

Developing a translational ecology workforce

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We define a translational ecologist as a professional ecologist with diverse disciplinary expertise and skill sets, as well as a suitable personal disposition, who engages across social, professional, and disciplinary boundaries to partner with decision makers to achieve practical environmental solutions. Becoming a translational ecologist requires specific attention to obtaining critical non-scientific disciplinary breadth and skills that are not typically gained through graduate-level education. Here, we outline a need for individuals with broad training in interdisciplinary skills, use our personal experiences as a basis for assessing the types of interdisciplinary skills that would benefit potential translational ecologists, and present steps that interested ecologists may take toward becoming translational. Skills relevant to translational ecologists may be garnered through personal experiences, informal training, short courses, fellowships, and graduate programs, among others. We argue that a translational ecology workforce is needed to bridge the gap between science and natural resource decisions. Furthermore, we argue that this task is a cooperative responsibility of individuals interested in pursuing these careers, educational institutions interested in training scientists for professional roles outside of academia, and employers seeking to hire skilled workers who can foster stakeholder-engaged decision making.

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As the severity of global environmental challenges deepens, ecologists are being increasingly called upon to engage with decision makers to identify solutions that are socially acceptable. Such solutions must be salient, credible, and legitimate in order to be effective (Cash *et al.* 2003).

In a nutshell:

- Translational ecologists are professional ecologists who engage across social, professional, and disciplinary boundaries to partner with decision makers in order to achieve practical environmental solutions to primary challenges
- To be effective, translational ecologists must have disciplinary knowledge beyond ecology (eg law), as well as specific skill sets (eg negotiation) and personal traits (eg humility, a professional focus toward society)
- Individuals should self-evaluate to determine whether this is a path that is right for them and, if so, seek opportunities and experiences to hone personal qualities and acquire necessary skills
- Agencies, universities, industries, and non-governmental organizations that require translational ecologists must support professional development of translational skills
- Training of translational ecologists is a responsibility shared among individuals, employers, educators, and academic administrators

For research to inform natural resource decision making, it must be driven by stakeholder problems and concerns, and should involve a collaborative process between researchers and users of the products of that research. However, bridging gaps among the varied cultures of requisite disciplines to formulate practical, implementable policy and management solutions remains a major impediment (Cook *et al.* 2013). Natural resource managers, for example, routinely highlight the lack of meaningful personal interactions with scientists as a primary limiting constraint on the use of science in developing adaptation strategies (eg Armitage *et al.* 2015; Meadow *et al.* 2015).

Traditional graduate training, which continues to emphasize the importance of curiosity- and theory-driven inquiry, is often insufficient for developing aptitude to inform practical solutions (Graybill *et al.* 2006). Framing research is classically motivated by targeting the most intellectually novel and stimulating research questions based on the scientific literature. These cutting-edge science questions, however, are often not tuned to finding solutions to society's most pressing problems. Furthermore, this emerging training need for science to meet global environmental challenges extends beyond "Pasteur's quadrant" (Stokes 1997), in which science can represent both novel inquiry and practical application. Scientists also require training on how natural resource management decisions are made and how science can be integrated to inform decisions. When ecologists make discoveries relevant to natural resource management in cases where the management objectives themselves may be contested (eg water-resource allocation), the use of research-based results in decisions

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Panel 1. Example lists of representative multidisciplinary knowledge, practical skills, and personal aptitudes that members of the TE Working Group have found useful for engaging science in natural resource decision making; these represent a first-pass definition of translational-ecologist attributes

(1) Multidisciplinary knowledge

Ecology, law, economics, government, ethics, sociology, business management

(2) Practical skills

Communication, decision science, risk assessment, project management, conflict resolution, group facilitation, scenario planning

(3) Personal aptitudes

Patience, humility, empathy, leadership, sociability, commitment to inclusivity and diversity, commitment to process

may be very complicated. In such cases, the practical application of science requires researchers who are interested in engaging deeply in the decision-making processes and who have skills relevant to such engagement.

As a consequence, there is a gap between the needs and expectations of society for the application of research knowledge and practices of traditional ecologists who focus on publishing outcomes, leaving the translation of research to applications on societal issues to others. For this Special Issue, we chose to focus on the education and training of current and future ecologists that is needed to create a sufficient workforce of translational ecologists with the skills to fully participate in resolving the most pressing environmental challenges. We define a translational ecologist as a professional ecologist who engages across social, professional, and disciplinary boundaries to partner with decision makers in order to achieve practical environmental solutions to primary challenges (Enquist *et al.* 2017). Here, we adopt a broad view under this definition. Although much of the translational science literature focuses on researchers talking to other researchers about how to frame translational research for application (eg Horowitz *et al.* 2009; Sood *et al.* 2016), we suggest that translational ecologists may be translators of ecological research, resource decision makers, or individuals conducting research.

