BioScience Advance Access published April 13, 2016

At a Crossroads: The Nature of Natural History in the Twenty-First Century

CAMERON W. BARROWS, MICHELLE L. MURPHY-MARISCAL, AND REBECCA R. HERNANDEZ

The relevance of natural history is challenged and marginalized today more than ever. We addressed the hypothesis that natural history is still relevant to the field of ecology by assessing the attitudes and perceptions related to natural history by early-career scientists and environmental-science professionals across 31 universities in California. Early-career scientists surveyed agreed that natural history is relevant to science (93%), and approximately 70% believed it "essential" for conducting field-based research; however, 54% felt inadequately trained to teach a natural-history course and would benefit from additional training in natural history (more than 80%). Of the 185 professionals surveyed, all felt that natural history is relevant to science and "essential" or "desirable" in their vocation (93%). Our results indicate a disconnection between the value and relevance of natural history in twenty-first-century ecological science and opportunities for gaining those skills and knowledge through education and training.

Keywords: ecology, education, field-based research, natural history, survey

Natural history **can be broadly defined as the** observational study of organisms in their environment. For those who may call themselves *naturalists*, its practice spans a wide range and intensity of activities, from recreational bird watching and botanizing to following structured protocols while collecting data on the presence, abundance, and distribution for any measure of biodiversity. Within a scientific framework, natural history fosters the establishment of transdisciplinary connections among species, habitats, and ecosystems, as well as the abiotic fabric on which those biotic elements exist. Despite this foundational nature, a shift has been occurring in ecology away from teaching and research rooted in natural history and toward modeling, laboratory, and theoretic research—disciplines that currently attract larger grant funding and result in publications in higher-impact journals (Greene and Losos 1988, Noss 1996, Wilcove and Eisner 2000, Pyle 2001, Schmidly 2005, Tewksbury et al. 2014). Natural history and theory, modeling, or laboratory research are becoming increasingly dichotomous when, in reality, their fusion should be complementary, if not required, to ensure that conceptual or experimental findings are consistent with the complexities of nature (Lazcano 2011). For decades, natural-history courses have awakened students to that complexity and the multitude of unanswered questions in the natural environment—an experiential, often revelatory observation-based learning that propelled them from other fields into ardent and dedicated careers in ecology. The relevance of natural history went beyond recruiting passionate, bright minds. Natural history has long been the underpinning for ecological research, providing the foundation from which ecological theories, discoveries, and conservation activities have spawned and later evolved. Here, we explore two distinct questions: Do attitudes regarding the importance of natural history in ecological research indicate a continued relevance by twenty-first-century scientists, and are colleges and universities providing the coursework and support for natural history commensurate with that relevance?

Naturalist pioneers

The nineteenth century saw the emergence of naturalists as a respected component of the scientific community. Although their efforts filled museum cabinets, several of note, including Charles Darwin (Egerton 2011) and Alfred Russel Wallace (Slotten 2004), were explicit in placing their observations and collections within a theoretical framework. Their combined work created the foundation for what would emerge as the ecological disciplines of biogeography and evolutionary ecology.

One of the twentieth century's most prolific ecological theoreticians was Robert MacArthur. His graduate advisor and a theoretician of equal standing, G. E. Hutchinson

BioScience XX: 1–8.
doi:10.1093/biosci/biw043 Advance Access publication XX Xxxx XXXX

(1975), reflecting on MacArthur's career, unfortunately cut far too short, stated, "Modern biological education may let us down as ecologists if it does not insist, and it still shows too few signs of insistence, that a wide and quite deep understanding of organisms, past and present, is a basic requirement of anything else in ecological education. It may be best self-taught, but how often is this difficult process made harder by a misplaced emphasis on a quite specious modernity. Robert MacArthur really knew his warblers" (p. 516). Here, Hutchinson underscores the role that natural history plays in the first-hand observations of the distributions of species. Such observations are fodder for questioning whether those observations are consistent with the theoretical framework that modernity confers—and if not, for developing new theories that better explain the patterns of nature and therefore more accurately predict the effects of environmental change. In our training of new scientists, if we explicitly represent natural history as passé or imply it by omission from our curricula, we may, without new observations testing the status quo of theories, provide little opportunity to advance the discipline of ecology. The twentieth century is punctuated with theoretical advances, similar to the work of MacArthur, that have changed the course of ecology. George Grinnell (ecological niche; Grinnell 1917), Ellen Swallow Richards (mineralogy, air and water quality; "the woman who founded ecology"; Clarke 1973), Hutchinson (limnology, population ecology, niche theory, the "father of modern ecology"; Slack 2011), Eugene Odum (ecosystem ecology; Craige 2001), Edith Schwartz Clements (climax theory, vegetation science; Langenheim 1996), Ruth Patrick (island biogeography, aquatic ecology; Langenheim 1996), MacArthur (island biogeography, competition, foraging theory), E. O. Wilson (island biogeography, sociobiology, biodiversity; Wilson 1994), and Rachel Louise Carson (marine biology, founder of environmentalism; Leisher 2008) all self-identified as "naturalists" without reservation. Arguably, or perhaps undeniably, it was natural history that allowed these pioneers, as well as their academic progeny and others, to formulate the most important scientific advances in ecology of their time.

