**NRT: Next-Generation Biodiversity Training**

**A. List of Core Participants University of Tennessee, Knoxville (UTK); University of Tennessee Institute of Agriculture (UTIA)**

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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 |

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

Understanding biodiversity is key for building workforce capacity and knowledge in many 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% of students are hired in academia within five years of graduation [2]. A critical need exists to train STEM students for high-priority careers in non-governmental organizations (NGOs), government agencies, and businesses related to biodiversity, careers that are often explicitly seen as “alternate” paths by faculty mentors; however, students are not encouraged to pursue these career paths [3]. In addition, an analysis, recently published in *Proceedings of the National Academy of Sciences*, identified training students for the breadth of available careers as one of eight consensus recommendations out of 250 total recommendations [4]. It is becoming increasingly clear that 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. The proposed NRT seeks to train such biodiversity scientists for careers outside academia.

Motivated by the increasing interests of UTK/UTIA students in non-academic careers, the current state of relevance and marginalization of natural history knowledge [2, 5], and the importance of linking natural history knowledge with new technologies to the benefit of science and society [6], we surveyed potential employers of biodiversity STEM graduates regarding the needed skills of future employees. Repeatedly, employers indicated a desire for detailed expertise in one or more taxonomic groups, along with technical competencies (e.g., GIS, genomics, statistics, technical writing) to both gather and synthesize biodiversity data. Our regional data align with the findings of Blickley et al. [7], 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, the combined flagship and land grant university of the state, 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 UTK campus with UTIA, this NRT program will create an interdisciplinary environment for the next generation of experts in biodiversity science. Our goal is to generate a culture change, which will generate biodiversity science 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 science expertise in the US.

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

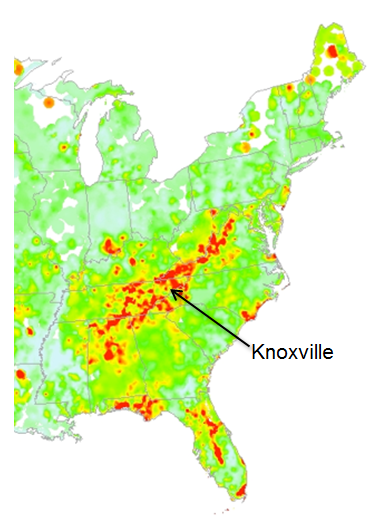
*Understanding the Need:* Human health, food security, resource conservation and management, and recreation all rely on knowledge of biodiversity. At their intersection, many of the ecosystem services that society deems important — increased agricultural and natural resource production, water quality and fresh water abundance, and disease control [8] — are directly correlated with biodiversity in both agricultural [9] and natural [10] systems. Assessing and conserving biodiversity, especially in our current era of anthropogenic change, will require biologists trained in a wide array of skills [6] 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 NRT participant 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 business skills such as project management [7]. Students are eager for these skills; for example, a pilot course in professional development in Hawaii attracted three times as many students as expected [11].

*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. It 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 hands-on experiences with new technologies into the traditional realm of biodiversity research has only recently been posed [6]. However, the benefits of experiential learning are well substantiated in higher education and include increased retention [12], increased abilities to solve complex problems [13], and greater student motivation [14].

UT and its environs are the ideal location to establish such a program. For national and global biodiversity experts, we are a key destination because of the region’s high biodiversity (see *Fig. 1)* and existing groundwork to map it (e.g. All Taxa Biodiversity Inventory has mapped 19,000 species locations in the Great Smoky Mountains National Park (GSMNP); Discover Life in America), research collections (TENN Herbarium housing vascular plants, bryophytes and fungi, Etnier Ichthyology Collection, UT Caddisfly Collection, McClung Museum), proximity to two National Ecological Observatory Network (NEON) sites [15], and faculty-led field courses about fish, fungi, plants, reptiles, amphibians, birds, mammals, and invertebrates. Further, The Howard H. Baker Jr. Center for Public Policy, located at UTK, provides policy makers, citizens, scholars, and students with the information and skills necessary to work effectively within our political system and to serve our local, state, national, and global communities through a series of public lectures and programs focused on Energy & Environment, Global Security, and Leadership & Governance. 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. UT also has extensive collaborations, including graduate student training, with Oak Ridge National Laboratory (ORNL), a US Department of Energy facility with research efforts on biofuels, climate and biochemical models, urban dynamics, and high-performance computing.UTK and UTIA faculty’s technological skills are at the cutting edge, with expertise in environmental DNA monitoring, high-performance computing, next-generation sequencing, statistics and modeling, and use of drone, satellite imagery and spatial analyses for addressing biological questions.



