**NRT: Next-Generation Biodiversity Training**

1. **List of Core Participants**

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| **Name** | **Project Role** | **Department and Institutional Affiliation** | **Discipline(s)** |
| Brian O’Meara | PI | Ecology and Evolutionary Biology, UTK\* | Phylogenetics, macroevolution |
| Charles Kwit | CoPI | Forestry, Wildlife and Fisheries, UTIA\*  Ecology and Evolutionary Biology, UTK | Conservation, wildlife-plant interactions |
| Susan Kalisz | CoPI | Ecology and Evolutionary Biology, UTK | Evolution, ecology, and conservation of plants |
| Meg Staton | CoPI | Entomology and Plant Pathology, UTIA | Plant pathology, genomic tools, and science communication |
| John Kevin Moulton | CoPI | Entomology and Plant Pathology, UTIA | Insect taxomomy, biodiversity, and phylogenetic relationships |
| Barbara Heath | Evaluator | East Main Evaluation & Consulting, LLC | STEM education assessment |

\* UTK: University of Tennessee, Knoxville; UTIA: University of Tennessee Institute of Agriculture

**B. Theme, Vision, and Goals**

Understanding biodiversity is key for building workforce capacity and knowledge in key areas of national need, including the science of sustainability, conservation, ecosystem services, agriculture, wildlife management, forestry and public health. American graduate education programs in STEM do an excellent job training students for academic careers related to biodiversity science, but only 20% are hired in academia within five years of graduation (Hansen et al. 2014). Thus, a critical need exists to train students for careers in non-governmental organizations (NGOs), government agencies, and businesses related to biodiversity, careers that are often explicitly seen as an “alternate” paths. We believe the US needs a stream of well-trained students prepared for jobs outside academia, where they can have immediate, real-world impact in a different way than is possible in many academic positions. This program seeks to train such biodiversity scientists for careers outside academia.

Motivated by the increasing interests of our students in non-academic careers, the current state of relevance and marginalization of natural history knowledge (Hansen et al, 2014; Barrows et al. 2016), and the importance of linking natural history knowledge with new technologies to the benefit of science and society [1], we surveyed potential employers of biodiversity STEM graduates regarding the needed skills of future employees. Repeatedly, they indicated that knowledge of geographic information system software, experimental design, technical writing skills, and detailed expertise in one or more taxonomic groups was key. This is consistent with the findings of Blickley, Deiner [2], who analyzed job advertisements and interviewed employers in conservation nonprofits, government agencies, and private companies to find key skills needed, which included domain knowledge and project management skills.

*Vision:* We will capitalize on the expertise at the University of Tennessee and engage with local and national partners to provide real-world experience to students through strategic internships. By bringing together faculty and students from the University of Tennessee, Knoxville (UTK) campus with the University of Tennessee Institute of Agriculture (UTIA), this project will create an interdisciplinary environment for the next generation of experts in biodiversity. Our goal is to generate a culture change, which will generate biodiversity experts who will effectively face today’s societal and scientific grand challenges.

*Goals:* Our project has two main goals:

1. Enhance workforce development to fill the need for biodiversity expertise in the US.

2. Create a prototype for institutional culture change toward non-academic career paths.

*Understanding the Need:* Human health, food security, resource conservation and management, and recreation all rely on knowledge of biodiversity. At their intersection, many of the ecosystem services that society deems important — increased agricultural and natural resource production, water quality and fresh water abundance, and disease control (Rodriguez et al. 2006) — are directly correlated with biodiversity in both agricultural (Wagg et al. 2014) and natural (Gamfeldt et al. 2013) systems. Assessing and conserving biodiversity, especially in our current era of anthropogenic change, will require biologists trained in a wide array of skills [1] that are normally not integrated in existing, single-discipline graduate training programs.

Typical training often produces (1) researchers with deep taxonomic and evolutionary knowledge of one group but little training in how to broadly apply general biological principles, or (2) workers trained in applied details without sufficient depth of knowledge of evolutionary or ecological contexts. This leads to a lack of synergy: questions and approaches in one field, even within various fields of biology, only slowly diffuse to others. Even within the three departments on our campus, this is the first grant incorporating all of us, and the first interaction between many of the involved faculty.

Further, traditionally narrow training paths yield graduates who lack skills in the latest technology revolutionizing their fields. Such skills include next-generation sequencing abilities allowing detection of organisms from wisps of DNA in a stream or sequencing entire viral genomes in a day, drones allowing remote sensing of biodiversity data, and geographic information systems allowing precise mapping and correlation of abiotic factors with responses of organisms. Moreover, potential leaders require training in skills such as project management [2]. Add references to the need for diversity and synergy.

*The Next-Generation Biodiversity Solution:* Our strategy is a training program for graduate students that combines interdisciplinary emphases and experiential learning to address current biodiversity-related challenges. This will pave the way for next-generation biodiversity scientists to enter careers in alternative academic paths in partner or associated organizations. The call to incorporate new technologies into the traditional realm of biodiversity research has only recently been posed (Tewksbury et al. 2014). However, the benefits of experiential learning experiences have been well substantiated at the collegiate level and include increased retention (Kuh 2008), abilities to solve complex problems (Batchelder and Root 1994), and increased student motivation (Tumlin et al. 2009).

UT is the ideal location to establish such a program. For biodiversity experts, we are already a key destination given the region’s high biodiversity and existing groundwork to map it (e.g. All Taxa Biodiversity Inventory, which has mapped 19,000 species in the Great Smoky Mountains National Park (GSMNP)), research collections (TENN Herbarium housing vascular plants, bryophytes and fungi, UT Fish Collection, UT Caddisfly Collection), and faculty-led courses about fish, fungi, plants, reptiles, amphibians, birds, mammals, and invertebrates. We have a tradition of collaboration with and placement of graduates in federal and state agencies and NGOs such as The Nature Conservancy and the Tennessee Clean Water Network. Our technological skills are at the cutting edge, with expertise in environmental DNA monitoring, high-performance computing, next-generation sequencing, and use of drone and satellite imagery for addressing biological questions.

Our program covers six components: five modular areas (Table 1) plus a multidisciplinary advisory structure: (1) core biology training in an interdisciplinary approach including several academic disciplines, such as ecology, evolution, genetics, and natural history; (2) technology training in remote sensing, genomics, and GIS; (3) leadership, management and communication training; (4) internships; and (5) trainee outreach. A sixth component, Multidisciplinary Advisory Committees, will facilitate interdisciplinary synergy and guide trainees’ research projects. Through these research projects (described below), NRT trainees will use skills developed in these modular areas to prepare for top jobs. This model for graduate student training will be monitored as a prototype for building student awareness and faculty support for non-academic career choices.