The concept of translational ecology (TE) is relatively new (Schlesinger 2010). Literature to describe attributes associated with successfully participating in environmental decision making as a translational ecologist, as with translational medicine (eg Rubio *et al.* 2010; Pickering *et al.* 2015), relies primarily on consensus opinion rather than data (Brunson and Baker 2016). We use our collective experiences as ecologists, educators, and translators in addition to the sparse translational education literature to (1) propose characteristic skill sets and personal attributes relevant to translational ecologists; (2) outline potential pathways to becoming a translational ecologist; (3) suggest how to develop individual and institutional capacity to mentor and train translational ecologists; (4) discuss the potential demand for translational ecologists in the workforce; and (5) offer potential pathways for increasing the capacity of individuals to become transla-

tional ecologists, for educational institutions to train students interested in these careers, and for institutions to foster such skills in their employees.

■ Knowledge, skills, and aptitude for TE

Translational ecologists are often required to work across the boundaries between science and practice when participating in collaborative decision making. Taking part in such activities often involves working with non-scientists in complex and sometimes contentious circumstances (Enquist *et al.* 2017). Success in meeting societal needs for a healthy environment through the incorporation of relevant research results requires knowledge, experience, and skills that extend far beyond classical graduate research training. Given the lack of empirical data evaluating the skills requisite for translational ecologists, we borrowed from the more extensive literature on translational health sciences (eg Jensen and Amara 2014; Pickering *et al.* 2015) and pooled our collective experiences as translational ecologists to synthesize attributes we consider necessary for successful natural resource management application. Ours is, however, simply a perspective; evaluations of specific attributes that foster more (or less) effective skill sets for public engagement in translating ecology remain an endeavor worthy of study unto itself.

We cluster critical attributes for translational ecologists into three basic categories: (1) multidisciplinary knowledge, (2) translational skills, and (3) personal aptitudes (Panel 1). First, *multidisciplinary knowledge* within and beyond ecological expertise is needed to inform discussions and establish credibility, given that translational ecologists must work closely with individuals from other professional perspectives (eg law, economics, planning, policy, behavior). At a minimum, obtaining a survey-level knowledge of how other disciplines approach problem solving can facilitate and enrich discussions.

Second, *translational skills* in collaborative engagement are crucial because problem-solving processes in natural resource contexts often occur in value-laden, contentious settings and span a considerable range of scientific uncertainty. Under such conditions, decisions do not necessarily follow from the bare facts; a variety of tools, from formal decision-science and risk-assessment frameworks to processes designed to facilitate dialogue and reach consensus (eg structured decision making; Martin *et al.* 2009), are required to adjudicate among competing values and interests, and to ensure that technical information is understood and utilized effectively. Nonetheless, making sense of uncertainty is something that researchers can be effective at addressing. However, there is also increasing awareness of the value of non-traditional skills

in translational situations. For example, group leadership and facilitation skills help foster collaborative decisions (Goleman *et al.* 2002). Alternatively, incorporating ethics training appears to be important in translational medicine (Rubio *et al.* 2010; Pickering *et al.* 2015).

Finally, our collective experience suggests that *personal aptitudes* are critical to successful functioning within a translational context. Translational ecologists must be willing to accept ambiguity, to embrace the complexity that emerges when divergent objectives and multiple viewpoints intersect, to compromise, and above all, to invest the time required to see decisions through to their often long and arduous conclusions. Similarly, Brunson and Baker (2016) identified dispositional attributes they considered to be essential for translational ecologists, just as Goleman *et al.* (2002) identified “emotional intelligence” as being essential for effective leadership.

There are, however, no hard data on what personality traits contribute to functioning within a translational environment, and most authors of published translational papers rely on common sense and personal experience. Our own personal experiences suggest that translational ecologists must be comfortable informing decisions laced with uncertainty; willing to accept the challenge of examining problems from multiple vantage points; willing to embrace cultural diversity; and willing to recognize that although decisions can be informed by research, decision making is a social process and therefore scientific concerns may not prevail. Ecological researchers armed with the principles of adaptive management should be well prepared to engage in the iterative process of making better decisions as challenges are managed over time. Effective participation requires patience and humility; translational ecologists must be capable of listening carefully and speaking respectfully. Communication, for example, means far more than being effective at making a point; it also means making certain that everyone at the table is heard. Communication barriers can be lowered, and potential conflicts can be identified and addressed, before misunderstandings among participants reach toxic levels. We identify what, in our opinion, are helpful personal attributes for potential translational work in Panel 1, and note that such attributes can be further refined through experience and training.