**Figure 1.** Heat map of areas with high species biodiversity coupled with conservation need [1].

Our proposed NRT program covers six components (*see Fig. 2):* (1) Internships; (2) Core biology training in an interdisciplinary approach including several academic disciplines, such as ecology, evolution, genetics, and natural history; (3) Technology training in remote sensing, genomics, and GIS; (4) Leadership, management and communication training; (5) Trainee outreach, and (6) Interdisciplinary thesis research projects guided by Multidisciplinary Advisory Committees (MAC), which will facilitate interdisciplinary synergy and guide trainees’ research projects. Thesis committees will be comprised of three faculty from the student’s home department and two committee members who are chosen from affiliated faculty *(detailed in Section D)*. Through their thesis research, NRT trainees will use skills developed in these modular areas to prepare for top jobs. Satisfactory progress will be measured by benchmarks set in each of the students’ home departments. Our model for graduate student training will be monitored and assessed as a prototype for building student awareness and faculty support for non-academic career choices by an outside consulting agency.

**Figure 2.** The Next-Generation Biodiversity Training NRT builds interdisciplinary synergy with attention to training, experiential learning and engagement, and strong mentoring/advising.



In brief, 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 coordination with colleagues to create 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 UT, as well others, detailed in Section C, below.

*Outcomes:* The overall goal is to train graduate students with Master’s and Ph.D. degrees who intend to pursue careers in business, NGOs, or government. Throughout the life of the program, integration with our external partners will help us tailor training to meet their key needs and ensure student success. 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 evidence-based, 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 seen a substantial set of students move on to careers outside academia, like most science programs across the US, we have not done enough to prepare students for this path.

*Context for Added Value:* We will track NRT student outcomes to assess our program’s success relative to current student placement *(see Fig. 3).* All of our departments currently have a substantial proportion of graduates going on to academia, but many students *(red bars, Fig. 3)* are employed outside academia. These baseline data will help measure the effectiveness of our program in graduate placement. New data will allow us to track the integration of program participants into alumni networks, especially those outside academia. For example, EEB’s placement of graduate students over the past 16 years shows 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 3. Graduate student placement from EEB, EPP, and FWF departments at UT. Blue areas are academic career paths, red are non-academic paths [16].

**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 (*see Broader Impacts*); and
6. Interdisciplinary research projects guided by Multidisciplinary Advisory Committees (MAC) that build on the synergy among faculty in EEB, FWF, and EPP.

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| **Table 1.** Trainee course requirements. | |
| **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 1)*. 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 and synergistic mechanisms for novel outcomes.

*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 already 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. To further the connection between mentors and departments, at least two seminars a year will be delivered by members of partner organizations. 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. 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.

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. FWF has well-established internship opportunities for its undergraduate majors. 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.

*Coursework:*  Trainees will pursue courses across each of three types: core biology, technology, and management/communication/assessment. In addition to approximately 50 biological courses, this program will complement training with technology and business-related skills (*see Table 2 for examples)*. 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.

Semester-long courses utilize existing courses span three areas. Core biology courses are provided by traditional graduate student offerings across departments, spanning ecology, taxonomy, anatomy, physiology, evolution, and conservation.

**Table 2.** Examples of courses to supplement core biological training.

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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 including genomic data analysis |
| FWF 530 | GIS for Natural Resources | Geographic information system data for forestry |
| EEB 5XX (planned course) | Spatial Analyses using UAVs | Use of drones to gather environmental and species distribution data |
| EEB 5XX (planned course) | Introduction to Molecular Techniques | Hands-on course teaching lab techniques and troubleshooting to generate genomic and genetic data |
| BZAN 545 | Database and Big Data Technologies | Relational and non-relational databases; scripting 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 | Emerging philosophy of leadership in business, education, and foundations |
| ALEC 520 | Leadership Development in Organizations and Community Nonprofit | Emphasis on leadership in agricultural professions |

*Field Courses*: Hands-on experiences are key ways to promote learning [17] and are a central goal of the UT administration. UT faculty in our three departments currently teach field courses covering a wide variety of organisms and ecosystems that provide immersive learning environments. For example, 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 and Ornithology will be newly offered for mini-term 2017) that will leverage EEB’s field station just outside the Great Smoky Mountains National Park. EEB’s natural history courses constitute a critical area of biodiversity training that is lacking in most graduate programs.