Natural history in an academic setting

Today, research universities scrutinize prospective environmental science faculty candidates, weighing in particular their potential to produce impactful publications and secure large external grants. When can any of us recall a job posting for an academic, tenure-track faculty position that mentioned a transdisciplinary background in natural history as a selection criterion? That omission may exclude those self-identified naturalists and in doing so may be affecting our field in ways we have yet to fully understand. If natural history has lost relevance and has been relegated to the dusty shelves of museums and the weekend pursuits of amateur enthusiasts, then this academic hiring trajectory is justified. However, if it is relevant and arguably constitutes the building blocks for fostering the development of the next Robert MacArthur, E. O. Wilson, or Ruth Patrick, then we should reconsider the path we are on.

We posed the question, "Is teaching basic natural history skills at colleges and universities still relevant?" in an online forum (*https://goo.gl/JWRrOr*); none disagreed, and over 75% of contributors affirmed that natural history is still applicable. The discussion is far from over, but we wonder whether the recent and current university hiring objectives are handicapping a generation of early-career scientists who are not being taught the value and skills encompassing natural history and observation in the environment. In that Hutchinsonian sense, we may be stunting ecological advances by not valuing natural history. Will it be increasingly rare that someone, reflecting on a colleague's rich scientific career, as Hutchinson did with Robert MacArthur, link their deep knowledge of birds, lizards, plants, or fungi to new insights yielding theoretical advances? This is an important ongoing dialogue in which emerging perspectives have rebuffed natural history as *démodé* whereas others assert that its departure coincides with a reductionist approach to science (Lazcano 2011, Tewksbury 2014).

Assessing the relevance of natural history: A quantitative approach

Quantitative survey methods are increasingly used and relevant in ecology to assess, for example, public or stakeholder attitudes, historical and future decisions in ecological management, the needs of humans in reducing human–wildlife conflicts, and the nature and evolution of the field itself (White et al. 2005, Hernandez et al. 2012). Drawing from such methodologies, we sought to assess views of the relevance of natural history using a survey for *early-career scientists*, defined as master's and doctoral graduate students enrolled in or recently graduated from (within 5 years) academic departments related to the environmental or ecological sciences at academic institutions in California (supplemental material S1). Using online surveys, we partitioned our first overarching question, "Do attitudes regarding the importance of natural history in ecological research indicate a continued relevance by twenty-first-century scientists?" into two components. First, we aimed to evaluate the definition of natural history in the twenty-first century by comparing and synthesizing opinions about the activities and the extent to which they encompass natural history between and by early-career scientist and professional respondents, respectively. Second, we sought to determine the extent to which early-career scientists perceive a value of natural history across the many subdisciplines of ecology. To address our second overarching question, "Are colleges and universities providing coursework and support for natural history commensurate with its relevance?" we polled early-career scientists with questions regarding their coursework and how well that prepared them for applying natural-history skills and approaches in their scientific endeavors.

Finally, through a separate survey, we asked how potential employers—professional environmental scientists and

ecologists—valued a foundation in natural history. We wanted to evaluate whether natural-history skills would be of use once students earned their graduate degrees and entered the workforce, both in and outside academia. Our survey for workforce professionals (supplemental material S2) included questions tailored to a professional workplace environment but complementary to the early-career survey. We sent this survey solicitation to faculty and professionals in academia, environmental consulting firms, government agencies, and nongovernmental organizations. The professional participants who responded with a "no" answer to the question, "Does the field in which you are currently employed fall within the environmental, biological, or ecological sciences?" were removed from our analysis ($n = 5$).

Survey methods. Following the procedure conducted by Hernandez and colleagues (2012), we solicited survey responses via email, from July 2014 to February 2015, with a click-through link to the online, survey-based research platform, Qualtrics (*www.Qualtrics.com*). According to survey methodology (White et al. 2005), the question and answer content and formats were as simply and clearly stated as possible. Prior to the full release of the early-career scientist survey to all academic institutions, we sent a pilot questionnaire to graduate students enrolled in one department at the lead author's home institution to evaluate question format and survey response. Early-career scientist survey invitations were then sent to 31 universities in California, including 19 public universities in the California State University (CSU) system, 9 public schools in the University of California (UC) system, and 3 private schools. CSU institutions offer research-based master's degrees and do not generally support doctoral programs, although several joint doctoral programs between CSU and UC schools do exist. All the private universities and UC institutions surveyed support both masters and doctoral programs. Private universities were those classified as research institutions by the Association of Independent California Colleges and Universities that offer an environmental- or ecology-related graduate program and that were receptive to participation. When it was possible, we sent email solicitations to graduate student electronic mailing lists within each surveyed department. If such mailing lists were not available, we collected student email addresses from online department directory pages and emailed the students directly, or we emailed faculty members within the relevant departments and asked them to forward our solicitation email to students. Follow-up email solicitations were sent to faculty members generally one month later, unless the faculty member responded to our initial email.