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| **Table 1.** Modular Areas |
| Internships |
| Core Biology Training |
| Technology Training |
| Leadership, Management and Communication Training |
| Trainee Outreach |

The core biology training builds on existing courses and features two-week intensive field courses. The technological training will largely be delivered in workshops. Faculty already offer workshops that can draw interest from hundreds of applicants; by streaming these online, we can reach many more potential trainees. For leadership and management training we will capitalize on relevant courses in project management and team building, including coordinating with colleagues on the creation of new courses. In modular area 4, trainees will participate in at least one internship with our partners, which will help build their professional networks and expose them to the management of concrete issues. For outreach, we will capitalize on existing programs at our university, as well as train students in science writing and have them write and disseminate a short popular press article about their work.

*Outcomes:* Throughout the life of the program, integration with our external partners will help us tailor training to meet their key needs. The overall goal is to graduate students with Master’s and Ph.D. degrees who intend to pursue careers in business, NGOs, or government. Unusual for many biology graduate programs, especially those at liberal arts colleges (like that of one of our three collaborating departments), an academic career will not be the primary target for our students upon entry, and we expect few to go down that path. Because our partners have provided indications of the skills needed to address their current needs, we expect that our students will become viable candidates for careers within partner or related organizations.

Our interdisciplinary approach connects three departments, each with unique strengths. Ecology & Evolutionary Biology (EEB) brings a focus on ecological and evolutionary mechanisms, as well as expertise in fungi, plants, vertebrates, and some insects. Entomology & Plant Pathology (EPP) extends the taxonomic expertise to arthropods and disease organisms and has rich connections with agriculture. Forestry, Wildlife, & Fisheries (FWF) maintains a focus on harvestable natural resources (fish, timber, recreational hunting) but far less of an emphasis on biological mechanisms or question-driven science. Though these programs have a substantial set of students move on to careers outside academia, like most science programs across the US, they have not done much to prepare students for this path.

*Context for Added Value:* We will track the NRT student outcomes to assess our program’s success relative to current student placement (Fig. 1. All of our departments currently have a substantial proportion of graduates going on to academia, but many students (red bars, Fig. 2) are employed outside academia. These baseline data will help us measure the effectiveness of our program in placing our graduates. New data will also allow us to integrate program participants into alumni networks, especially those outside academia. For example, EEB’s long-term placement of our graduate students over the past 16 years show that out of the Master’s students, 27 (52%) have gone on to careers outside colleges and universities and are placed in jobs ranging from the US Forest Service, to education coordinator at the Jackson Zoo in Mississippi, to program director at the New York City Parks Department, to high school biology teacher.

***Figure 1.*** *Graduate student placement from EEB, EPP and FWF Departments at UTK (UT, 2016).*



**C. Education and Training**

The traineeship model has six main components:

1. Internships;
2. Core biological training, including semester-long coursework in ecology, evolution, statistics and field courses focused on the natural history of organisms;
3. Technology training through coursework in GIS and informatics, and workshops in R programming language;
4. Leadership, management and communication training, including semester-long courses in project management and workshops in science communication;
5. Trainee outreach; and
6. Multidisciplinary Advisory Committees that build on the synergy among faculty in EEB, FWF, and EPP to guide trainees’ interdisciplinary research projects.

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| **Table 2.** Graduate education. | |
| **Credit Hour Instruction** | **Credits (total of 24)** |
| Core Biological Training   * Semester-long course credits * Field course credits | 9+  3+ |
| Technology Training   * Semester-long course credits * Workshops | 3+ |
| Leadership/Management/ Communications   * Semester-long course credits * Workshops | 3+ |

We propose to use existing and new programmatic elements to enable students to select appropriate courses and experiences (see Table 2). Both the Master’s and Ph.D. programs across the three departments currently require 24 hours of course work (plus additional thesis or dissertation hours). All three departments offer flexible curricular choices for graduate students that will integrate with the components of this new traineeship program. This approach to graduate student training is described below, highlighting the interwoven mechanisms and approaches.

*Internships: C*onnecting with professionals outside academia is the key component of this NRT; thus a major aspect of training is placing students in strategic internships. We have willing partners in the National Park Service, US Fish and Wildlife Service, US Forest Service, Tennessee Department of Environment & Conservation, Tennessee Wildlife Resources Authority, Huber Engineered Woods, the Nature Conservancy, Discover Life in America, and several independent environmental consulting firms. Moreover, Dr. Thanos Papanicolaou of UTK’s Tickle College of Engineering has agreed to expand current engineering student intern opportunities with the US Geological Survey to include internships for our NRT students (*See Letter of Support*).

The team has experience facilitating intern arrangements for undergraduates that can be applied to the NRT trainee internships, and we have faculty liaisons already in place. For example, FWF has well-established internship opportunities for its undergraduate majors, including some with our graduate internship partner organizations (Table x). Likewise, many EEB faculty have mentored undergrads in successful internships that have opened career paths. For example, as an undergraduate intern, Stephen Nelson worked on a collaborative project between UTK and the Knoxville Zoo, assessing disease threats to amphibians. He is now head keeper in the zoo’s herpetology department and continues to collaborate with his faculty advisor at UTK on conservation and biodiversity discovery (they recently discovered a new species of mudpuppy). This NRT’s internships will develop a pipeline of STEM-enabled Ph.D. and Master’s students outside academia. We will continue to add more partner organizations to those that have already expressed interest in collaborating to establish a network of highly trained biodiversity professionals.

*Coursework:* Semester-long courses utilize existing courses span three modular areas. Core biology courses are provided by traditional graduate student offerings across departments, spanning ecology, taxonomy, anatomy, physiology, evolution, and conservation. Technology training courses include ENVE 561 – Climate and Environmental Informatics, GEOG 517 – Geographic Information Management and Processing, and EPP 622 – Bioinformatic Applications. Two courses coming online soon include FWF 530 – GIS for Natural Resources and EEB 550 Spatial Analyses using UAV. Management and assessment courses include EDAM 560 – Grant Writing and Project Management, ENMG 536 – Project Management, and ENMG 541 – Managing Change and Improvement in Technical Organizations.