The value of our courses to training next-generation biodiversity science experts is 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 current 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 further 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.

For example, 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 (National Institute for Mathematical and Biological Synthesis) led by new EEB/NIMBioS faculty, M. Papes.

A communications workshop, taught in conjunction with UTK’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 3.** Expected timeline for participation of funded trainees, affiliated students and external participants in this Next-Generation Biodiversity NRT. | | | | | | |
| **Participants** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Total** |
| Number of new NRT trainees admitted annually | 4 | 5 | 4 | 4 | 0 | **17** |
| Second-year funded trainees | 0 | 4 | 5 | 4 | 4 |
| Cumulative number of Master’s trainees graduating | 0 | 0 | 2 | 4 | 6 | 8 |
| Cumulative number of PhD trainees post 2-yr funding (to graduate in years 6-9) | 0 | 0 | 2 | 5 | 7 | 9 |
| New affiliate students per year (estimate) | 5 | 7 | 9 | 11 | 13 | **45** |
| New external participants per year (minimum estimate) | 10 | 15 | 15 | 15 | 15 | **70** |

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

* Trainees (funded students): Seventeen Ph.D. or Master’s students who fulfill the full slate of program components in our core NRT program and who receive stipends (plus tuition and benefits) for two years each. Based on available information from 54 NRT-eligible students admitted over the last five years, 74% identify as female, 5.6% identify as Hispanic, 5.6% identify as African-American, and 1.9% identify as American Indian. The majority of our graduate students are recruited from the national pool, only 24% graduated from UTK (usually as undergraduates) before enrolling in our graduate program. The timeline for admission of trainees is presented in Table 3. We expect an even mix of Master’s and Ph.D. students. Master’s students should graduate in two years, while the Ph.D. students are expected to graduate in five. Given a higher affinity for non-academic careers in some underrepresented groups [18], we anticipate greater participation from those groups.
* 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 can participate in one or more of the field courses or skills workshops. We expect the affiliate student numbers to grow per year; conservatively, we estimate a minimum of 45 affiliate students over the course of the NRT award.
* 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. We conservatively estimate 70 external participants 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 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, has supported 6,677 visitors from 94 countries to date.

**D. Major Research Efforts**

This project will catalyze and advance two types of research: thesis research performed by students while studying at the university and research based on assessments of the program’s success *(discussed in Section H: Performance Assessment / Project Evaluation)*. This research will address current research needs, recognizing that 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 agriculture in the US alone [19]), and the skills to identify critical species are being lost [20]. NRT trainees will pursue research-based dissertations in

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| **Table 4.** Biodiversity science capacity of departmental faculty. | | | | | |
| Department | Field skills / taxonomic knowledge | Conservation / invasion / biodiversity / policy | GIS / spatial analysis | Modeling / Statistics | Ecological & evolutionary theory & principles |
| EEB | 16 | 8 | 2 | 7 | 28 |
| FWF | 13 | 13 | 1 | 4 | 29 |
| EPP | 10 | 6 | 2 | 1 | 20 |
| **Total** | **39** | **27** | **5** | **12** | **77** |

areas relating to modern biodiversity issues. Thesis research will be shaped by the overlap in interest between the student and their potential advisor (*Table 4)*, guided by each student’s MAC. This innovative process will provide student access to top scholars, such as Dr. Dan Simberloff, a member of the National Academy of Sciences, and many other world-renowned scholars on campus. Anticipated thesis research projects will revolve around the following themes.