No single individual can realistically possess the full depth of knowledge, skill sets, and personal attributes needed to be an ideal translational ecologist (Panel 1), but individuals who have some level of knowledge and skills

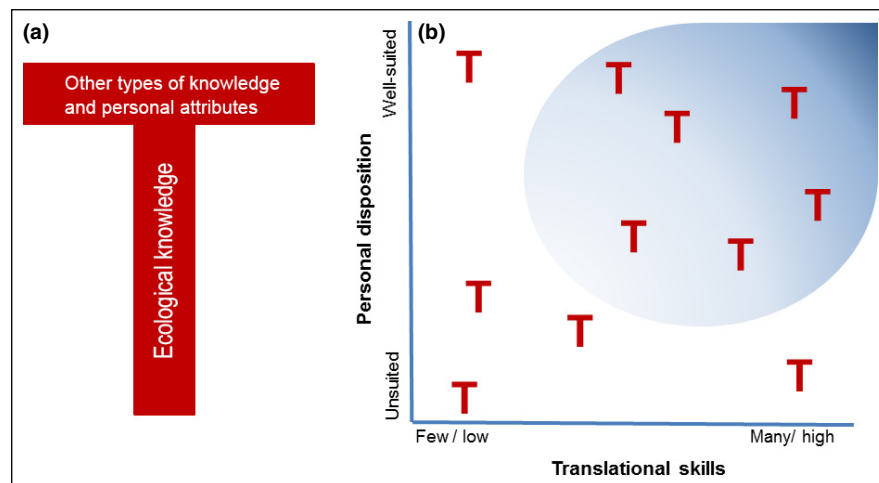


Figure 1. Two conceptual models of interdisciplinary scholarship. (a) “T-shaped” ecologists are those who develop deep disciplinary skills in ecology and accompany this training with knowledge in other areas, which can range from closely related disciplines (eg genetics) to unrelated scholarly fields (eg law). (b) A conceptual model for a “translational ecology space” that places T-shaped scholars within a spectrum of possible positions of having breadth in translational skills and personal attributes that can make them more, or less, effective as translational ecologists. We do not assert what constitutes minimal training, experience, or aptitudes that would suffice for a translational ecologist, merely that it would benefit individuals striving to become effective as translational ecologists to participate in training programs and to gain experiences that move them toward the upper-right portion of this model space.

across a spectrum of translational criteria are more likely to be successful in the practice of TE. Moreover, having personal attributes that allow one to engage in collaborative or adversarial environments effectively may be as important as any formal training; proficiencies in “meta-thinking” (a self-awareness about one’s thinking; Perry 1970) and reflective judgment (King and Kitchener 1994) may be particularly helpful in engaging with other disciplines and professions, for instance.

A goal of TE is to foster the appropriate and effective use of ecological knowledge, not to ensure that the researchers’ preferred outcomes are achieved. We believe that this goal can be attained only when scientists make a clear distinction between research findings and their own personal values, and that doing so can allow the translational ecologist to engage more deeply with others on the basis of both their knowledge and their values (Pretty and Smith 2004).

Training a TE workforce thus requires a flexible but deliberative approach for building multidisciplinary knowledge and skills among individuals based on their personal attributes and interests. Interdisciplinary training has been depicted as building “T-shaped” skill sets, whereby the stem of the T represents a core strength and the horizontal top represents a suite of interdisciplinary fields with which one has some acquaintance (eg Hansen and von Oetinger 2001; McClain *et al.* 2012) (Figure 1), but we suggest an alternative conceptual model based on our three primary knowledge axes (Panel 1), in which

