) have completed or are pursuing graduate degrees, including seven at PhD level. All six Hispanic and two of three African American students completed advanced degrees or are currently in graduate school. One student served as an environmental policy intern at the Obama White House and now holds a management position with an environmental NGO; four teach science at secondary, community college, or university levels, and one holds a science-policy postdoctoral fellowship from the National Academies of Sciences’ Gulf Research Program. Others are employed in science or related fields (e.g., GIS, environmental permitting, National
Ecological Observatory Network; two are medical doctors). Only four of 27 students did not pursue additional training, internships, or employment in STEM-related fields.

### 2.5 Project shortcomings

Despite the successes indicated by student retention in STEM and even in fields directly related to environmental management and conservation, evolution of CPB thinking since the REUBC has allowed us to identify deficiencies in our program. The greatest shortcoming of the REUBC was failure to cross the research-implementation gap. In conducting the REUBC, we emphasized demonstrating the importance of geohistorical knowledge in conservation biology and teaching research methods and soft skills useful in the conservation world. The environmental studies faculty member led a field trip focused on anthropogenic disturbance and management issues at a local beach community; each summer we also held several discussions of the environmental management implications of our research, providing students who might eventually hold positions in environmental management with a scientific foundation for conservation decisions. Nevertheless, in the evaluator’s final report to NSF she commented that some students would have liked “more in-depth conversations about environmental management issues.”

We realize now that, even had we held more such conversations, their impact would have been limited because we lacked a vehicle for our data to make a difference in the conservation world. Even our live-dead studies, with their potential to detect areas of anthropogenic eutrophication, are unlikely to be used in conservation decisions because of our failure to connect with conservation practitioners and establish a translational science partnership. Thus, the research-implementation gap remains.

In addition, our attempt to assemble transdisciplinary teams, though unusual among REU projects, omitted a key component: the human dimension of conservation training in such fields as economics, political science, sociology, and planning. Management decisions are not based solely on scientific data but must also consider stakeholder perspectives (see e.g., Pinel, López Rodriguez, Morocho Cuenca, Astudillo Aguillar, & Merriman, 2018); societal context may constrain implementing the solution best supported by the scientific results (Hallett et al., 2017; Kelley et al., 2018; Schwartz et al., 2017). Compromise will be necessary (Dietl & Flessa, 2018).

### 3 DESIGNING A BETTER CONSERVATION TRAINING EXPERIENCE

Given what we know now, how would we modify the REUBC to provide students with a translational science experience that better prepares them for careers in conservation? Rather than conducting research that we think should be useful in conservation biology, we would partner with practitioners to determine their needs (Boyer et al., 2017; Enquist et al., 2017; Flessa, 2017; Hallett et al., 2017). This approach (Figure 1) requires establishing contacts with local organizations and environmental managers to determine what problems need to be addressed and what data would help them address these problems, and to involve them in designing the research around those needs (Knight et al., 2008; Lang et al., 2012; Toomey et al., 2017). Such research into issues identified by, and done collaboratively with, the community, has been referred to as “community-based research” (Dunbar, Terlecki, Watterson, & Ratmansky, 2013; Israel, Schulz, Parker, & Becker, 1998). In community-based research, researchers collaborate with the community (in our case the conservation community, which might include local businesses, NGOs, government agencies, concerned citizens, and other stakeholders) through all stages of the research, from conceiving, planning, and conducting the research to disseminating and applying the results to address the problem (Israel et al., 1998).

The first step in this process may be the most challenging: establishing a link with local organizations and making a convincing case for the utility of the science (in our case, geohistorical data; Smith et al., 2018). Because trust must be established among the partners (Enquist et al., 2017; Hallett et al., 2017), building upon existing connections may hold promise. For example, some conservation scientists already have research partnerships with agencies or managers around which to frame an REU. Universities may also have agreements with organizations that offer internships to individual students, upon which REU collaborations can be built. Some universities include regional or civic engagement and service learning in their mission, with offices that facilitate such activities (Kelley et al., 2018). Connections with partners may take months or even years to develop; partnership building should begin in the earliest stages of planning a conservation training experience. Prior to undertaking a full-scale REU, it may be useful to offer a research experience that is more limited in scope (e.g., a course-based undergraduate research experience; Auchincloss et al., 2014; Corwin, Graham, & Dolan, 2015; Kelley, 2018).