*Conservation of Biodiversity:* Several research groups focus on topics related to biodiversity, conservation, and policy. For example, Buehler, C. Harper, Keyser, and Kwit (FWF) have all worked on management of disturbed systems and restoration, with aims driven toward increasing abundance and diversity of wildlife species. Wildlife diseases and their impacts constitute a main research area in the Alford, Eda, Gray, Hickling, D. Miller, Muller and Willcox labs (FWF). Projects in these labs have links with federal and state agencies and NGOs. In EEB, the Bailey, Kalisz, Fordyce, Schweitzer, Sheldon, and Simberloff labs investigate forces that shape individual phenotypes and genomes, drive population-level fitness and speciation, and alter standing levels of biodiversity within native communities. In addition, the Armsworth, Echternacht, Giam, Gaoue, Kalisz, McCracken, Simberloff and Schussler labs focus on invasion biology, conservation, and policy. Identifying biodiversity is an important first step for conserving it, and departmental members have described new species of hexapods [21-24], plants [25, 26], fungi [26, 27], and other organisms. Possible graduate projects could investigate mechanistic hypotheses and develop theory centered on how anthropogenic factors (e.g. habitat disturbance disease, invasive species) alter species interactions and drive native species declines. Current efforts focus on mechanisms underpinning invasive species disruption of native plant mutualisms (i.e. mycorrhizae and pollination), physiological, life history, and demographic responses of native biodiversity and invaders. These projects leverage long-term databases from NEON, 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 & Ecosystem Services:* 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 and seed dispersal. Graduate students could learn skills ranging from field identification of pollinators or seed dispersers, pollen or seeds, to the application of DNA sequencing approaches to quantify pollination and seed dispersal effectiveness. Graduate students with prior DNA sequencing skills could identify organisms providing ecosystem services. These students could move on to careers in federal or state agencies, NGOs, or agricultural businesses. Kwit (FWF) Kalisz, Armsworth (EEB) and Grant (EPP) work in this area; Buehler, Gray (FWF) and McCracken (EEB) could also contribute to this area.

*Analysis of Biodiversity Relationships and Communities:* Research in phylogenetic methods and the analysis of community structure address key questions in macroevolution and ecology. Notably, one focus of O’Meara, Moulton, and several faculty (Fitzpatrick, Hughes, Matheny, Budke, Williams, Small (all EEB), and Bernard (EPP)) has been the development and/or use of approaches to delimit species [28], including fungi, bryophytes and vascular plants, cave fishes of the Eastern US [29], North American bats [30], salamanders, springtails [21], and midges [23, 24]. In addition, empirical and statistical approaches addressing the role of genetic and phenotypic variation within species on community composition (Bailey, Fordyce, Riechert, Schweitzer (EEB)) are also currently being developed. These skills and approaches are necessary for delimiting biodiversity, rapid radiation, hybridization, and especially cryptic biodiversity that is of grave conservation concern. Students working on such projects could pursue careers in conservation, at NGOs or in state or federal conservation agencies.

*Technology and Model Development:*Developing software and statistical and mathematical models for biology are major research goals for the Staton (EPP), and O’Meara, Gross, Fefferman, Gavrilets, Gilchrist, and Fordyce (all EEB) lab groups. For example, 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 beds for its application. These students could move onto careers identifying genes of potential agricultural significance. Papeş (EEB), Trout, Fryxell (EPP), and Zobel (FWF) work extensively on GIS data analysis, which is of growing interest for careers in agriculture, invasive species management, and conservation.

**E. Broader Impacts**

Science graduate programs must train students for a broad array of careers [Nature Editorial Board 31]. However, few graduate programs are configured for broad career outcomes. By design, our program itself is a broader impact in that it builds connections between graduate students and professionals outside academia and trains students for a wide variety of positions focused on biodiversity. Practical skills including project management, science communication, and program assessment will position our NRT 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 national need and 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 projected climate, 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 science questions. The triumphs and failures of this program, which will be assessed and communicated throughout the life of the award, will help create a prototype that other programs can adopt to bring equal rigor and attention to non-academic and academic career paths in STEM.