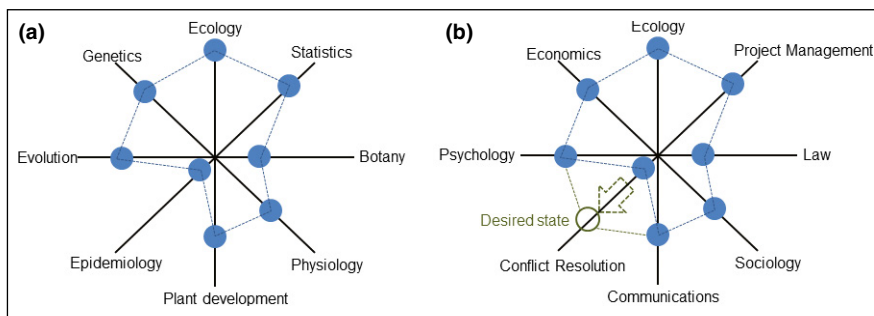


Figure 2. A schematic of two potential interdisciplinary scientists. Two ecologists might be differentiated by their particular depth and breadth across a complex of areas of knowledge. Case (a), an interdisciplinary scientist, might represent an academic ecologist with skills that support traditional university-based ecological research and teaching. Case (b), a hypothetical translational ecologist, possesses skills that allow her to work on resource management issues with people from diverse non-ecological backgrounds. The open circle and green dashed lines represent what might be a self-identified desired state of skills. Evaluating skill sets and desired states may suggest areas for additional training, as depicted for conflict resolution, highlighted by the green arrow, in this figure.

individuals acquire differing degrees of expertise among suites of specific skill sets (Figure 1).

■ Professional marketplace demand for skills in TE

Environmental problems are frequently “wicked” problems, involving complex landscapes of stakeholders, incomplete and often contradictory information, and shifting contexts (Brown *et al.* 2010). Solutions frequently emerge only through partnerships among technical experts (including ecologists) and diverse stakeholders (eg Pretty and Smith 2004). As the complexity of environmental problems faced by society will only increase in the future, the need for translational scientists will also increase, and in recent years more jobs have indeed become available in both the public and private sectors for individuals possessing translational skills. Evidence suggests, in fact, that for ecologists there are nearly as many professional opportunities outside of academia as there are within (Chang and Milan 2014), and that many of these opportunities involve the translation of ecological science in one form or another.

There is compelling evidence – in the form of burgeoning numbers of boundary organizations (described below) – suggesting that translational skills are currently in high demand (Safford *et al.* 2017). For example, needs for decision support and adaptive solutions in the context of climate change (NRC 2009) are being met by substantial investments of federal resources into programs specifically targeted to bridge the research–application divide. These include the National Oceanic and Atmospheric Administration (NOAA)-funded Regional Integrated Sciences and Applications (RISA) program (Parris *et al.* 2016), the US Geological Survey’s National Climate Change and Wildlife Science Center (NCCWSC), the Department of the Interior’s Climate Science Centers (CSCs) and Landscape Conservation Cooperatives

(LCCs), and the US Department of Agriculture’s Regional Climate Hubs. All of these programs strongly emphasize research developed in partnership with decision makers and stakeholders, and many of them are staffed with translational ecologists; moreover, these US federal entities are part of a much broader network of non-federal boundary organizations (eg Land Grant University cooperative extension programs, non-governmental organizations [NGOs]) whose mission is to interpret science for informing policy and management (Cook *et al.* 2013). Boundary organizations normally operate within a collaborative context and can take many forms, including translational research centers, coordinating entities, and disseminating bodies, and

can also act as conveners and partners in collaborative decision making. As public agencies and NGOs around the world are increasingly held accountable for identifying global adaptation solutions, it is imperative to coordinate professional training and development to create a workforce that is both trained and interested in engaging with agencies involved in natural resource management problem solving.

The rapid pace and increasing complexity of environmental, economic, technological, and societal changes portends a growing demand for translational ecologists, but developing the broadened perspectives, familiarity with multiple disciplines, practical skills, and refined personal traits required for TE entails substantial transactional costs (Hallett *et al.* 2017). Such costs cannot be eliminated, but they can be reduced for individuals by the various professional and institutional training programs discussed above. The earlier these skills are developed in one’s career, the lower the likely transaction costs will be.

■ Pathways to becoming a translational ecologist

We argue that succeeding in the realm of TE requires ecological knowledge along with at least some understanding of other disciplines relating to natural resource decision making (eg law, ethics, sociology), translational skills (eg communications, decision science, project management), and appropriate personal attributes (eg good listener, empathetic). Given the diversity of these skills, it is unlikely for individuals to develop depth in all of them, and thus we recommend personal evaluation of potential professional pathways in order to assess and match one’s personal strengths to a chosen profession. In our experience, most scientists think of themselves as broadly trained and possessing multiple skills, but what one means by “broadly trained” may vary substantially (Figure 2). A structured approach allows for an assessment

of one's abilities in specific disciplines and to identify areas for potential further training (Figure 2).