Establishing connections with partners is only the first step; Enquist et al. (2017) argued that trust depends on communication among partners that allows multidirectional sharing of knowledge, commitment of all parties to the science translation process, and continued engagement in this process. Through this long-term process, knowledge is developed collaboratively by partners within a decision-framing context that leads to action. In the case of an REU, communication of students with REU personnel and community partners should be initiated as early as possible. We recommend holding pre-site virtual meetings, followed by face-to-face interactions with community partners as soon as students arrive on-site. Beginning the communication
process with partners before students arrive will maximize the time available on-site for conducting research, including designing the research with input from the partners.

In developing use-driven research, we would expand transdisciplinary collaboration to include what Jacobson (1990) termed the social environment (e.g., economics, political science, sociology, philosophy), the applied management sciences, and the implementational environment (e.g., planning, communication). In addition to involving practitioners (managers and planners) and stakeholders from the community, we would recruit students from outside the natural sciences. Such an approach to research is not without challenges (Pooley et al., 2014); not only is the knowledge base disparate (as occurred in the REUBC), but methodologies, values, and philosophies also differ among disciplines, and communication across disciplines is paramount. Nevertheless, negotiating and implementing such research would provide students with a more realistic view of doing conservation on the ground. Students would also acquire skills useful in crossing the research-implementation gap (Cook et al., 2013), such as project management, leadership, networking, communication, policy analysis, negotiation, group facilitation, conflict resolution, decision making, and fundraising (Kelley et al., 2018; Schwartz et al., 2017).

But is such an approach feasible? Given the time constraints of an REU, how can interactions with community partners, expanded disciplinary content, and academically diverse participants be accommodated without sacrificing meaningful research? The REUBC lasted 8 weeks, divided equally between group work and individual projects, which most students continued during the academic year. We suggest the following adjustments. (a) Operate the site for 10 weeks (as occurs already in many REU projects). (b) Require students to attend virtual meetings with partners (see above) and complete background readings before arriving on-site. (c) As in the REUBC, use lectures and mini-workshops to introduce interns to unfamiliar disciplines. However, each student need not become an expert in each discipline. Instead, (d) allow students to contribute their own disciplinary expertise to group projects, such that students further the collective goal while becoming familiar with other disciplines. Note that this approach involves de-emphasizing individual projects, which are the focus of most REU projects. (e) Conduct multi-year projects, so that each cohort can build on work done in previous years, thus increasing the utility and meaningfulness of the research.

A few REU sites already follow such an approach. For example, the NSF “REU in Community GIS and Citizen Science,” for which Visaggi is co-PI, is a transdisciplinary collaborative project involving stakeholders in addressing coastal management issues such as marine debris (see Box 1). The project involves faculty and student researchers from the United States and Belize, NGOs, and community members from the village of Hopkins, Belize. Students, faculty, and staff represent a range of disciplines (sociology, GIS, urban planning, marine science, geology, geography, environmental science, sustainability, public health, anthropology, and biology), allowing issues to be attacked from different perspectives. Expectations of all parties were discussed before and at the start of the REU, and a memorandum of understanding (MOU) was developed with the village council under the leadership of the PI; the goal was to work with local citizens to collect data meaningful to both them and the academic community. The MOU, signed by student and faculty participants and the village council chair, included a purpose statement, a statement of collaboration, and information regarding what would and would not be included among deliverables. Student deliverables include interviewing village members, incorporating their perspectives in designing geodatabases, and providing reports to the community that emphasize major findings important to the village (instead of only presentations at conferences in the United States).