A key aspect of broadening participation in science is showing the various career paths one can take. For example, a traditional academic path often requires a scientist to make multiple moves around the world, receive low financial rewards, and experience great uncertainty. Alternative paths may offer better options, while posing other tradeoffs (fewer opportunities to affect students through teaching, limited access to research, etc). To showcase the career opportunities in STEM, we will leverage existing UT events to reach both undergraduates and the broader public. First, we will participate in creating research and career path displays at our university’s Ag Day event, a way to connect the local community with the UT Institute of Agriculture. Strategically scheduled on the same day as a UTK football game (which draws over 100,000 attendees) and featuring an insect petting zoo, farm animals, departmental displays, free food, and other activities, this well-liked outreach event is designed to draw in a broad swath of the community. Trainees will create a display and talk to visitors about their chosen career paths and options in science. Additionally, we will partner with Darwin Day Tennessee (PI O’Meara is the faculty advisor), a group founded 20 years ago to educate the public 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 (McClung Museum of Natural History & Culture). Trainees will run a panel on careers involving evolution outside academia, targeted at local teachers and guidance counselors. These efforts will help inform the local community about the importance of evolution (in areas ranging from antibiotic resistance to invasive species) as well as give educators the information and tools 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 communications 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 in Fig. 4, outlining responsibilities.

As PI, O’Meara will oversee the program to ensure NextGen Biodiversity NRT 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. Together, they 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 FWF in UTIA’s College of Agricultural Sciences & Natural Resources and EEB 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 handle connections between them and internship opportunities.

Staton will lead the development of tutorials and workshops, assisted by O’Meara. Moulton and Kalisz will help foster MAC faculty for thesis work by onboarding affiliate faculty chosen by students to be part of their MAC. They will also help ensure that data generated are deposited appropriately.

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

**Figure 4.**  Next-Generation Biodiversity NRT organizational chart.



Each trainee will be housed in the lab of a member of one of the three participating departments (faculty mentors will be approved to advise students after receiving training in cross-cultural mentoring), but will have at least two faculty from any of the following departments on their committee (*Table 5*). Students will thus be mentored by faculty with a wide variety of knowledge and experiences. This structure also serves as a 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.

**Table 5.** Interdisciplinary Affiliate Faculty Departments

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

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 (annually 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, share information, 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 best available 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 essential, both as members of the External Advisory Board and as internship hosts. The advisory board will consist of one representative, each, from an NGO, 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.

*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 Ernest 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, 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 sustainable programmatic capacity 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 will lead to institutionalization of those training elements shown to be effective. 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 of 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, the number of non-academic career workshops or other opportunities, and more. Our proposed NRT will create incentive for other departments to encourage affiliate students.

*Sustainment Plan:* Sustaining the program after the conclusion of NSF funding is a primary goal, and UT has committed to funding four students’ tuitions for the four years following the grant period. The long-term vision is that this new traineeship 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 initially undertaken by the Project Coordinator will transition 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. 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). Seminars featuring partner organizations will continue past the life of the award.

**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 coordinate our graduate student recruitment activities to increase underrepresented students by partnering with UT’s Office of Graduate Training and Mentoring (OGTM) and PEER. Working with existing undergraduate diversity programs at UT (e.g. Tennessee Louis Stokes Alliance for Minority Participation *(*TLSAMP*)* program) and other institutions will expand our existing diversity recruiting pipeline. 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 Dr. 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 ORNL and a workshop, “Strategies for Mentoring Diverse Graduate Students and Faculty” to UT’s Psychology Department. He will present similar workshops for NRT 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 TLSAMP, 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. Trainees will be mentored through their MACs but also through annual meetings with the Project Coordinator (one of the core faculty). Students will be further mentored through the informal networks fostered by their internships in first summer year of grant funding. The EEB department has created its own tracking software to monitor grad student progress toward degree and to automatically highlight potential issues while building up a long-term, secure, database of progress and outcomes.

Co-PI Kwit will oversee trainees’ mentoring activities and coordinate collaboratively with Dr. Brothers, who also oversees the Office of Graduate Training and Mentorship (OGTM) 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 provide 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 (IDP) 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 an appropriate placement in her or his first summer. IDPs for graduate students are now a requirement for NIH grantees [32] based on best practices in training.

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 make use of existing resources, such as UT’s Multi-Cultural Graduate Student Organization, which connects members of underrepresented groups across campus, to help students form meaningful relationships 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**

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 NRT program activities. The program impact theory (*Fig. 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.*

Our NRT program evaluation will be conducted by East Main Evaluation & Consulting (EMEC), 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, which provides a comprehensive model to analyze the project activities while gathering data on the program effects. Within this framework, a logic model (*Table 6*) is used to represent the sequence of steps between program services and outcomes [33]. The outputs and outcomes (*Table 6*) include identified performance measures and expected competencies that are anticipated effects of the project activities. An evaluation timeline is provided in Table 7.