**Table 3.** Course titles.

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| **Number** | **Course Title** | **Knowledge and Skills** |
| ***Technology Training Courses*** | | |
| ENVE 561 | Climate and Environmental Informatics | Risk management, dealing with uncertainty, extreme events |
| GEOG 517 | Geographic Information Management and Processing | Geographic database design, manipulation, sampling and analysis |
| EPP 622 | Bioinformatic Applications | Bioinformatics for agriculture, bash and python scripting, open source software |
| FWF 530 | GIS for Natural Resources | Geographic information system data for forestry |
| EEB 550 | Spatial Analyses using UAVs | Use of drones to gather environmental data |
| BZAN 545 | Database and Big Data Technologies | Relational and non-relational databases; scritping languages, analytics in big data environments |
| CBE 672 | Computational Bioinformatics | Modeling and analysis of DNA; algorithms; probability theory |
| ***Management and Assessment Courses*** | | |
| EDAM 560 | Grant Writing and Project Management | Writing grant proposals, negotiating with funding sources |
| ENMG 536 | Project Management | Team building, conflict resolution, and contract negotiations |
| ENMG 541 | Managing Change and Improvement in Technical Organizations | Organizational effectiveness, employee empowerment, performance measurement. |
| HRM 545 | Compensation and Benefits | Compensation, benefits, legal compliance |
| ALEC 551 | Servant Leadership in Agriculture and Natural Resources | Leadership in business, education, and foundations |
| ALEC 520 | Leadership Development in Organizations and Community Nonprofit | Emphasis on leadership in agricultural professions |

Trainees will pursue courses across each of the three types (core biology, technology, and management/communication/assessment). Additional targeted graduate courses, depending on trainees’ needs, may also be utilized. Capitalizing on established courses helps create a sustainable program and exposes trainees to students and instructors from a variety of perspectives.

*Field Courses*: Hands-on experiences are key ways to promote learning [3] and are a central goal of the UTK administration. UTK Faculty in our three departments currently teach field courses covering a wide variety of organisms and ecosystems that provide immersive learning environments. EEB-led courses include Field Botany; Biodiversity of Fungi; Wetlands Ecology; Aquatic Insects; Herpetology; Ecology and Diversity of Fishes; and Field Ecology. New courses are being developed at the graduate level (e.g. Natural History of the Smoky Mountains for mini-term 2017) that will leverage EEB’s field station just outside Great Smoky Mountains National Park. Our natural history courses constitute a key area of biodiversity training that is lacking in most graduate programs.

The value of our courses to training NextGen biodiversity experts are clear from the participation by NGO and government agencies employees. For example, in the last two semesters, a total of nine students attended three EEB courses (Ecology and Diversity of Fishes; Environmental Toxicology; Aquatic Insects) and are employees of the Tennessee Valley Authority (2), Tennessee Department of Environment and Conservation, Conservation Fisheries, Oak Ridge National Laboratory (ORNL) (3), and private consulting firms (2). New and existing grad courses in this NRT program will stimulate interaction across agencies and UT.

*Workshops:* Each year, trainees will have access to workshopsorganized as two to three days of intensive learning involving both lecture and practical exercises. The workshops will cover areas of technology training, communication, and modeling/analysis.

O’Meara will offer two technology workshops based on his prior tutorials: “High Performance Computing for Phylogenies” and “Computing in the Cloud: What Every Computational Life Scientist Should Know.” Co-PI Staton will sponsor and co-teach a Data Carpentry workshop each year as well as continuing to offer her two-day next generation sequencing and bioinformatics workshop on RNASeq. Staton is a certified instructor in Data Carpentry (Teal 2015), a vetted two-day training curricula utilized worldwide for teaching data analysis and reproducibility principles. Customized curricula are available for ecology, genomics, and geospatial data approaches. Additional workshops on the use of drones and LiDAR for spatial data collection and remote sensing will be held in the new Spatial Analysis Lab of EEB/NIMBioS led by new EEB/NIMBioS faculty, M. Papes.

A key communications workshop, taught in conjunction with UT’s School of Journalism and Electronic Media, will tap into the expertise of Dr. Mark Littmann. It will focus on written and verbal communication necessary to convey complicated scientific topics to the general public or government officials. In the process, NRT trainees will learn how to craft press releases about their research, how to write a query letter to pitch their story to the media, and gain a basic understanding of how the mainstream media communicates scientific topics. Additional communications workshops will focus on skills for the range of information presentations employed outside academia, as well as report development and web design.

Trainees at the Master’s level will participate in at least one workshop prior to graduation, and Ph.D.-level trainees will participate in a minimum of two. Topics will either be updated yearly or replaced with new relevant material to reflect state-of-the-art approaches in biodiversity and the particular research needs of the trainees. Materials from all workshops will be available online through live streaming and posting all teaching materials (slides, exercises, scripts) to an open access website. This successful model is used by PI O’Meara for several NIMBioS tutorials on computing, phylogenetics, R, and genetics, as well as an NSF CAREER grant-sponsored course and will be the standard for all workshops. Assessment of domain knowledge at the beginning, completion, and a year after each field course and skills workshop will help highlight effective strategies and long term impact.

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| **Table X.** Student timeline | | | | | |
| **Students** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** |
| New students | 4 | 5 | 4 | 4 | 0 |
| Continuing funded students | 4 | 9 | 9 | 8 | **4** |
| Graduated students (masters) | 0 | 0 | 2 | 4 | **6** |
| Continuing unfunded students (PhD) | 0 | 0 | 2 | 5 | **7** |
| New affiliate students | 5 | 7 | 9 | 11 | 13 |
| Total affiliate students | 5 | 12 | 21 | 32 | **45** |
| New external participants | 10 | 15 | 15 | 15 | 15 |
| Total external participants | 10 | 25 | 40 | 55 | **60** |

*STEM Graduate Populations to Be Served:* This grant will serve four audiences:

* Trainees (funded students): 17 Ph.D. or Master’s students will receive stipends (plus tuition and benefits) for two years each will be full participants in our core NRT program. Based on available information from 69 students admitted over the last five years, 83% of admitted students would have US citizenship, 61% dentify as female, 10.1% identify as Hispanic, 4.3% identify as African-American, and 2.9% identify as American Indian. Thirty-one percent attended the U. of Tennessee (usually as undergraduates) before enrolling in the graduate program. We will accept 17 students for funding: four for funding in each of Years 1, 3, and 4, and five students in Year 2. We expect an even mix of Master’s and Ph.D. students: the Master’s students should graduate in two years, while the Ph.D. students are expected to graduate in five; thus, the first ones will just be graduating at the grant’s conclusion.
* Affiliate students: other degree-seeking graduate students in EEB, FWF, and EPP, as well as students in related UTK departments and institutes such as Earth and Planetary Sciences, Genome Sciences and Technology, and Geography. Affiliate students: will participate in one or more of the field courses or skills workshops. We expect the affiliate students to grow per year as the involved departments become more familiar with this program and its training; conservatively, we estimate five students joining as affiliates in the first year and more joining each year after that to have a total of 45 affiliate students.
* External participants: graduate students from other institutions, land managers, biocontrol workers, agency employees, or other non-academics who attend a field course or skills workshop. These experiences will deepen connections between the program and the broader community, and importantly expose students to professionals outside academia. A very conservative estimate of this number is 60 over the life of the grant, though given current interest in our field courses and skill workshops we expect the actual number to be far higher.
* Remote participants: a broad range of students who will access online teaching and training materials. NIMBioS experiences reveal that online video tutorials draw hundreds of views, and O’Meara’s course website for his NSF-sponsored flipped phylogenetics methods course, launched in January, 2016, supported 6,136 visitors from 94 countries to date.