We acknowledge that the respondents of such surveys are not necessarily random samples and may be skewed to those who have an interest in this topic. Early-career scientist and professional surveys that were only partially completed were removed from the analysis ($n = 168$ and 65, respectively). We processed and statistically analyzed all of the survey data using scripts in R (*www.r-project.org*). Data were not normally distributed and samples sizes were small, therefore nonparametric Wilcoxon rank-sum and Fisher's exact test were used to explore data relationships. For all of the survey questions, means were derived using the number of responses for the respective survey question as a weight, and the associated margins of error (half-width of a 95% confidence interval) were reported, with the exception of the Wilcoxon rank-sum results in which the Hodges-Lehmann estimator (HL, the estimate of the difference between the two treatment groups) was reported.

Survey responses

Through our effort to reach early-career scientists, faculty, and other professionals in the ecology, environmental science, and natural-resources fields, we received completed survey responses from 212 early-career scientists and 185 professionals. Early-career scientists were asked to identify the type of institution they currently attend: 46.5% ($n = 93$) were from the CSU system, 47% ($n = 94$) were from UCs, and 6.5% ($n = 13$) were from private universities. Of the early-career scientists that had recently completed graduate school, 33.3% ($n = 4$) were from the CSU system, 41.7% ($n = 5$) were from UCs, 8.3% ($n = 1$) were from a private university within California, and 16.7% ($n = 2$) received their degrees from public institutions outside of California. Fields of study included biology, evolution, population biology, ecology, plant science, environmental science, and entomology (table 1). Professional responses comprised 38.4% ($n = 71$) academic professors, 15.2% ($n = 28$) academic full-time researchers or postdocs, 14.6% ($n = 27$) private consultants, 13.5% ($n = 25$) scientists associated with nonprofit or otherwise nongovernment conservation organizations (NGOs), 10.3% ($n = 19$) federal government and 4.3% ($n = 8$) California State agency scientists, and finally, 3.8% ($n = 7$) local government staff leads for regional conservation efforts. The majority of early-career scientists self-identified as being white/Caucasian females between 25 and 29 years of age (26.4%, $n = 56$), whereas the majority of the professional respondents self-identified as being white/Caucasian males between the ages of 35 and 54 years (23.2%, $n = 43$; supplemental table S3). "Black/African American/Caribbean" and "Native American/Alaskan native" were the least common ethnicities identified by both the early-career scientist and professional survey respondents.

Perceptions. Both the early-career scientist and professional respondents shared similar perspectives regarding natural history. At least 80% of all respondents agreed or strongly agreed that structured activities, such as describing species distributions and identifying plant pollinators, and relatively less structured activities, including observations of animal behavior and those outside of the scientific methods, encompass natural history (figure 1). In responding to the statement that natural history is relevant to science today, 93.4% (± 3.3%) of early-career scientists, and 97.3% (± 2.3%) of the professionals agreed. The professionals added that

Table 1. The programs or departments of participating early-career scientists.

Program or Department	
Biological Sciences (*n* = 71)	Environmental and Physical Sciences (*n* = 81)
Animal Behavior	Earth and Planetary Sciences
Animal Sciences	Earth Sciences
Biological Science	Earth System Science
Biology	Environment and Resources
Botany and Plant Sciences	Environmental and Occupational Health
Conservation Biology	Environmental Earth System Science
Entomology	Environmental Sciences
Forestry	Environmental Science and Engineering
Marine Biology	Environmental Science, Policy and Management
Marine Science	Environmental Studies
Plant Biology	Environmental Systems
Plant Pathology	Geography
Population Biology	Geological Sciences
Ecology and Evolution (*n* = 56)	Geology
Ecology	Geophysics
Ecology and Conservation	Geographic Information Systems
Ecology and Evolutionary Biology	Soils and Biogeochemistry
Ecology and Sustainability	Transportation Technology and Policy
Ecology, Evolution, and Conservation Biology	Declined to state (*n* = 4)
Evolution, Ecology, and Organismal Biology	
Evolutionary Biology	

natural history is relevant to their current line of work, with 92.9% (± 3.7%) saying that it was "essential" or "desirable"; none disagreed. Similarly, 96.7% (± 2.4%) of the early-career scientists felt that natural history is an "essential" or "desirable" component of field ecological research.