The evaluation will use 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 are 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 (LT) 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 LT 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 LT 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 6.** Logic model for evaluation and assessment of trainee progress and placement.

**Goal 1:** Enhance workforce development to fill the need for US biodiversity science expertise.

|  |  |  |  |
| --- | --- | --- | --- |
| **Strategy** | **Output** | **Outcome** | **Data Method** |
| Course work w/ two week field course | # and description of courses offered pre/post program  # and description of field courses  # 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  # of faculty teaching program courses  # of departments collaborating | * 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 * 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 * Trainee follow-up survey |
| Workshops | # and description of workshops offered  # of streamed workshops  # of workshop participants  # of workshop views  # workshop instructors | * Trainees are satisfied with workshops * Trainees gain technological skills * Trainees gain leadership, management, and/or communication skills * Trainees gain domain knowledge * Expand program reach through streaming | * Document review * Pre, post, knowledge measure * 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 * Program develops pipeline of STEM-enabled students outside of academia | * Document review * Intern survey * Leadership Team interviews |
| 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 implement-ation 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 external advisory board  # advisory board meetings  Advisory board 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 |
| Dissemin-ate program results via publications and presen- tations | # and description of presentations  # and description of publications | * Prepare and submit publication for peer review * Prepare and present results at conferences | * Document review |

**Table 7.** 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 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Workshop, knowledge measure |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 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 Master’s 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, an 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.

Over the past five years, Co-PI Kalisz has mentored seven Ph.D. students. Three have defended and graduated (from the University of Pittsburgh), three are current students in EEB at UTK, and one continues in the Ph.D. program at Pittsburgh. Of the seven students, five self-identity as female. Of the current three female students in the Kalisz lab at UTK, and one self identifies as African-American. Kalisz serves as faculty mentor in the Program for Excellence and Equity in Research (PEER), an effective recruiting and graduate training program that offers students from underrepresented minority groups a framework of training and other support activities. Kalisz serves on five additional graduate student committees at UTK and is the sole faculty advisor for Pipeline: Vols for Women in STEM, a Committee of UTK’s Commission for Women. This student organization provides a campus-wide support system that fosters an environment of interdisciplinary engagement while providing networking and professional development opportunities in STEM fields. Additionally, Kalisz is the Head of EEB at UTK since Aug 2015.

**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: This project 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. Models were created to allow inference about species delimitation (whether a set of populations should be treated as one species or multiple species). Broader Impacts: Workshops were run in Ohio and Louisiana with travel support for students to train them in phylogeography, and students are already using this software in their research. To aid in communication and outreach, this 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. The postdoc involved in the grant chose to take a position in cancer research outside academia. A website and discussion group were created to promote long-term use of the software, which is open source. Products: Results include publications of two papers about this approach [30, 34], two more in press, and a general review paper currently being developed 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 decadal project investigates long-lived herbaceous species experiencing disrupted species interactions through exotic invasion and overabundant deer. Results demonstrate the deer facilitate invader success and native decline. The allelopathic invader suppresses the AMF-native plant mutualism, essentially turning the AMF fungal mutualist into a parasite that suppresses native plant species’ physiological function and vital rates. Broader Impacts*:* Kalisz presented 12 lectures to the public and state, local, and national officials on this work. Results were highlighted in 10 popular press articles and 64 radio spots. Kalisz advises the Fox Chapel Borough on stewardship, management, and conservation of their land holdings, served as Science Advisor on "Virtual Trillium Trail" game software, an interactive K-12 educational tool for exploring biodiversity built on Kalisz’s database. The game is free to any educator for classroom use and fits the State of PA STEM guidelines for middle school students. Products*:* 11 publications [35-45], 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.), nine 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 [24, 46-89]. 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 [90-92], software products: BDSS v1.0.1b2 [93]; Tripal v3 alpha [94]; blend4php [95]; Docker Images with Tripal and Galaxy [96, 97] ; Tripal elastic search [98], NGS data Galaxy workflows [99].