**D. Major Research Efforts**

This project will catalyze foour areas of research. The first will be research performed by students while studying at the university, both while funded as part of this grant and, for Ph.D. students, while funded from other sources. The second will be research enabled through cross-disciplinary interactions fostered through non-academic partners affiliated with this project. The third will be published research based on assessments of the program’s success.

Students in this program will pursue research-based dissertations in areas relating to modern biodiversity. Most notably, the world faces a biodiversity crisis: human activities are driving some species to extinction, invasive species are a major economic risk ($70.4 billion for the agriculture in the US alone [4]), and the skills to identify critical species are being lost [5]. Student projects depend on an overlap in interest between the student and her or his potential advisor. Anticipated research projects will revolve around the following themes.

*Conservation of Biodiversity:* Several research groups focus on this area. For example, the Kalisz lab investigates forces that shape individual phenotypes and genomes, drive population level fitness and speciation, and alter standing levels of biodiversity within native communities. Possible graduate projects will investigate mechanistic hypotheses centered on how anthropogenic factors (e.g. habitat disturbance, overabundant deer, invasive species), alter species interactions in forests and drive native species declines.  Current effort focuses on mechanism underpinning invasive species disruption of native plant mutualisms (i.e. AMF, pollination), physiological, and demographic responses to invasion and the maintenance of native biodiversity. These projects leverage long-term databases from GSMNP and other field sites to address conservation and management issues at national and regional scales, creating links to careers in government, conservation NGOs, and state and national parks.

*Sustainability:* Research interests include plant-animal interactions and bioenergy sustainability. Connections with partner organizations include common interests in assessing landscape change and silvicultural practices on pollination. Graduate students could assist such efforts with field identification skills of pollinators interested in identifying pollen to species via DNA sequencing approaches to quantify pollen communities of specific pollinators. So, too, could graduate students with DNA sequencing skills interested in identifying insects. These students could move on to careers in federal or state agencies or agricultural businesses. Kwit and Kalisz work in this area, as well as potential affiliate faculty such as Paul Armsworth (EEB) and Jerome Grant (EPP)

*Analysis of Biodiversity Hierarchies:* Research in phylogenetic methods to address key questions in macroevolution and ecology. Most notably, one focus of O’Meara, Moulton, and several of potential affiliate faculty (Benjamin Fitzpatrick (EEB), Karen Hughes (EEB), Brandon Matheny (EEB), Jessica Budke (EEB), and Ernest Bernard (EPP)) has been development and/or use of approaches to delimit species [6], including cave fishes of the Eastern US [7] and North American bats [8]. Such skills are key to being able to identify biodiversity, especially cryptic biodiversity that is of grave conservation concern. Students working on such projects could pursue careers in conservation, at non-governmental organizations or in state or federal conservation agencies.

*Technology:*Developing software for biology is a major research goal for the Staton and O’Meara lab groups. The Staton group builds software for developing websites that store genotype and phenotype data (the open source Tripal project), and is currently funded to expand this software base to a mobile device application and online website interface for ecological data sampling. The software will enable scientists to develop an ontology-driven data collection schema, deploy this across mobile devices for field data collection, upload their data to the cloud, and return to the lab to filter, sort, and share data from an intuitive map interface. O’Meara’s group develops software for understanding evolution using phylogenetic trees. Graduate students interested in programming could help with software development, while field courses and student research projects could be used as test bed for the application. These students could move onto careers identifying genes of potential agricultural significance. Potential affiliate faculty member Mona Papeş (EEB) works extensively on GIS data analysis, which is of growing interest for careers in agriculture and invasive species management.

**E. Broader Impacts**

Science graduate programs must train students for a broad array of careers [Nature Editorial Board 9]. However, few graduate programs are configured for broad career outcomes. This project builds connections between graduate students and professionals outside academia and trains students for a wide variety of positions focused on biodiversity. The addition of necessary practical skills such as project management, science communication, and program assessment will position graduates to be competitive and successful in industry or academia. The open nature of the training pushes scientific knowledge into the public domain where professionals can learn from it, fulfilling a classic role of land grant institutions. Sponsored student research projects will span a variety of biodiversity questions, likely ranging from alpha taxonomy, to modeling population movement with climate change, to studies of urban ecology. Our approach is radically different. With this program, the “alternate” career is academia – our goal is to get our students out into the world working with real world biodiversity questions. Both the academic and non-academic paths have great value, but the latter needs much more emphasis. The triumphs and failures of this program, which will be communicated throughout the grant, will help create a prototype that other programs can adopt when they choose to bring the same rigor and attention to non-academic paths as to academic ones.

A key aspect of broadening participation in science is showing the various career paths one can take. For example, a traditional academic path involves multiple moves around the world, low financial rewards, and great uncertainty, while other paths may offer better options than this while having tradeoffs (fewer opportunities to affect students through teaching, more limits to possible research, and so forth). To achieve this, we will take advantage of events to reach undergraduates and the broader public. The first is to set up displays of research and career paths at our university’s Ag Day event, a way to connect the local community with the UT Institute of Agriculture. This is scheduled on the same day as a football game (which draws over 100,000 attendees) and features an insect petting zoo, farm animals, departmental displays, free food, and other activities designed to draw in a broad swath of the community. Core students will have a display and will talk to visitors about their chosen career paths and options in science. We will also partner with Darwin Day Tennessee (PI O’Meara is the faculty advisor), a group founded twenty years ago to educate the community about evolution. It has grown to feature nearly a week of events, ranging from keynote speakers like Neil Shubin who draw hundreds of visitors plus media coverage to teacher workshops to birthday parties for Darwin at the local museum. Core students will run a panel on careers involving evolution outside academia, targeted at local teachers and guidance counselors. This will help inform the local community about the importance of evolution (in areas ranging from antibiotic resistance to invasive species) as well as give those with extensive student contacts the ability to direct students into science-based careers other than academia.