Our own diverse personal experiences have some attributes in common, including a combination of serendipity, resourcefulness, and adaptive experiential learning. None of the authors of this paper have received formal, in-depth, comprehensive training in TE, although several of us have benefitted from various short courses, workshops, and training sessions (eg communication, leadership, decision science). Although serendipity and experiential learning will continue to play important roles, development of a 21st-century TE workforce to meet contemporary critical environmental challenges requires a more focused effort. We believe responsibility for this effort lies cooperatively with (1) those individuals interested in gaining skills to become translational ecologists, (2) employers seeking to foster translational skills within their scientific workforce, and (3) educational institutions that are committed to training scientists for professional roles outside of traditional research and teaching (Rubio *et al.* 2010; Blickley *et al.* 2013).

Experiential learning pathways

TE is not a discipline but rather an inherently interdisciplinary approach to incorporate ecological knowledge into decision making (Enquist *et al.* 2017). As such, TE lacks formal curricula or academic degrees, and most current TE practitioners have gained their particular skill set through experiential learning and informal training opportunities that expanded on their formal academic training. A similar course of action was cited by first-generation conservation biologists and climate-science integrators (ie translators), whose skills were honed from a combination of on-the-job experience, interaction with professionals from outside their area of expertise, and life experiences prior to their professional careers (Brugger *et al.* 2015).

Although many forms of experiential learning exist, none can substitute for direct participation in real-world settings (Figure 3). Activities ranging from disciplinary working groups and on-the-ground management activities to federally sponsored committees represent excellent opportunities for acquiring practical skills (eg leadership, group facilitation). These experiences allow individuals to assess personal attributes (eg openness to different perspectives or values) and learn technical details of other disciplines (eg law, policy, resource management). Participation in collaborative science teams, particularly those that are interdisciplinary, can foster dialogue and engagement skills, and allow individuals to gauge their comfort with contrasting and even conflicting perspectives, all within a relatively "safe space" that distinguishes knowledge from values.

We call upon aspiring professionals to seek out experiential learning opportunities while in university or college, with the understanding that experiences in environmental decision making can be gained even through



Figure 3. The recently formed RxFire Science Consortium consists of a voluntary group of researchers and fire managers dedicated to discourse and annual "experiential learning" events in which research needs from multiple perspectives are discussed. In this photo, the group is shown at the Wade Tract in southern Georgia, one of the largest old-growth longleaf pine (*Pinus palustris*) stands in the US. One of the authors (JKH) is part of the Consortium and has developed his skills in translational ecology working in a number of environments throughout the southeastern US where balancing land use (eg military operations on Eglin Air Force Base) with conservation objectives for endangered species (eg red-cockaded woodpecker, *Leuconotopicus borealis*) required partnering with research and operations managers, along with deploying skills in negotiation and adaptive management. Through his work, he has helped operations continue and exceed conservation goals for target species through increasing the use of ecologically based managed fire. JKH's training is largely on-the-job, experiential, and driven by the necessity to complete the project objectives.

participation as stakeholders rather than as scientists. In addition, educational institutions must structure programs so that they foster the capacity for students to engage in research projects that entail collaborative decision making. We suspect that employers who work in collaborative decision making already place their ecologists in positions to gain experience in TE, but these organizations should not simply expect their scientists to operate in this fashion, but instead view it as a process that benefits from mentored participation. Below, we provide additional details regarding how these groups may engage more effectively in training this future workforce.

Non-degree training opportunities

Most STEM (Science, Technology, Engineering, and Math) PhDs do not lead to careers at research institutions (Turk-Bicakci *et al.* 2014). A large number of employers (government agencies, NGOs, and private-sector corporations and consultancies) hire PhD ecologists. In these roles, the ecologist's responsibilities often entail the application rather than the production of scientific knowledge, and ecological training may often be secondary to other TE skills (eg synthesis and communication skills in areas

Table 1. Three examples of institutions that specialize in translational training targeted at professionals working in the ecological sciences

Course name	Skill/attribute
(1) National Conservation Training Center (NCTC) – http://training.fws.gov	
Negotiation Skills for Conservation Professionals: Building a Foundation	Communication
Structured Decision Making	Decision analysis
Increasing Your Personal Effectiveness	Employee development
Introduction to Team Leadership	Leadership
Human Dimensions Foundations of Natural Resource Conservation	Outreach and partnership
Interagency Consultation for Endangered Species	Policy and planning
(2) Communication Partnership for Science and the Sea (COMPASS) – www.compasscomm.org	
Short message box training	Fundamentals of science communication; refining goals; developing a story
Partial day training	Engaging non-scientists; social-media training
1–2 day training	Practice interviews with journalists; Q&A with journalists; understanding the culture of journalism
Lecture and plenary sessions	
(3) Conservation Coaches Network (CCNet) – www.ccnetglobal.com/about-ccnet	
Online training material (90+ guided lectures)	Understanding and using the Open Standards for the Practice of Conservation
Group training sessions (3–5 day coach training)	Hands-on practice developing a multi-stakeholder natural resource management plan
Individual coaching (variable)	Specialized problem solving on topical issues
Coach rallies (biennial, 3–5 days)	Sharing best practices with other practitioners; skills development
Notes: These three organizations are featured because they are national or global in scope, host numerous trainings annually, are routinely accessed, and are utilized by a large number of prominent employers (eg US federal agencies, large conservation NGOs).	