We asked early-career scientists whether natural history was foundational for the pursuit of a series of current topics in ecological research on a Likert scale (figure 2). General ecology, conservation biology, and restoration ecology received the top rank ("very applicable") by 90% or more of the early-career scientists (± 3.5%, 3.8%, and 4.1%, respectively). Soil microbiology, genetics, and taxonomy were top ranked by 60% or fewer of the early-career scientists (± 6.7%, 6.7% and 6.6%, respectively).

Natural history–related coursework. Based on the responses, early-career scientists had taken an average of 14 courses (range: 1–51) with potential natural-history ties while obtaining their undergraduate and graduate degrees. The majority (69.3% ± 6.2%) of early-career scientists felt their exposure to natural-history concepts and approaches was adequate to enable them to conduct or interpret ecological studies. However, just 11.1% (± 1.8%) felt their academic training alone provided that needed exposure; others were either self-taught or felt it was a combination of self-led and academic training. When asked whether their research would benefit from additional natural-history training, 80.2% (± 5.4%) answered yes. In addition, the number of natural-history courses taken influenced whether a respondent felt adequately exposed to natural-history knowledge ($p = 0.003$, Fisher's exact test). In a final related question, we asked whether the early-career scientists felt adequately trained to teach a course that included natural history; just 16.5% (± 5.0%) were confident that they could, and another 37.7% (± 6.5%) felt that they "probably could" teach such a class.

We suspected that early-career scientists with backgrounds in the environmental and physical sciences ($n = 81$; table 1) may have had less exposure to natural-history courses than had early-career scientists with biological science and ecology backgrounds ($n = 127$). When their responses were compared, Wilcoxon rank-sum tests revealed that an early-career scientist's major did not influence whether they felt natural history was relevant ($W = 5105$, $p = .836$, HL = $-2.96e^{-05}$), whether they felt adequately exposed to natural-history lessons or experiences ($W = 4609$, $p = .123$, HL = $-5.09e^{-05}$), or whether they felt their research would be benefitted by additional natural-history training ($W = 4650$, $p = .096$, HL = $-2.19e^{-05}$). However, most environmental-science majors (30.8%, $n = 25$) felt that they were "probably not" adequately trained to teach a natural-history course, whereas most biological-science and ecology majors (46.5%, $n = 59$) felt that they "probably were" ($W = 4375.5$, $p = .057$, HL = $-5.73e^{-05}$). The number of courses an early-career scientist had taken was related to whether they felt adequately trained to teach a natural-history course ($p < .001$, Fisher's exact test).

We asked the early-career scientists what classes they had taken as either an undergraduate or graduate student that were pertinent to a greater understanding of region- or biome-based natural history. Just 36.3% ($n = 77$) had taken classes in a region-based course such as California ecosystems or California natural history. The numbers were smaller for biome-based courses; deserts constitute nearly one third of California's landmass, but just 11.8% ($n = 25$) of the students had taken a course in desert ecology or the natural history of arid lands. The numbers were slightly larger for tropical biomes, in which 18.8% ($n = 40$) of the early-career scientists had taken such classes. We did not ask whether classes were available or not, just whether the early-career scientists had taken them.