Finally, this is an unprecedented time of threats to biodiversity. Our country desperately needs more research on threats and how to mitigate them, but we also need muddy boots on the ground to implement best practices. Students from our program will have deep knowledge of biodiversity, ecology, and evolution, while also having skills in project management and contacts with NGOs and private companies required to effect real change.

**F. Organization and Management**

The faculty involved in this grant as PIs and Co-PIs will comprise the Leadership Team. They already are well-connected (for example, Kwit has appointments in both EEB and FWF; O’Meara has served on committees for Ph.D. students of Moulton and Kalisz; and Staton, Kalisz, and O’Meara are all affiliated with NIMBioS). An organizational chart is included below, outlining responsibilities .

As PI, O’Meara will oversee the program to ensure goals are met. His management experience includes being an Associate Director for NIMBioS, filling leadership positions in the Society of Systematic Biologists, codirecting the annual iEvoBio conference for three years, mentoring 11 postdocs through his lab, and managing over $2.2 million in grants. O’Meara will oversee the Project Coordinator, a half time staff position based in EEB. He or she will be responsible for tracking student progress, matching students with internship opportunities, coordinating scheduling and space requirements for workshops, and the day-to-day tasks required in managing a set of students.

Kwit will serve as a bridge between the various academic communities, both on and off campus. Kwit’s research spans areas from warbler winter habitat management in the Bahamas, to bioenergy sustainability of switchgrass as a biofuel crop, oak savanna restoration, and animal-mediated seed dispersal, much of which is collaboratively supported from state and federal agencies and NGOs. He has a joint appointment in the Department of Forestry, Wildlife, and Fisheries in UTIA’s College of Agricultural Sciences & Natural Resources and the Department of Ecology and Evolutionary Biology in UTK’s College of Arts and Sciences. He is an ideal resource for students in this program, and will receive support to enable his time to be used for this. Kwit will oversee steady progress of the students and handling connections between them and internship opportunities.

Figure 2: Next-generation biodiversity organizational chart

Staton will lead the development of tutorials and workshops, assisted by O’Meara. Moulton and Kalisz will help foster multidisciplinary advisory teams by recruiting other faculty. They will also help ensure that data generated are deposited appropriately.

Evaluations will be handled by East Main Evaluation and Consulting, LLC; Dr. Barbara Heath will lead this group, assisted by staff or interns within her group.

**Figure 2.**  Next-Generation Biodiversity NRT organizational chart

Affiliate faculty will serve on multidisciplinary advisory teams. Each trainee will be housed in the lab of a member one of the three participating departments (faculty mentors could be member approved to advise students after receiving training in cross-cultural mentoring), but may have faculty from any of the following departments on her or his committee:

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| --- | --- |
| **Department for affiliate faculty** | **College** |
| Agricultural & Resource Economics | Agriculture & Natural Sciences |
| Agricultural Leadership, Education & Communications | Agriculture & Natural Sciences |
| Animal Science | Agriculture & Natural Sciences |
| Anthropology | Arts & Sciences |
| Biochemistry and Molecular Biology | Arts & Sciences |
| Biosystems Engineering & Soil Science | Agriculture & Natural Sciences |
| Business Analytics And Statistics | Business |
| Civil and Environmental Engineering | Engineering |
| Earth & Planetary Sciences | Arts & Sciences |
| Ecology & Evolutionary Biology | Arts & Sciences |
| Entomology & Plant Pathology | Agriculture & Natural Sciences |
| Food Science & Technology | Agriculture & Natural Sciences |
| Forestry, Wildlife, & Fisheries | Agriculture & Natural Sciences |
| Geography | Arts & Sciences |
| Management | Business |
| Mathematics | Arts & Sciences |
| Microbiology | Arts & Sciences |
| Plant Sciences | Agriculture & Natural Sciences |

Students will thus be mentored by faculty with a wide variety of faculty. This also serves as a gentle way to infuse the idea of non-academic jobs as a major focus of a graduate program to a wider audience within this university, as affiliate faculty will be introduced to this idea through their participation.

A sense of community will be fostered organically through overlapping courses and workshops taken by students and taught by faculty. Two social gatherings per year will be scheduled: one in February at the time of recruiting and one at the end of the academic year. These will feature core students and their families, recruited applicants (in Feb.), the Leadership Team, and other members of involved departments. We will also create a website and chat room for the project. The chat room will allow participants to discuss issues as they arrive, celebrate successes, and ask for advice. The technology we will use is a service such as Slack or Gitter; given the anticipated start date for the grant approximately 1.5 years in the future, these particular services may have been replaced; we will use the equivalent at that time.

Students in our program will be full members of one of the three collaborating departments. Our plan is that each department receives at least 25% of all students. Admitted students will be assured of funding until graduation (as long as they meet adequate progress guidelines). After their NRT funding is completed, EEB Masters and Ph.D. students will continue on guaranteed TA or RA lines until graduation, a model used for trainees in our NIH PEER program. For EPP and FWF students, most admitted students will be seeking Master’s degrees and are expected to graduate in two years.

*External Advisory Board:* Collaborating with external partners is key, both as members of the External Advisory Board and as internship hosts. The advisory board will consist of one representative each from a nonprofit entity, a government agency, and a private company, plus one graduate of each department with a career outside of academia. The board will meet annually to discuss program progress and will provide guidance on emerging training and skills needs. Our external partners will also provide internship opportunities and mentoring. As students enter the program, additional internship partners will be sought as needed based on each student’s intended career path, so that professional networks formed during internships can help students receive placement after graduation.

*Coordination with Administrators:* A training grant will fail without institutional support. At the level of department heads, we have one department head as a Co-PI on the grant, an associate head as PI, and have had frequent contacts in developing it with heads of the other two departments (with particular concern for how participation in this grant affects tenure considerations for Co-PIs who are junior faculty). We have also met with Associate Dean Brothers in the Graduate School and will continue to consult with him moving forward.

We will coordinate with higher level administrators in two ways. The first is informal: we will invite them to our two annual social events so they can form connections with our students and our external partners. The second is through an annual joint meeting with heads of the three collaborating departments, grant personnel, the Dean of the Graduate School, the Associate Dean for Academic Programs at the College of Arts and Sciences, and the Associate Dean at the College of Agricultural and Natural Resources. One week before the meeting, all the involved parties will receive a written report listing grant goals for the previous year; delivery of those goals; goals for the next year; and university, college, and department policies or procedures that have helped or hindered the achievement of those goals.