The proposed approach (and that of the REUBC) is very different from that of typical REU projects (Figure 1). The current REU solicitation (NSF, 2013) stresses the importance of interactions between students and mentors, and indeed REUs excel at providing such attention to individual students, with positive outcomes regarding student educational and scientific success (Wilson et al., 2018). However, despite the claim that NSF prioritizes interdisciplinary research (NSF, 2018c), teamwork by REU interns across (and even within!) disciplines is
Box 1. Community-based REU model: The marine debris crisis

Environmental destruction from anthropogenic marine debris is a crisis threatening ecosystems worldwide. Economic, health, and ecological impacts of marine debris are global, with insufficient management of refuse being particularly problematic in developing nations (STAP, 2011). Plastics comprise the majority of marine debris, with detrimental effects for wildlife (e.g., fatalities due to digestion blockages or strangulation) and humans who rely heavily on seafood, which may contain microplastics, for sustenance. Marine debris affects tourism and fishing, which provide revenue for many coastal villages, such as the small community of Hopkins, Belize.

At the beginning of the REU in Community GIS and Citizen Science, data were collected on perceptions in the Hopkins community concerning marine debris, to better understand high concentration locations, reasons marine debris was a concern, factors contributing to the problem, and how community members thought the problem could be addressed. This local input identified issues of which the researchers were unaware, such as how debris accumulations pool standing water that invites mosquitoes, and that natural debris (e.g., cut coconuts discarded from a factory up river) concerned villagers as much as plastics washed ashore or dumped nearby. Once issues were identified, students worked with community members to gather data on the composition and distribution of marine debris on local beaches; debris patterns were analyzed relative to land use, and site-suitability analyses yielded recommendations on where hot spots of debris were concentrated, enabling improved waste management efforts.

Support from the village council and participation of community members in data design, collection, and mapping (Figure 4) provided more meaningful, translational research experiences for the students, who could observe how their results were shaping future directions in the village. Furthermore, involvement of community members, and especially the youth of Hopkins, created a sense of ownership of the work among local citizens. Citizens and students gained new skills and knowledge that will empower them moving forward.

The success of the Community GIS project depends on trust among partners, including REU personnel, REU students, and Belize personnel (from government agencies, NGOs, University of Belize, the village council, and local citizens). For several years prior to developing the REU, a study abroad program, involving students in small GIS projects, was used to initiate contacts with partners in Belize, cultivate these partnerships, and build credibility. Repeated contact and honoring of promises served to demonstrate long-term commitment by REU personnel to the project. Subsequent buy-in by the village council and other local groups then facilitated citizen recruitment. Both personal conversations with local businesses and structured events (e.g., an open house at the community center, a youth academy on flying drones) encouraged citizen participation in the project.

4 | RECOMMENDATIONS

The REUBC was a first step toward an overall goal to build a diverse pool of students who were comfortable working in transdisciplinary teams and aware of issues in biodiversity conservation, and who could develop innovative approaches to addressing these issues. More projects like ours, in which undergraduate students from varied academic backgrounds collaborate with each other and not just one-on-one with a mentor, are needed. We recommend that NSF be proactive in promoting to REUs this admittedly more cumbersome but ultimately more valuable (and, in NSF parlance, transformative) approach. In developing such training in the conservation sciences, the goal should be to give students real-world experience that matters, by working with conservation practitioners, local organizations, and community members in translational science partnerships. In other words, training must be transdisciplinary, team-focused, and yield actionable results. Students need to acquire not only scientific research experience but also soft skills required for conservation careers. REU projects that involve students in
transdisciplinary teamwork with real-world applications can help meet these goals. Conservation paleobiologists are primed to lead the way in these endeavors.

ACKNOWLEDGMENTS
We thank the editors and two anonymous reviewers for their thoughtful comments and Helaina Blume and John Gamble for advice and help with figures. The Research Experiences for Undergraduates in Biodiversity Conservation was funded by NSF grant EAR-0755109. Data analyzed in this paper concerning NSF REU awards were downloaded from the NSF website and are included in the Supporting Information.

AUTHORS’ CONTRIBUTIONS
Kelley and Dietl were Principal Investigator and co-Principal Investigator, respectively, and Visaggi was a PhD student who assisted in all aspects of the program. The REU in Community GIS and Citizen Science is funded by NSF grant SMA-1560015 (PI T. Hawthorne, co-PI C. Visaggi). All authors were involved in developing the ideas presented in this paper. Kelley drafted the manuscript and Dietl and Visaggi contributed to the writing and editing of the manuscript. All authors approved the final version of the manuscript.