**C. Kwit,** no prior NSF support over the past five years.

**References**

1. Kutner, L., *NatureServe Hotspots Map*. 2013.

2. Hansen, G.J.A., S. Sadro, M.M. Baustian, and B.A. Stauffer, *Is it time to redefine the “alternative” career path for ecologists?* Limnology and Oceanography Bulletin, 2014. **23**(1): p. 2-5.

3. Sauermann, H. and M. Roach, *Science PhD career preferences: levels, changes, and advisor encouragement.* PloS ONE, 2012. **7**(5): p. e36307.

4. Pickett, C.L., B.W. Corb, C.R. Matthews, W.I. Sundquist, and J.M. Berg, *Toward a sustainable biomedical research enterprise: Finding consensus and implementing recommendations.* Proceedings of the National Academy of Sciences, 2015. **112**(35): p. 10832-10836.

5. Barrows, C.W., M.L. Murphy-Mariscal, and R.R. Hernandez, *At a crossroads: the nature of natural history in the twenty-first century.* BioScience, 2016: p. biw043.

6. Tewksbury, J.j., J.G.T. Anderson, J.D. Bakker, T.J. Billo, P.W. Dunwiddie, M.J. Groom, S.E. Hampton, S.G. Herman, D.J. Levey, N.J. Machnicki, C.M. del Rio, M.E. Power, K. Rowell, A.K. Salomon, L. Stacey, S.C. Trombulak, and T.A. Wheeler, *Natural History's Place in Science and Society.* BioScience, 2014. **64**(4): p. 300-310.

7. Blickley, J.L., K. Deiner, K. Garbach, I. Lacher, M.H. Meek, L.M. Porensky, M.L. Wilkerson, E.M. Winford, and M.W. Schwartz, *Graduate student's guide to necessary skills for nonacademic conservation careers.* Conservation Biology, 2013. **27**(1): p. 24-34.

8. Rodríguez, J., T.D. Beard Jr, E. Bennett, G. Cumming, S. Cork, J. Agard, A. Dobson, and G. Peterson, *Trade-offs across space, time, and ecosystem services.* Ecology and society, 2006. **11**(1).

9. Wagg, C., S.F. Bender, F. Widmer, and M.G.A. van der Heijden, *Soil biodiversity and soil community composition determine ecosystem multifunctionality.* Proceedings of the National Academy of Sciences, 2014. **111**(14): p. 5266-5270.

10. Gamfeldt, L., T. Snäll, R. Bagchi, M. Jonsson, L. Gustafsson, P. Kjellander, M.C. Ruiz-Jaen, M. Fröberg, J. Stendahl, and C.D. Philipson, *Higher levels of multiple ecosystem services are found in forests with more tree species.* Nature Communications, 2013. **4**: p. 1340.

11. Guannel, M.L., B.C. Bruno, M.M. Grand, N. Lee, and E.A. Day‐Miller, *In Hawaii, a pilot course in professional development fulfills an unmet need in graduate education.* Limnology and Oceanography Bulletin, 2014. **23**(3): p. 56-59.

12. Kuh, G.D., *High-impact educational practices: What they are, who has access to them, and why they matter.* Association of American Colleges and Universities, 2008.

13. Batchelder, T.H. and S. Root, *Effects of an undergraduate program to integrate academic learning and service: Cognitive, prosocial cognitive, and identity outcomes.* Journal of Adolescence, 1994. **17**(4): p. 341.

14. Tumlin, K.I., R. Linares, and M.W. Schilling, *Student motivation and Assessment of Applied Skills in an equine Studies Program.* Applied Learning in Higher Education, 2009. **1**: p. 93-108.

15. National Ecological Observatory Network, *Data accessed on Feb. 6, 2017. Available on-line data.neonscience.org from Battelle, Boulder, CO, USA.* 2017.

16. UTK, *Internal reporting on graduate student placement*. 2017.

17. McLaughlin, J.S. and D.K. Johnson, *Assessing the Field Course Experiential Learning Model: Transforming Collegiate Short-Term Study Abroad Experiences into Rich Learning Environments.* Frontiers: The Interdisciplinary Journal of Study Abroad, 2006. **13**: p. 65-85.