An important aspect of sustainability is aligning with broader university directions. The university has recently implemented its VolVision 2020 strategic plan, which includes goals as well as assessment metrics. It notes that “doctorate recipients are more likely to pursue nonacademic careers than in the past, which relates to the need for additional career development for doctoral students.” Assessment goals include career placement, and specific recommendations include improved career coaching and career placement support. Our project, with its robust assessment model (see below), will provide a prototype that other academic units can adopt, and its dovetailing with the overall University direction suggests long term support for the aspects that work best. The College of Arts and Sciences is preparing a strategic plan in response to the university’s overall goals. It will be completed in Spring 2017, and its current draft includes increasing recognition on non-academic careers and strategies to enhance non-academic career options, as well as assessment tools for what aspects prepared graduates for their careers. Concrete metrics include whether a unit participates in career development opportunities, number of non-academic career workshops or other opportunities, and more. This will create incentive for other departments to encourage affiliate students.

*Sustainment Plan:* Sustaining the program after the conclusion of NSF funding is key. First, the involved departments will continue funding the NRT trainees in the same manner as regular trainees, assuming adequate progress, once the grant ends. The long term vision is that this new traineeship gradually becomes integrated into regular graduate training: as faculty and students see the benefits of biodiversity training for careers outside academia, cultural expectations of the programs will shift. In the same way training for academic careers is currently the default, and which thrives despite lack of NSF funding explicitly for this, we expect our training model to diffuse through the relevant programs. Similarly, tasks that will be undertaken by the Project Coordinator to start will devolve to the graduate coordinators of each department. Similarly, the paradigm shift in training approach, including partnerships with potential employers through internships, will be continued as faculty, students, and partners experience the benefits of this. Cross-disciplinary mentorship of students will foster research projects and grant proposals spanning the included departments (and this will be measured as part of the assessment process).

**G. Recruitment, Mentoring, and Retention**

This NRT has a two-fold strategy to recruitment and retention: providing student access to the program and ensuring that potential graduate students from all walks of life are aware of the opportunity to apply, and creating an environment of inclusion with mentoring and enrichment experiences to maintain retention and facilitate attainment of students’ goals.

*Recruitment:* This NRT program will work closely with UT’s Graduate School, which supports 55 doctoral degree and 76 Master’s degree programs, to recruit a diverse population of students. We will join Graduate School representatives as they participate annually in graduate school fairs across the Southeast and at national conferences such as the annual Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) conference, which has 3,600 attendees from a wide variety of backgrounds, as well as professional conferences. In addition, we will provide printed and online promotional materials about the NRT Traineeship, which will be disseminated in these venues and others.

We will also leverage the Graduate School’s recruitment activities that focus specifically on underrepresented students, such as campus visits from TRIO, McNair, and NSF LSAMP programs throughout the region. Finally, we will work with colleges throughout UT that engage in decentralized recruitment activities taking place at the departmental level. Each year, we will sponsor two major events for students and prospective students, one during a graduate recruitment weekend in early spring, focused on prospective students, and the other at the end of the spring semester, focused on celebrating graduate students’ progress.

Institutional support will come from Associate Dean of the Graduate School Ernest Brothers (see letter of support), who is an expert in graduate student diversity and mentoring. He recently presented a workshop, “Diversity and Mentoring in Academia,” to Oak Ridge National Laboratory and a workshop, “Strategies for Mentoring Diverse Graduate Students and Faculty” to UT’s Psychology Department. He will present similar workshops for our faculty, to set the stage for a welcoming environment upon NRT Trainees’ arrival in Knoxville. Brothers is on several advisory boards related to diversity and graduate student training, including the Tennessee Louis Stokes Alliance for Minority Participation, and serves as a CoPI on UT’s NIH-funded Program for Excellence and Equity in Research (PEER). The Graduate School also sponsors a diversity job fair and training in teaching, presentations, and research conduct.

*Mentoring and Retention:* Mentoring and retention will build on the strengths of our programs. The EEB department has also created its own tracking software to monitor grad student progress towards degree and to automatically highlight potential issues while building up a long term, secure, database of progress and outcomes. Trainees will be mentored through standard committee structures but also through annual meetings with the Project Coordinator (one of the core faculty). Students will also be mentored through the informal networks fostered by their internships in their second year of grant funding.

Co-PI Kwit will oversee trainees’ mentoring activities and coordinate collaboratively with Dr. Brothers, who also oversees the Office of Graduate Training and Mentorship within the Graduate School. One of these activities is a weekly discourse session, modeled on a NIH-funded PEER initiative to increase the number of exceptional underrepresented students graduating with doctoral degrees in STEM disciplines at UT. This session will create cohesion for our students (the funded trainees and those affiliate students who opt in) within and between cohorts. These will be opportunities for students to discuss current challenges and solutions, professional and scientific skills, plans for outreach, and experiences during internships. Students will develop an individual development plan in their first semester and monitor their progress toward accomplishing their goals. This plan will help keep their focus on the skills needed for their chosen career and ensure timely graduation. It will also be crucial in helping to identify whether they want to intern at one of our existing external partners or whether Co-PI Kwit and the Program Coordinator should reach out to a new potential partner so the student will have a good placement in her or his first summer.

We will create a community of scholars within NRT cohorts and connect students with other programs at UT. The goal is to create experiences that further each student’s professional aspirations. We will leverage existing resources, such as UT’s Multi-Cultural Graduate Student Organization, which connects members of underrepresented groups across campus, to help students connect with others. Working with the Graduate School’s new customer relationship management system, we will be able to identify where students were recruited and when they applied, were accepted, enrolled, and matriculated. Such a system enables the NRT program to automatically respond to students, providing immediate feedback.

**H. Performance Assessment / Project Evaluation**

The evaluation of this NRT program will be conducted by East Main Evaluation & Consulting, LLC of Wilmington, NC. EMEC provides consulting and evaluation services with expertise in science and mathematics education and technology. This effort will be managed by Barbara P. Heath, Ph.D., with implementation support from additional staff. Dr. Heath founded EMEC in 2004 and has evaluated over 30 STEM focused programs including CyVerse (formerly iPlant), multiple Math and Science Partnerships, and various informal education efforts.

The evaluation of this NRT will follow a process-and-outcome framework. This approach provides a comprehensive model to continue to analyze the project activities while gathering data on the program effects. Within this framework, a logic model (see Table 4) is used to represent the sequence of steps between program services and outcomes [10]. The evaluation tables represent the logic model developed for the proposed NRT program. The outputs and outcomes shown include identified performance measures and expected competencies that are anticipated effects of the project activities.