CONFLICT OF INTEREST
The authors declare no conflict of interest.

ORCID
Patricia H. Kelley ★ https://orcid.org/0000-0003-1319-0571
Gregory P. Dietl ★ https://orcid.org/0000-0003-1571-0868

REFERENCES
Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T. S., Sierro, A., Watson, J. E. M., & Braunisch, V. (2010). From publications to public actions: When conservation biologists bridge the gap between research and implementation. *Bioscience*, 60, 835–842.

Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., Hanauer, D. L., ... Dolan, E. L. (2014). Assessment of course-based undergraduate research experiences: A meeting report. *CBE Life Sciences Education*, 13(1), 29–40.

Blickley, J. L., Deiner, K., Garbach, K., Lacher, L., Meek, M. H., Porensky, L. M., ... Schwartz, M. W. (2012). Graduate student’s guide to necessary skills for nonacademic conservation careers. *Conservation Biology*, 27, 24–34.

Boyer, A. G., Brenner, M., Burney, D., Dunbar, D., Terlecki, M., Watterson, N., & Ratmansky, L. (2013). An honors interdisciplinary community-based research course. *Honors in Practice, Online Archive*, 176, 129–140. http://digitalcommons.unl.edu/nchchip/176

Enquist, C. A. F., Jackson, S. T., Garfin, G. M., Davis, F. W., Gerber, L. R., Littell, J. A., ... Shaw, M. R. (2017). Foundations of translational ecology. *Frontiers in Ecology and the Environment*, 15, 541–550.

Fall-Krzesinski, H. J., Börner, K., Contractor, N., Fiore, S. M., Hall, K. L., Keynton, J., ... Uzzi, B. (2010). Advancing the science of team science. *Clinical and Translational Science*, 3(5), 263–266. https://doi.org/10.1111/j.1752-8627.2010.00223

Dietl, G. P., & Flessa, K. W. (2013a). Introduction. In G. P. Dietl & K. W. Flessa (Eds.), *Conservation paleobiology: Science and practice* (pp. 1–3). Chicago: University of Chicago Press.

Dietl, G. P., & Flessa, K. W. (eds.). (2017b). *Conservation paleobiology: Science and practice*. Chicago: University of Chicago Press.

Dietl, G. P., & Flessa, K. W. (2018). Should conservation paleobiologists save the world on their own time? In C. L. Tyler & C. L. Schneider (Eds.), *Marine conservation paleobiology* (pp. 11–22). New York, NY: Springer.

Dietl, G. P., Kidwell, S. M., Burney, D. A., Brenner, M., Flessa, K. W., Jackson, S. T., & Koch, P. L. (2015). Conservation paleobiology: Leveraging knowledge of the past to inform conservation and restoration. *Annual Review of Earth and Planetary Sciences*, 43, 79–103.

Dunbar, B., Terlecki, M., Watterson, N., & Ratmansky, L. (2013). An honors interdisciplinary community-based research course. *Honors in Practice, Online Archive*, 176, 129–140. http://digitalcommons.unl.edu/nchchip/176

Enquist, C. A. F., Jackson, S. T., Garfin, G. M., Davis, F. W., Gerber, L. R., Littell, J. A., ... Shaw, M. R. (2017). Foundations of translational ecology. *Frontiers in Ecology and the Environment*, 15, 541–550.

Fall-Krzesinski, H. J., Börner, K., Contractor, N., Fiore, S. M., Hall, K. L., Keynton, J., ... Uzzi, B. (2010). Advancing the science of team science. *Clinical and Translational Science*, 3(5), 263–266. https://doi.org/10.1111/j.1752-8627.2010.00223

Dietl, G. P. (2016). Brave new world of conservation paleobiology. *Trade in Ecology and Evolution*, 4, 1–3. https://doi.org/10.3389/fevo.2016.00021

Dietl, G. P., & Flessa, K. W. (2017a). Introduction. In G. P. Dietl & K. W. Flessa (Eds.), *Conservation paleobiology: Science and practice* (pp. 1–3). Chicago: University of Chicago Press.

Dietl, G. P., & Flessa, K. W. (Eds.). (2017b). *Conservation paleobiology: Science and practice*. Chicago: University of Chicago Press.