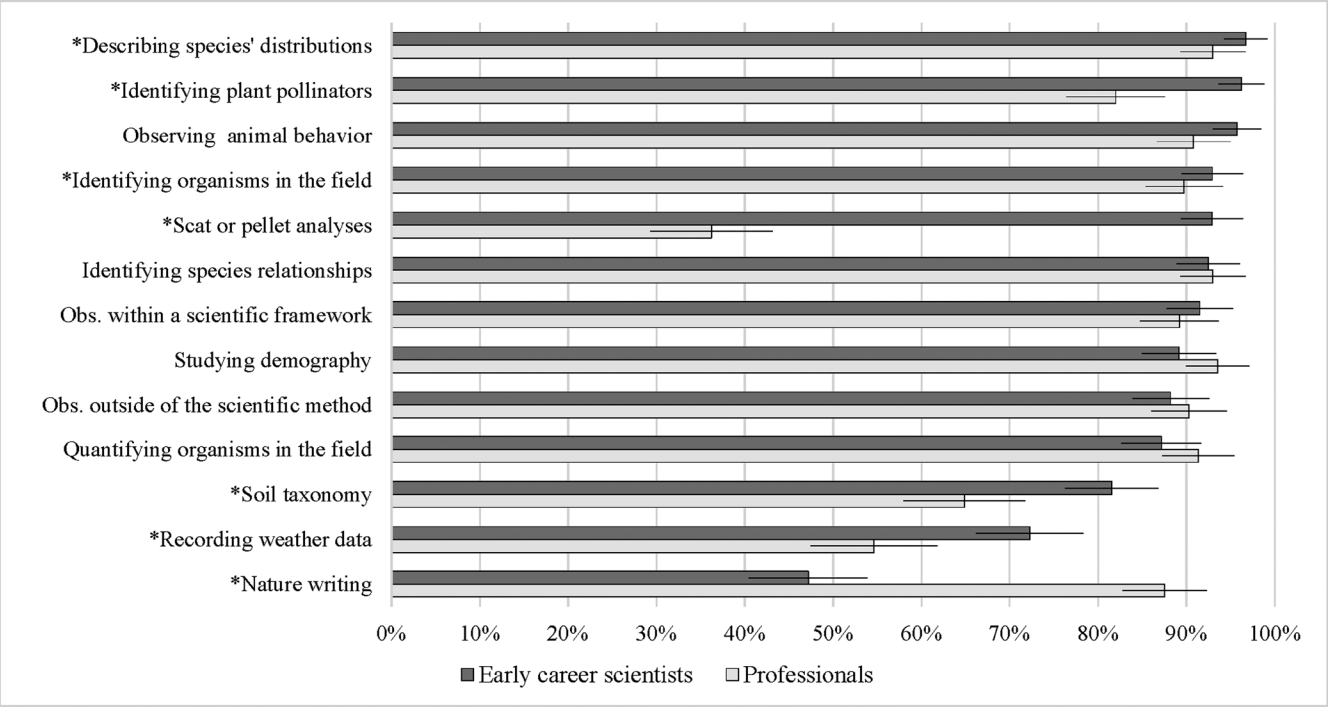

Figure 1. The survey results regarding whether the described activities encompass the term* natural history. *The percentages are those respondents indicating that they agree or strongly agree that natural history encompasses these activities. The error bars represent the margin of error (half-width of a 95% confidence interval).

We found that "interesting course content" ranked as the highest motivating factor, followed closely by "opportunities to gain desired skills" and "opportunities for exposure to natural areas and environments" behind early-career scientists' enrollment in natural-history courses that had a field component. The weakest motivation for enrollment was the perceived ease of the course compared with alternative elective course options. Of the skills obtained from those courses, the majority of early-career scientists indicated that they were required or given the opportunity to collect observational data (96.2% ± 2.6%) and analyze collected data (93.9% ± 3.2%); however, few (24.1% ± 5.8%) had been given the opportunity to participate in a citizen science–type field campaign (supplemental figure S4).

Field notebooks are essential tools for natural history–based research dating back to Dampier, Linnaeus, Wallace, Darwin, Grinnell, and E. O. Wilson (Canfield 2011, Greene 2011). Such notebooks can serve as an invaluable source of data for the development of hypotheses, proposals, and manuscripts, as well as a lasting historical archive for assessing environmental changes. As an example, Joseph Grinnell's field books, dating from the early twenthieth century have proved invaluable as a means of measuring the effects of climate change across California (Mortiz et al. 2008, Tingley and Beissinger 2009). Natural-history courses are often those in which a student is first exposed to the importance of recording field observations, whether that notebook is paper-based or a digital platform (e.g., iNaturalist), and documenting ecological changes. Promisingly, of the early-career scientists that responded to our survey, the majority—83.9% (± 4.9%)—said that they had previously taken at least one course in which they were required or given the opportunity to keep a field notebook to record observations made in the field. Whether early-career scientists continue to document field observations beyond the classroom is not known, but the foundation on which that habit can form was obtained as a result of natural-history coursework.

Putting natural-history knowledge to use. Finally, by polling professional environmental scientists and ecologists we wanted to understand whether natural-history skills would still be valued once students earned their graduate degrees and entered the workforce, both in and outside academia. We found that 81.6% (± 5.6%) of the respondents indicated that writing grants, research reports, and manuscripts for publication was a daily to monthly component of their job, whereas over half indicated that conducting field research (52.4% ± 7.2%) and identifying local plants and animals (70.3% ± 6.6%) were also regular aspects of their employment (figure 3).

When evaluating candidates for employment, the professional respondents indicated that experience writing grants, research reports, and manuscripts for publication were "very important" skills (72.0% ± 8.1%), followed by presenting results to peers (58.4% ± 8.9%; figure 3). Of skills with close