Process evaluation seeks to answer two main questions. First: Are the services and support functions consistent with the program design? Second: Are the services reaching the target population? This approach was selected as the most appropriate method for measuring the processes related to the primary program activities. The program impact theory (Figure 3) guides the evaluation team in establishing the links between program services and the overall benefits or effects of the program. This approach provides the most appropriate means for measuring the intermediate effects of the target populations.

***Figure 3:*** *Program Impact Theory*

The evaluation will utilize a mixed methods approach to gather both qualitative and quantitative data. Data collection for the external evaluators will include document review, surveys, interviews, and observations. Project documents will be collected and reviewed with assistance from the Project Coordinator. Documents will include (but not limited to) rosters, student data, course descriptions, and university policies. Document review will provide the opportunity to generate program outputs as well as track the project implementation and related changes. Surveys will be developed and deployed to trainees to collect data for satisfaction and knowledge and skill gains. Trainee surveys will be deployed each semester, post-workshop, post-internship, and post-graduation. Trainee surveys will be deployed to all participant students regardless of their funding status within the project. Additional surveys will be deployed to faculty and administrators to collect satisfaction, course or departmental changes, and suggestions for improvements. A trainee exit interview will be developed and instituted as trainees complete the program of study to collected final impressions of their experiences. Last, observations will occur when evaluators visit the site. This will include observing courses and field experiences. Regular observation will also occur during Leadership Team meetings.

The data collected will be analyzed, and results will be provided to the Leadership Team through formative reports and committee meetings. The formative process will enable the Leadership Team to make data-informed shifts to the project implementation plan if warranted. An annual report will be produced for Years 1-4. All results will be provided to the Leadership Team and disseminated as appropriate to participants, faculty, and administrators. The summative evaluation process will occur during the final phase of program implementation and will result in a summative report at the conclusion of Year 5. This report will include all data analyses and results for the full program implementation. It will be the basis for a peer-reviewed manuscript that describes the program model and effects on the target populations.

**Table 4.** Evaluation and assessment

**Goal 1:** Create a workforce to fill the need for biodiversity expertise in the US.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Strategy | | Output | Outcome | Data Method |
| Course work | # and description of courses offered pre/post program  # students enrolled in each course each semester  # students completing each course each semester  # trainees completing comprehensive examination  # completed theses  # completed dissertations  # of students graduating from the program | | * Trainees are satisfied with program * Trainees gain a understanding of biodiverse concepts * Trainees gain professional skills * Trainees successfully defend their thesis or dissertation * Increase graduate student retention rate * Trainees secure related career post-graduation | * Document review * Trainee survey (semester) * Trainee exit interview * Trainee follow-up survey |
| Two week field course | # and description of field courses  # students enrolled in each course each semester  # students completing each course each semester  # of faculty teaching program courses  # of departments collaborating | | * Trainees are satisfied with field course * Trainees gain understanding of field methods * Faculty and institution undergo paradigm shift * Increase in departmental collaboration | * Document review * Trainee survey (semester) * Trainee exit interview |
| Workshops and tutorials | # and description of workshops and tutorials offered  # of streamed workshops and tutorials  # of workshop participants  # of tutorial views  # workshop instructors | | * Trainees are satisfied with workshops * Trainees gain technological skills * Trainees gain domain knowledge * Expand program reach through streaming | * Document review * Post workshop survey |
| Internships | # students accept internship  # students complete internship  # students placed in internship companies  # companies offering internships  # interns hired | | * Trainees increase professional network * Trainees gain skills needed for career outside academia | * Document review * Intern survey |
| Outreach | # and description of outreach events  # trainee participants per event  # trainee displays per event  # non-academic publications | | * Connect trainees with undergraduates and targeted community members (e.g. teachers) * Disseminate findings to broad audience | * Document review |

**Goal 2:** Create a prototype for institutional culture change toward non-academic career paths.

|  |  |  |  |
| --- | --- | --- | --- |
| Strategy | Output | Outcome | Data Method |
| Document program implementation over 5 years (including revisions) | # leadership team meetings  Timeline  Leadership meeting minutes  # significant revisions made to program  Description of rationale for changes  Updated timeline  # and description of advisory committee  # advisory committee meetings  Advisory committee meeting minutes  # of faculty teaching program courses  # of departments collaborating | * Narrative description of program implementation * Faculty and institution undergo paradigm shift * Increase in departmental collaboration | * Document review * Leadership team interviews * Meeting attendance * Faculty survey (semester) * Department Chair survey or interview |
| Disseminate program results via publications and presentations | # and description of presentations  # and description of publications | * Prepare and submit publication for peer review * Prepare and present results at conferences | * Document review |

*Evaluation Timeline*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Activity | Year 1 | | | Year 2 | | | Year 3 | | | Year 4 | | | Year 5 | | |
|  | Fall | Spr | Sum | Fall | Spr | Sum | Fall | Spr | Sum | Fall | Spr | Sum | Fall | Spr | Sum |
| Baseline data |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Document review |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Student survey, post |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Trainee exit interview |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Trainee follow-up |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Workshop survey, post |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Internship survey |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| LT interviews |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Meeting attendance |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Faculty survey, post |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Dept chair interview |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Observation |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Annual report |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Summative report |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Manuscript prep |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**I. Recent Student Training Experiences**

Over the past five years, PI O’Meara has had four graduate students. All are still currently enrolled: two are on schedule to receive their Ph.D. in ecology and evolutionary biology as well as a Masters in statistics this semester, another recently received a DDIG award, and a fourth recently took his Ph.D. qualifying exam. The two students planning to finish this semester have decided to pursue careers outside of academia, and enrolled in and successfully completed a program to earn a Master’s degree in statistics while in a Ph.D. program with this intention. They both had internships at the Tennessee Valley Authority (one received an offer of a job once she graduated), and one has also interned with our athletic department analyzing academic progress of athletes. Half of O’Meara’s students identify as women, and one identifies as Hispanic. O’Meara serves on approximately one-third of graduate student committees in EEB and has also served on student committees in EPP, Earth & Planetary Sciences, Microbiology, and Genome Sciences and Technology. O’Meara has served on EEB’s graduate admission committee and now is associate head for graduate affairs in the department; as part of this, he has run training for graduate students in grant writing. As associate director for postdoctoral training for NIMBioS, he has also organized training sessions for postdocs pursuing careers in biology, math, and statistics.