outside one's disciplinary expertise). These non-academic ecologists may benefit from postgraduate continuing education to develop and refine diverse practical professional skills, which can be science-focused (eg population viability analysis or structured equation modeling) but often comprise skill sets well outside the realm of the ecological sciences (Panel 1).

Training for active professionals in non-academic positions comes in many varieties, including short courses (eg courses offered by the National Conservation Training Center [NCTC]), onsite workshops (eg Communication Partnership for Science and the Sea), or online courses (eg Conservation Coaches Network) (Table 1). Topics span the breadth of disciplinary skills outside of ecology, including interpersonal skills, meeting facilitation, and conflict negotiation. Many agencies and other organizations are becoming proactive, offering or supporting courses for their employees that impart the non-technical skills that are important at the research–action boundary (eg US Fish and Wildlife Service; <http://training.fws.gov/courses/programs>). Other organizations expect employees to acquire requisite knowledge through documented work

experiences (eg National Wildfire Coordinating Group; <https://onlinetraining.nwccg.gov>) or create opportunities to share learned experiences (Figure 4). In addition to gaining knowledge through practical experience, many individuals seek out structured training opportunities independent of their employment.

We call on employers to recognize the value of specific postgraduate training in communication, leadership, negotiation, and conflict resolution, among others, to elevate the capacity of their scientific staff. By acknowledging and taking responsibility for training in translational axes (Figure 2) relevant to the employers' mission, ecologists who believe in the mission can learn the necessary translational skills required to succeed if given adequate time.

Another promising pathway to building translational capacity is through non-traditional fellowship opportunities for graduate students, postdoctoral scholars, or early career scientists (Table 2). Programs such as the Smith, Wilburforce, and Liber Ero fellowships provide training in science communication and engaged scholarship, while fellowships such as the American Association for the Advancement of Science's Science and Technology Policy

Fellowship and the Federal Presidential Management Fellowship place postdoctoral scholars in agencies or with legislative staff to gain practical experience. Increasingly, such opportunities provide a means for young scientists dedicated to informing natural resource management decisions to learn on the job by working directly with an agency or NGO, or by conducting research in partnership with practitioners.

Educational institutions and degree programs

Recognizing the increasing demand for public relevance (Hoffman 2016), universities are developing innovative training programs (eg Graybill *et al.* 2006) and funders are creating fellowship-training opportunities specifically designed to broaden skills among scientists. For educational institutions, these programs must strive for diversity and inclusivity. Unpaid internship opportunities help develop appropriate skills but also differentially select for students who have the resources to volunteer. Educational institutions are critical in the effort to create a diverse translational workforce, and engaging students at the undergraduate level represents a prime opportunity to build this diversity.

Educational initiatives to meet emerging needs in practice-based training span a range of activities. For instance, many ecologists have called for increasing practical training through professional master's degrees (Colwell 2009; Musante 2009; Lynch 2012). The majority of formal programs that integrate ecological training into broad interdisciplinary graduate training consist of non-thesis master's degree programs, of which there are an increasing number each year (Table 3). Many of these programs have goals that overlap with those of TE; perhaps most prominently is



Figure 4. USGS Climate Science Center Fellows (graduate students and postdoctoral scholars) gather from across the country to discuss potential pathways for communicating and integrating their science into socially acceptable management solutions through distillation and translation.

a shared commitment to building interdisciplinary breadth and experiential learning, but other common patterns also emerge. For example, many non-thesis master's programs require some training in law, economics, policy, and business management, and many recognize the importance of professional skill sets and offer training in group dynamics, leadership, negotiation, and communication skills. Degree programs with which we work recognize that important decisions are made by groups, and as such integrate client-driven group work into their curricula. In our view, such programs can be an excellent way to develop the breadth of skills required from a theoretical standpoint and to gain practical experience in applying these skills.