Dietl, G. P., & Flessa, K. W. (2018). Should conservation paleobiologists save the world on their own time? In C. L. Tyler & C. L. Schneider (Eds.), *Marine conservation paleobiology* (pp. 11–22). New York, NY: Springer.

Dietl, G. P., Kidwell, S. M., Burney, D. A., Brenner, M., Flessa, K. W., Jackson, S. T., & Koch, P. L. (2015). Conservation paleobiology: Leveraging knowledge of the past to inform conservation and restoration. *Annual Review of Earth and Planetary Sciences*, 43, 79–103.

Dunbar, B., Terlecki, M., Watterson, N., & Ratmansky, L. (2013). An honors interdisciplinary community-based research course. *Honors in Practice, Online Archive*, 176, 129–140. http://digitalcommons.unl.edu/nchchip/176

Enquist, C. A. F., Jackson, S. T., Garfin, G. M., Davis, F. W., Gerber, L. R., Littell, J. A., ... Shaw, M. R. (2017). Foundations of translational ecology. *Frontiers in Ecology and the Environment*, 15, 541–550.

Fall-Krzesinski, H. J., Börner, K., Contractor, N., Fiore, S. M., Hall, K. L., Keynton, J., ... Uzzi, B. (2010). Advancing the science of team science. *Clinical and Translational Science*, 3(5), 263–266. https://doi.org/10.1111/j.1752-8627.2010.00223

Della, K. W. (2017). Putting the dead to work: Translational paleoecology. In G. P. Dietl & K. W. Flessa (Eds.), *Conservation paleobiology: Science and practice* (pp. 283–289). Chicago: University of Chicago Press.

Hallett, L. M., Morelli, T. L., Gerber, L. R., Moritz, M. A., Schwartz, M. W., Stephenson, N. L., ... Woodhouse, C. A. (2017). Navigating translational ecology: Creating opportunities for scientist participation. *Frontiers in Ecology and the Environment*, 15, 578–586.

Israel, B. A., Schulz, A. J., Parker, E. A., & Becker, A. B. (1998). Review of community-based research: Assessing partnership approaches to improve public health. *Annual Review of Public Health*, 19, 173–202.

Jacobson, S. K. (1990). Graduate education in conservation biology. *Conservation Biology*, 4, 431–440.

Jacobson, S. K., & Robinson, J. G. (1990). Training the new conservationist: Cross-disciplinary education in the 1990s. *Environmental Conservation*, 17, 191–327.

Jarvis, R. M., Borrelle, S. B., Breen, B. B., & Towns, D. R. (2015). Conservation paleobiology roundtable: From promise to application. In G. P. Dietl & K. W. Flessa (Eds.), *Conservation paleobiology: Science and practice* (pp. 291–302). Chicago: University of Chicago Press.

Briskie, D. D. (2012). Translational science partnerships: Key to environmental stewardship. *Bioscience*, 62, 449–450.

Brunson, M. W., & Baker, M. A. (2015). Translational training for tomorrow’s environmental scientists. *Journal of Environmental Studies and Sciences*, 6, 295–299.

Chapron, G., & Arlettaz, R. (2008). Conservation: Academics should “conserve or perish”. *Nature*, 451, 127–127.
Knight, A. T., Cowling, R. M., Rouget, M., Balmford, A., Lombard, A. T., & Campbell, B. M. (2008). Knowing but not doing: Selecting priority conservation areas and the research-implementation gap. Conservation Biology, 22, 610–617.

Lang, D. J., Wiek, A., Bergmann, M., Staffacher, M., Martens, P., Moll, P., … Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. Sustainability Science, 7(Supplement 1), 25–43.

Ledford, H. (2015). Team science. Nature, 525, 308–311.

Lucas, J., Gora, E., & Alonso, A. (2017). A view of the global conservation job market and how to succeed in it. Conservation Biology, 31, 1223–1231.

Molveni, M. J., Capps, K. A., Johnson, M. S., Maul, J., McIntyre, P. B., Melvin, A. M., … Weiss, M. (2009). Training tomorrow’s problem solvers: An integrative approach to graduate education. Bioscience, 59, 514–521.