Co-PI Kwit has had four graduate students in his lab over the past five years. All are still currently enrolled: two are on schedule to receive their Ph.D. in EEB, another is a co-advised natural resources Ph.D. candidate in FWF, and a fourth is pursuing a Master’s degree in wildlife and fisheries science in FWF. The latter is pursuing a career outside of academia, and is about to participate in an internship with the National Parks Conservation Association. Three of Kwit’s graduate students identify as women. Over the past two years, Kwit and one of his EEB graduate students have served as undergraduate mentors at the University of Virginia’s Mountain Lake Biological Station, a NSF-funded Research Experience for Undergraduates program. Kwit currently serves on graduate student committees in FWF, EEB, Plant Sciences, and at other universities.

Over the past three years, Co-PI Staton has trained three graduate students in her lab. One graduated with a Master’s degree in EPP; the other two are currently enrolled and on schedule to receive Ph.D.s; one in EPP, the other in Genome Science and Technology. The graduated Master’s student is currently working as a staff scientist at ORNL. Two of the three students self-identify as female and two are foreign nationals. Staton serves on 14 graduate student advisory committees across five departments: EPP, EEB, Energy Science and Engineering, Genome Science and Technology, and Animal Science. Co-PI Staton’s position is unique in that her appointment specifies 50% time devoted to providing bioinformatic and data analysis expertise and consulting for faculty, staff and students. This positions her to successfully build interdisciplinary programs spanning multiple departments and to focus on developing and running workshops and courses for broadly needed data analysis techniques.

**J. Results from Prior NSF Support**

**B. O’Meara** DEB-1257669: Collaborative Research: *Phylogeographic Inference Using Approximated Likelihoods,* $340,000, 2/28/13 – 2/28/17. Intellectual Merit: we developed, implemented, and tested models for examining phylogeographic structure of populations or species. These models can allow for gene flow between populations, speciation events, and population size changes. We also created models to allow inference about species delimitation (whether a set of populations should be treated as one species or multiple species). Broader Impacts: We have run workshops in Ohio and Louisiana with travel support for students to train them in phylogeography, and students are already using our software in their research. To aid in communication and outreach, our software allows creation of 3D models, which can be embedded in presentations or even 3D printed using an output file from the open source software R (see figure). The postdoc involved in the grant chose to take a position in cancer research outside academia. We have also created a website and discussion group to promote long term use of the software, which is open source. Products: We have published two papers about this approach [8, 11], have two more in press, and are working on a general review paper about model comparison in phylogeography.

**S. Kalisz,** NSF DEB 0958676, $619,208, (includes equipment [NSF DEB 144552] and REU supplements) 5/1/2009-4/30/2015, *LTREB: The population dynamics of forest understory invasion: mechanistic experiments with generalist herbivores, natives, and invaders*, LTREB RENEWAL DEB 1457531 $520,383 (included REU supplements) 5/1/2015-4/30/2020. Intellectual Merit*:* This long-term project investigates long-lived herbaceous species experiencing disrupted species interactions through exotic invasion and overabundant deer. Results demonstrate the deer facilitate invader success and exotic decline, and the allelopathic invader suppresses the AMF-native plant mutualism in the soil, essentially turning the AMF fungal mutualist into a parasite resulting in suppression of native plant species’ physiological function and vital rates. Broader Impacts*:* Kalisz presented 12 lectures to the public and state, local, and national officials on deer, forest health, and invasive species management. Publications from this LTREB were highlighted in 10 popular press articles including Nature News, on the radio including 64 public radio stations in the northeast US and Canada. Kalisz functions as an advisor to the Fox Chapel Borough government regarding stewardship, management, and conservation of their land holdings. Kalisz served as the Science Advisor on the development of "Virtual Trillium Trail" game software, an interactive K-12 educational tool for exploring biological diversity in the eastern deciduous forest built on Kalisz’s database from Trillium Trail in PA. The game is freely distributed any educator for classroom use and fits the State of PA STEM guidelines for middle school students. Products*:* This resulted in 11 publications [12-22], six papers in review, and a virtual *Trillium* trail website.

**J. K. Moulton**, DEB-0933218; *MIDGEPEET: A Collaborative Effort to Increase Taxonomic Expertise in Understudied Families of Nematoceran Diptera;* $750,000, 09/1/2009–08/31/2015. Intellectual Merit: Morphological and molecular systematic studies were conducted on a number of understudied dipteran families,, resulting in new species descriptions, identification keys, phylogenetic inferences, and increased basic knowledge of the families and the order. Broader Impacts: This multi-institutional collaboration of researchers provided mentoring to the next generation of taxonomic specialists (i.e., systematists) for several families of lower Diptera identified as being in need of young specialists capable of providing taxonomic expertise for the next several decades. These new systematists received hands-on training in field research and traditional morphology-based and molecular systematics, including phylogenetics. This award provided training to nine international visiting scholars, one technician, three postdoctoral researchers, 10 graduate students (7 Ph.D. & 3 M.S.), 9 undergraduate students, and one high school student. Synergistic activities through the Iowa State University Insect Zoo (e.g., development of outreach programs focused on the role of aquatic Diptera in medical entomology and in the biomonitoring of aquatic ecosystems) and the Iowa State Insect Collection (e.g., collection-improvement projects, initiation of a database system, and digitization of slide- and fluid collections) further enhanced the impact of the project. Lucid keys to Chironomidae have been improved, increasing our ability to identify this important group of freshwater indicators of water quality. A molecular workshop conducted at UT provided experiential learning to PEET- and non-PEET-supported participants. Products: Outputs include traditional and web-based products, , six book chapters, and nearly four dozen peer-reviewed articles [23-67]. Improvements to existing assets were made, including improvements to LUCID keys for Chironomidae, and the Taxonomic Inventory of Simuliidae. Several repositories have and will continue to receive primary types and voucher specimens of all Dipteran families studied. Numerous genetic sequences have been and will continue to be deposited in GenBank.

**M. Staton**,NSF DIBBS-1443040, *Tripal Gateway, a Platform for Next-Generation Data Analysis and Sharing,* $1,485,021, 1/1/2015-12/31/2017. Intellectual Merit: This award supports expansion and new functionality of Tripal, an open source software package for building community genomic and biological websites and databases. Broader Impacts: This work establishes exciting new cyberinfrastructure resources for biological science communities that opens new data analysis opportunities for scientists through faster and more powerful online resources. Products: papers [68-70], software products: BDSS v1.0.1b2 [71]; Tripal v3 alpha [72]; blend4php [73]; Docker Images with Tripal and Galaxy [74, 75] ; Tripal elastic search [76], NGS data Galaxy workflows [77].

**C. Kwit** has not had prior NSF support over the past five years.

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