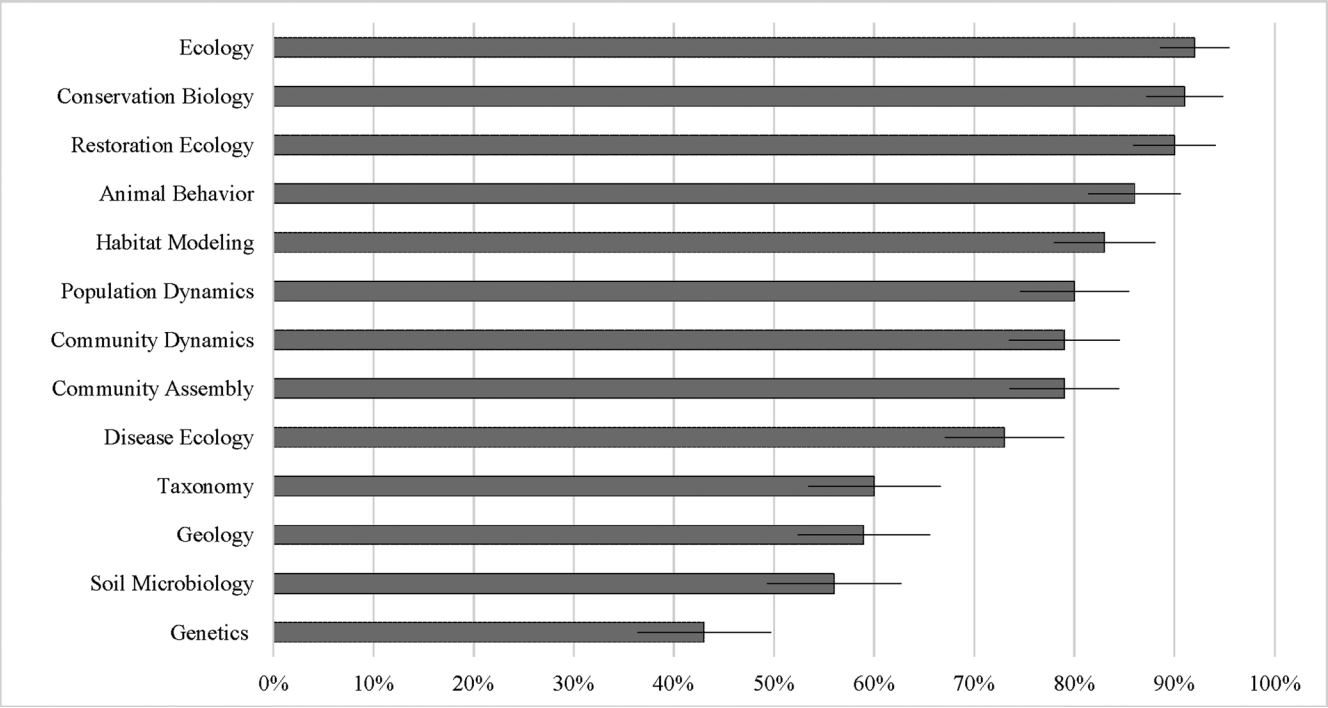

Figure 2. The early-career scientists' responses to whether natural history was foundational to current areas of active research in the ecological or environmental sciences. The percentages indicate the proportion of "very applicable" responses. The error bars represent the margin of error (half-width of a 95% confidence interval).

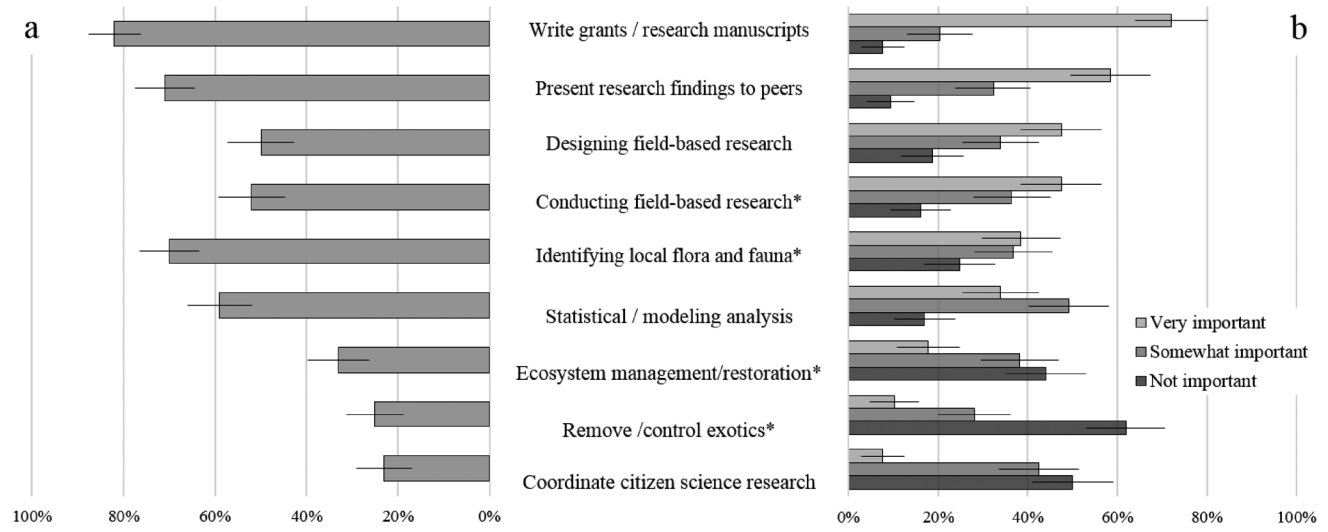

Figure 3. The proportion of responses from ecological professionals regarding (a) the frequency they employ identified skills daily to monthly in their current employment and (b) the level of importance placed on having those skills when evaluating potential employees. The asterisks (*) indicate activities with direct links to natural-history skill sets. The error bars represent the margin of error (half-width of a 95% confidence interval).

ties to natural history, professionals identified conducting and interpreting field research and identifying local plants and animals as important skills, whereas management and restoration skills were generally not. Of the skills deemed "somewhat" or "very important," the professional respondents indicated that the majority (50.8% ± 9.0%) of potential candidates generally possessed only about half of those skills.