Muir, M. J., & Schwartz, M. W. (2009). Academic workplace: A case study of graduate student alumni who work in conservation. Conservation Biology, 23, 1357–1368.

NSF (National Science Foundation). (2013). Research Experiences for Undergraduates (REU) sites and supplements program solicitation NSF 13-542. Retrieved from www.nsf.gov/pubs/2013/nsf13542/nsf13542.htm#pgm_desc_txt.

NSF (National Science Foundation). (2018a). For faculty. Retrieved from www.nsf.gov/od/oia/additional_resources/interdisciplinary_research/index.jsp.

NSF (National Science Foundation). (2018b). Research Experiences for Undergraduates (REU). Retrieved from www.nsf.gov/funding/pgm_summ.jsp?pims_id=5517.

NSF (National Science Foundation). (2018c). Introduction to interdisciplinary research. Retrieved from www.nsf.gov/od/oa/additional_resources/interdisciplinary_research/index.jsp.

Newing, H. (2010). Interdisciplinary training in environmental conservation: Definitions, progress and future directions. Environmental Conservation, 37, 410–418.

Pietri, D. M., Gurney, G. G., Benitez-Vina, N., Kuklok, A., Maxwell, S. M., Whiting, L., … Jenkins, L. D. (2013). Practical recommendations to help students bridge the research-implementation gap and promote conservation. Conservation Biology, 27, 958–967.

Pinel, S. L., López Rodriguez, F., Morocho Cuenca, R., Astudilllo Aguilar, D., & Merriman, D. (2018). Scaling down or scaling up? Local actor decisions and the feasibility of decentralized environmental governance: A case of Paramo wetlands in southern Ecuador. Scottish Geographical Journal, 134, 45–70.

Pooley, S. P., Mendelsohn, J. A., & Milner-Gulland, E. J. (2014). Hunting down the chimera of multiple disciplinarity in conservation science. Conservation Biology, 28, 22–32.

Savarese, M. (2018). Effectively connecting conservation paleobiological research to environmental management: Examples from the greater Everglades restoration of Southwest Florida. In C. L. Tyler & C. L. Schneider (Eds.), Marine conservation paleobiology (pp. 55–73). New York, NY: Springer.

Schwartz, M. W., Hiers, J. K., Davis, F. W., Garfin, G. M., Jackson, S. T., Terando, A. J., … Brunson, M. W. (2017). Developing a transatlantic ecology workforce. Frontiers in Ecology and the Environment, 15, 587–596.

Smith, J. A., Durham, S. R., & Dietl, G. P. (2018). Conceptions of long-term data among marine conservation biologists and what conservation paleobiologists need to know. In C. L. Tyler & C. L. Schneider (Eds.), Marine conservation paleobiology (pp. 23–54). New York, NY: Springer.

STAP (Scientific and Technical Advisory Panel). (2011). Marine debris as a global environmental problem: Introducing a solutions based framework focused on plastic. A STAP information document. Washington, DC: Global Environment Facility.

Toomey, A. H., Knight, A. T., & Barlow, J. (2017). Navigating the space between research and implementation in conservation. Conservation Letters, 10, 619–625.

Turner, B. L., II, Esler, K. J., Bridgewater, P., Tewksbury, J., Situs, N., Abrahams, B., … Mooney, H. (2016). Socio-environmental systems (SES) research: What have we learned and how can we use this information in future research programs. Current Opinion in Environmental Sustainability, 19, 160–168.

Tyler, C. L., & Schneider, C. L. (2018). An overview of conservation paleobiology. In C. L. Tyler & C. L. Schneider (Eds.), Marine conservation paleobiology (pp. 1–10). New York, NY: Springer.

Wilson, A. E., Pollock, J. L., Billick, I., Domingo, C., Fernandez-Figueroa, E. G., Nagy, E. S., … Summers, A. (2018). Assessing science training programs: Structured undergraduate research programs make a difference. BioScience, 68, 529–534. https://doi.org/10.1093/bioscip/biy052

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Kelley PH, Dietl GP, Visaggi CC. Model for improved undergraduate training in translational conservation science. Conservation Science and Practice. 2019;1:e5. https://doi.org/10.1002/csp2.5