Although professional master's programs train students in the multidisciplinary skills useful to translational ecologists,

Table 2. Eight training opportunities that allow professional scientists, from graduate level to mid-career, to develop knowledge, skills, and attributes that would be useful for emerging translational ecologists

Program	Intended audience	Sponsor	Website
The Leopold Leadership Program	Early- to mid-career academic scientists	Stanford University	https://leopoldleadership.stanford.edu
Smith Fellows	Postdoctoral scholars	Society for Conservation Biology and the Cedar Tree Foundation	http://conbio.org/mini-sites/smith-fellows
NatureNet Science Fellows	Postdoctoral scholars	The Nature Conservancy	www.nature.org/science-in-action/naturenet-science-fellowship.xml
Wilburforce Fellowship in Conservation Science	Early to mid-career	The Wilburforce Foundation	www.wilburforce.org/fellowship
Liber Ero Fellowship	Postdoctoral to early career	The Liber Ero Foundation	http://liberero.ca
Switzer Environmental Fellowship	Senior graduate students	Robert & Patricia Switzer Foundation	www.switzernetwork.org/become-fellow
AAAS Science & Technology Policy Fellowships	Postgraduate researchers	American Association for the Advancement of Science	www.aaas.org/program/science-technology-policy-fellowships
California CCST Policy Fellowship	Postgraduate	California Council on Science and Technology	http://fellows.ccst.us

Table 3. Seven example university degree opportunities that foster interdisciplinary skills associated with ecological training for managing natural resources

Program	Website
Yale University, Master of Environmental Management (MEM)	http://environment.yale.edu/academics/degrees/mem
UC Santa Barbara, Bren Master of Environmental Science and Management	www.bren.ucsb.edu/academics/MESM.html
Duke University, Nicholas School of the Environment, MEM	https://nicholas.duke.edu/programs/masters/mem
University of Wisconsin, Nelson Institute for Environmental Studies, Professional Master's Program in Environmental Conservation	www.nelson.wisc.edu/graduate/professional-programs/environmental-conservation/index.php
University of Waterloo, School of Environment, Resources and Sustainability	https://uwaterloo.ca/environment-resources-and-sustainability
University of Maryland, Master's Degree in Environmental Management	www.umuc.edu/academic-programs/masters-degrees/environmental-management.cfm
Portland State University, MEM	www.pdx.edu/esm/master-of-environmental-management

structurally they cannot provide the disciplinary depth in ecology that comes with earning a research-based doctorate. Our experience is that many students from such master's programs continue on to obtain PhD degrees, followed by careers at the research–application boundary.

A PhD in ecology

Finally, a common pathway to becoming a translational ecologist is through traditional doctoral training in ecology. Universities excel at guiding students to degrees based on disciplinary theory and curiosity-driven science, and some emphasize the extension of such knowledge to practical applications. Broadening programs to include more solution-based research would be one step toward developing translational skills; another would be to promote coursework in related fields of practice (eg forestry, fisheries management, environmental engineering) for graduate students in ecology. Offering cross-disciplinary classes that emphasize social engagement is another (Figure 5). There is, however, a trade-off created in reducing time spent developing disciplinary expertise in favor of developing translational skills. Success in graduate school is most often defined as succeeding within the academic realm, with less emphasis on non-academic professional careers. We are not suggesting that universities abandon the pre-eminent role of research excellence as a metric of success; research excellence is at the core of the university mission and provides genuine benefit to society. However, for universities to maintain and increase their relevance to the public, a balance must be found between training for non-research skills and traditional research imperatives (Hoffman 2016).

There are clear signs of change. The University of Georgia, for example, recently introduced an Integrative Conservation PhD Program for the interdisciplinary study of coupled social–ecological challenges (<http://cicr.uga.edu>), as did the University of Waterloo (<https://uwaterloo.ca/environment-resources-and-sustainability>). Likewise, the Santa Cruz and Davis campuses of the University of

California have developed degree certificate programs in science communication and conservation management, respectively, to augment existing disciplinary PhD training. The US National Science Foundation (NSF) is increasingly committed to interdisciplinary and transdisciplinary research (Pinter *et al.* 2013), and has supported the Integrative Science for Society and Environment (ISSE) program within its Long Term Ecological Research (LTER) Network to advance the integration of ecological, physical, and social sciences, including graduate and postdoctoral training (Felson *et al.* 2013; Waide and Thomas 2013). The NSF has also developed the Integrative Graduate Education and Research Training (IGERT) program, which – along with its successor, the NSF Research Traineeships (NRT) program – focuses on promoting training and collaborative research experience to foster transdisciplinary thinking (eg Graybill *et al.* 2006; Borrego *et al.* 2014). Many individuals currently active in TE have relied on these programs for training, but such programs also reveal challenges and deep cultural barriers to innovation in graduate education (Graybill *et al.* 2006; Borrego *et al.* 2014). We urge universities with graduate programs in ecology to systematically review the role of these programs in preparing students for both academic and non-academic career paths. Moreover, overarching organizations like the National Council for Science and the Environment's Council of Environmental Deans and Directors or the Council of Graduate Schools (both in the US) provide a structure under which general discussions about creating translational scientists across fields could be fruitful.