Natural history in the twenty-first century

Surveying opinions from both students and professionals, we found similar perspectives as to the breadth of what

constituted natural history–related activities. They viewed natural history as going beyond a casual, unstructured observation of nature. Rather they saw it as an integral component of multiple types of field studies within a scientific framework with quantitative sampling and hypothesis testing. Further, we found a nearly unanimous support for the belief that natural history writ large was both relevant and foundational to the ecological sciences today. There was no indication of a dichotomy between natural history and science; rather, natural history was seen as a desirable—if not essential—tool for conducting many types of ecological research. Early-career scientists saw the value of natural history in nearly every subdiscipline of modern ecological research. Professionals also identified that value and many were still actively involved in research or related tasks that incorporated natural-history knowledge and skills. In addition, we found that early-career scientists desired more instruction in the methods and uses of natural-history skills than they were receiving; their perceived needs in this area were not being fully met by their colleges and universities. Follow-up studies evaluating the ability of novel programs such as the UC California Naturalist program (*www.CalNat.UCcanr.edu*) in mitigating or fulfilling this need would be useful. Overall, our findings document the concerns first voiced by Hutchinson (1975) and echoed by others since (Greene and Losos 1988, Noss 1996, Wilcove and Eisner 2000, Tewksbury et al. 2014).

Based on survey responses, participation in a citizen science–type field campaign was the least frequent opportunity early-career scientists obtained as part of their field-based coursework and a skill that was not highly valued by employers when evaluating a potential candidate during the hiring process. In this case, although the demand and the acquisition of the skill in question directly correspond to each other, we contend that the incorporation of citizen scientists in field ecological research is becoming an increasingly used tool, allowing sustainable data collection over large temporal and spatial scales while also providing valuable attendant benefits, such as the expansion of a more ecoliterate public (Theobald et al. 2015, Barrows et al. 2016). Acquiring skills such as engaging the public, organizing data collection by large field teams, and expanding on traditional methods of data collection may be the key to keeping natural history relevant in the twenty-first century and keeping pace with the direction of modern ecology. Modern natural historians are in a unique position to act as a bridge between science and nonscientists (Schmidly 2005) and should capitalize on the inclusion of the public in ways that will empower them to make societal changes to combat looming environmental and conservation issues.

We did not identify the individual colleges and universities that the students attended; therefore, we could not determine whether the patterns we found from our survey reflect a general pattern across all the California colleges and universities or whether some schools still value faculty with the philosophies and skills that embody natural history, whereas at others, those faculty have long since retired and been replaced by faculty with other skills. Although we have no way to test that question with our current survey, a keyword search of UC's and CSU's home pages using the term *natural history* gave support for an uneven treatment of natural history. Several UC campuses highlighted their natural-history research programs; UC Santa Cruz's Kenneth Norris Center for Natural History and UC Berkeley's California Biodiversity Center represented collaborative research centers that explicitly embraced a natural-history ethos and, along with UC Davis, highlighted classes that focused on natural history. Other campus searches directed us to their history departments, to on-campus or nearby museums, or to nothing at all. Searches of CSU websites did not yield any explicit natural history–based programs, even though some, such as Humboldt State University and CSU Fullerton, are noted for field studies.

At least for California's institutions of higher learning, our study supports the argument that natural history is relevant to environmental science in the twenty-first century: The early-career scientists and professional respondents alike placed high value on the contribution of a natural history–based skill set to a wide range of ecological research areas. Despite this perception, many feel that their institutions' support for natural history–based research and training is waning. This shift has occurred at the same time younger students are increasingly raised in cities without easy access to woodlots and parklands with natural vegetation where they might develop interests in environmental science, let alone hone natural-history skills on their own. Although our surveys were limited to California colleges and universities, based on comments to our ongoing online forum (*https://goo.gl/JWRrOr*), this issue appears to resonate at institutions for higher education worldwide.

The remaining unasked question is what to do about it? Assuming curricula are zero sum, meaning added course work necessarily would be contingent on the commensurate elimination of other courses, how do you weigh adding classes that focus on the newest theoretic paradigms, modeling techniques, or statistical approaches versus removing arguably foundational courses that introduce students to fieldwork and developing natural-history skills? Perhaps the zero-sum assumption should be challenged; adding summer or spring-break sessions at field stations that start with relevant questions and then engage students in collecting data that answer those questions would be a solution and an excellent use of often-underused field stations. Of course, hiring and retaining faculty capable and with the energy to teach such courses would also be necessary. There are countless unanswered questions remaining within the broad umbrella of ecology, and with rates of environmental change increasing, many of those questions, if left unanswered, could have dire consequences for worldwide biodiversity and ultimately for the human race. We need to support the new generation of Alfred Wallaces, G. E. Hutchinsons, Ellen Swallow Richards, Robert MacArthurs, Ruth Patricks, E. O.