■ Conclusions

Public agencies, NGOs, private utilities, municipalities, and even corporations are increasingly seeking individuals who have the skills and personalities needed to work at the interface between science, policy, and decision making. Here, we identified not only a strong, diverse, and growing suite of opportunities through which interested individuals can gain translational skills

but also pathways for development of a TE workforce that require changes in the behaviors of universities, agencies, and individuals.

Expansion of formal education opportunities may occur through ongoing changes within universities that result in greater support of professional master's programs (Colwell 2009) and secondarily from emerging research-based doctoral programs that specifically emphasize breadth in training. As universities adapt to modern educational needs (Hoffman 2016), there is an opportunity to consider specific programs that train doctoral-level candidates in ecology and related fields for the non-academic job market. Such training requires careful thought regarding the role of curiosity-driven versus solution-based dissertations, as well as the skills required for ecologists to have successful careers helping to resolve critical issues in natural resource management. Several outstanding professional master's degree programs have laid the groundwork by investing in the development of relevant skill sets and may provide models for innovation in future doctoral programs in TE. We believe that national and international leadership is required to guide graduate programs toward providing broader training for the majority of their graduates who will end up in non-academic careers.

Many fields (eg engineering, physical therapy) require board certification, creating structured graduate learning in order to achieve defined skills. The Ecological Society of America has a certified ecologist program, but this certification is based purely on ecological knowledge. Much remains to be studied and considered before any kind of certification for translational ecologists can be formalized. We believe that our conceptual model of multidimensional axes (Figure 2) dispersed across a suite of disciplinary knowledge and specific skills provides a framework for education. Moreover, this framework may also be useful for organizations in defining expected job skills when hiring translational professionals, and can be used both for evaluation of candidates during hiring and, more importantly, to create a structure around which on-the-job training can help fill out needed expertise among valued staff. Professional societies can also work with universities to develop standards of expectations for certified translational ecologists that exceed strict ecological knowledge and extend into an understanding of how ecological knowledge is applied and used.

We urge employers seeking a well-trained staff to invest in continuing education that explicitly recognizes the skills we identify here as essential for translational ecologists. For large employers, such as government agencies and large NGOs, opportunities for continuing education may be available within the institution (eg the NCTC has developed many courses that focus on the development of non-ecological skills in which federal agency ecologists may enroll). Smaller entities (eg small NGOs, such as land trusts) are unlikely to have the resources to develop this training on their own and thus must seek collaboration with larger agencies. Alternatively, many



Figure 5. The University of California–Davis has developed field-based ecogeomorphology courses for both graduate and undergraduate classes. The course intentionally brings together ecologists, geologists, hydrologists, and environmental policy students to learn about the Grand Canyon and each other's science, and to discuss issues relating to science communication. The class shown here is listening to graduate student Carson Jeffres lecturing on native fish management in the Colorado River.

universities, through their University Extension services, provide training in generalized skills such as leadership, negotiation and conflict, and business administration, which could be an asset to employee breadth training.

Finally, we urge interested individuals to take ownership of their training. Although learning is a life-long process, formal education is not. Aspiring translational ecologists need to be aware of the variety of jobs that align with their skill set, since these positions take many forms and jobs evolve quickly in response to environmental change. Becoming a translational ecologist is not for everyone, nor should it be. Careful reflection is required to consider whether one has the personal disposition and willingness to make the commitment needed to function effectively within this context; aspiring translational ecologists should in effect be able to map themselves onto a diagram like the one depicted in Figure 1. In addition to disciplinary expertise and skills training, individuals must also reflect on the necessary personal aptitudes (Panel 1) in order to determine whether one is suited to TE and to best define how to engage effectively as a translational ecologist; while disciplinary knowledge and technical skills are trainable and learnable through experience, personal aptitude is not. Thus, we urge individuals seeking such professional pathways to engage in careful self-examination to identify their strengths and weaknesses.

Those interested in becoming translational ecologists must be conscious of the time constraints and trade-offs when sacrificing breadth for depth. It is neither expected, nor reasonable to expect, someone to have deep knowledge across the spectrum of areas we have identified as core knowledge areas for TE. How much translational knowledge is enough is context-dependent. Nevertheless, those wanting to be translational ecologists have a world of need awaiting them.

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