Wilsons, and Rachel Carsons to address the most challenging of those questions.

Supplemental material

The supplemental material is available online at *http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/biw043/-/DC1*.

References Cited

Alreck PL, Settle RB. 2004. The Survey Research Handbook. McGraw-Hill.

Barrows CW, Hoines J, Vamstad MS, Murphy-Mariscal ML, Lalumiere K, Heintz J. 2016. Using citizen scientists to assess climate change shifts in desert reptile communities. Biological Conservation 195: 82–88.

Canfield MR. 2011. Introduction. Pages 1–18 in Canfield MR, ed. Field Notes on Science and Nature. Harvard University Press.

Clarke R. 1973. Ellen Swallow, The Woman Who Founded Ecology. Follett.

Craige BJ. 2001. Eugene Odum: ecosystem ecologist and environmentalist. University of Georgia Press.

Egerton FN. 2011. History of ecological sciences, part 40: Darwin's evolutionary ecology. Bulletin of the Ecological Society of America 92: 351–374.

Greene E. 2011. Why keep a field notebook? Pages 251–276 in Canfield MR, ed. Field Notes on Science and Nature. Harvard University Press.

Greene HW, Losos JB. 1988. Systematics, natural history, and conservation: Field biologists must fight a public-image problem. BioScience 38: 458–462.

Grinnell J. 1917. The niche-relationships of the California thrasher. Auk 34: 427–433.

Hernandez RR, Mayernik MS, Murphy-Mariscal ML, Allen MF. 2012. Advanced technologies and data management practices in environmental science: Lessons from academia. BioScience 62: 1067–1076.

Hutchinson GE. 1975. Variations on a theme by Robert MacArthur. Pages 492–521 in Cody ML, Diamond JM, eds. Ecology and Evolution of Communities. Belknap Press–Harvard University Press.

Langenheim JH. 1996. Early history and progress of women ecologists: Emphasis upon research contributions. Annual Review of Ecology and Systematics 27: 1–53.

Lazcano A. 2011. Natural history, microbes, and sequences: Shouldn't we look back again to organisms? PLOS ONE 6 (art. e21334). doi:10.1371/journal.pone.0021334

Leisher C. 2008. What Rachel Carson knew about marine protected areas. BioScience 58: 478–479.

Moritz C, Patton JL, Conroy CJ, Parra JL, White GC, Beissinger SR. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322: 261–264.

Noss RF. 1996. The naturalists are dying off. Conservation Biology 10: 1–3.

Pyle RM. 2001. The rise and fall of natural history: How a science grew that eclipsed direct experience. Orion 20: 16–23.

Schmidly DJ. 2005. What it means to be a naturalist and the future of natural history at American universities. Journal of Mammalogy 86: 449–456.

Slack NG. 2011. G. Evelyn Hutchinson and the Invention of Modern Ecology. Yale University Press.

Slotten RA. 2004. A Heretic in Darwin's Court: The Life of Alfred Russel Wallace. Columbia University Press.

Tewksbury JJ, et al. 2014. Natural history's place in science and society. BioScience 64: 300–310.

Theobald EJ, et al. 2015. Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. Conservation Biology 181: 236–244.

Tingley MW, Beissinger SR. 2009. Detecting range shifts from historical species occurrences: New perspectives on old data. Trends in Ecology and Evolution 24: 625– 633.

White PCL, Jennings NV, Renwick AR, Barker NHL. 2005. Questionnaires in ecology: A review of past use and recommendations for best practice. Journal of Applied Ecology 42: 421–430.

Wilcove DS, Eisner T. 2000. The impending extinction of natural history. Chronicle of Higher Education, 15 September, p. B24.

Wolfe VL. 2001. A survey of the environmental education of students in non-environmental majors at four-year institutions in the USA. International Journal of Sustainability in Higher Education 2: 301–315.

Cameron W. Barrows (cbarrows@ucr.edu) and Michelle L. Murphy-Mariscal are affiliated with the Center for Conservation Biology at the University of California, in Riverside. MLMM is also with the Biological Monitoring Program at Western Riverside County Multiple Species Habitat Conservation Plan, in Riverside, California. Rebecca R. Hernandez is affiliated with the Energy and Resources Group at the University of California, in Berkeley; the Climate and Carbon Sciences Program Area at Lawrence Berkeley National Laboratory, in Berkeley; and the Department of Land, Air, and Water Resources at the University of California, in Davis.