18. Gibbs Jr, K.D., J. McGready, J.C. Bennett, and K. Griffin, *Biomedical science Ph. D. career interest patterns by race/ethnicity and gender.* PLoS ONE, 2014. **9**(12): p. e114736.

19. Paini, D.R., A.W. Sheppard, D.C. Cook, P.J. De Barro, S.P. Worner, and M.B. Thomas, *Global threat to agriculture from invasive species.* Proceedings of the National Academy of Sciences, 2016. **113**(27): p. 7575-7579.

20. Agnarsson, I. and M. Kuntner, *Taxonomy in a changing world: Seeking solutions for a science in crisis.* Systematic Biology, 2007. **56**(3): p. 531-539.

21. Felderhoff, K.L., E.C. Bernard, and J.K. Moulton, *Survey of Pogonognathellus Börner (Collembola: Tomoceridae) in the Southern Appalachians based on morphological and molecular data.* Annals of the Entomological Society of America, 2010. **103**(4): p. 472-491.

22. Moulton, J.K. and G.R. Curler, *A new species of net-winged midge of the genus Blepharicera Macquart (Diptera: Blephariceridae) from the Cumberland Plateau of Tennessee.* Proceedings of the Entomological Society of Washington, 2007. **109**(4): p. 920-929.

23. Moulton, J.K., *The true identity of Dixa modesta Johannsen (Diptera: Dixidae) resolved: synonymy of Dixa similis Johannsen, designation of the Dixa ubiquita species group, and description of three new eastern Nearctic species.* Zootaxa, 2017. **4216**(3): p. 247-260.

24. Moulton, J.K., *The Dixa inextricata Dyar Shannon (Diptera: Dixidae) species group, with two new cryptic species from the eastern Nearctic Region.* Zootaxa, 2016. **4121**(4): p. 458.

25. Schilling, E.E., A. Floden, and S.B. Farmer, *A new sessile-flowered Trillium species from Tennessee.* Castanea, 2013. **78**(2): p. 140-147.

26. Estes, D. and R.L. Small, *Two new species of Gratiola (Plantaginaceae) from eastern North America and an updated circumscription for Gratiola neglecta.* Journal of the Botanical Research Institute of Texas, 2007: p. 149-170.

27. Mata, J.L., C.L. Ovrebo, T.J. Baroni, and K.W. Hughes, *New species of neotropical Rhodocollybia.* Mycotaxon, 2016. **131**(1): p. 235-245.

28. O'Meara, B.C., *New Heuristic Methods for Joint Species Delimitation and Species Tree Inference.* Systematic Biology, 2010. **59**(1): p. 59-73.

29. Niemiller, M.L., T.J. Near, and B.M. Fitzpatrick, *Delimiting species using multilocus data: diagnosing cryptic diversity in the southern cavefish Typhlichthys subterraneus (Teleostei: Amblyopsidae).* Evolution, 2011. **Accepted pending minor revisions**.

30. Jackson, N.D., B.C. Carstens, A.E. Morales, and B.C. O'Meara, *Species Delimitation with Gene Flow.* Systematic Biology, 2016: p. syw117.

31. Editors, *Editorial: There is life after academia.* Nature, 2014. **513**(7516): p. 5.

32. National Institutes of Health, *Revised Policy: Descriptions on the Use of Individual Development Plans (IDPs) for Graduate Students and Postdoctoral Researchers Required in Annual Progress Reports beginning October 1, 2014*. 2014, Bethesda, MD: National Institutes of Health.

33. Rossi, P.H., M.W. Lipsey, and H.E. Freeman, *Evaluation: A Systematic Approach*. 2004, Thousand Oaks, CA: Sage publications.

34. Morales, A.E., N.D. Jackson, T.A. Dewey, B.C. O’Meara, and B.C. Carstens, *Speciation with gene flow in North American Myotis bats.* Systematic biology, 2016: p. syw100.

35. Knight, T.M., J.L. Dunn, L.A. Smith, J. Davis, and S. Kalisz, *Deer facilitate invasive plant success in a Pennsylvania forest understory.* Natural Areas Journal, 2009. **29**(2): p. 110-116.

36. Knight, T.M., H. Caswell, and S. Kalisz, *Population growth rate of a common understory herb decreases non-linearly across a gradient of deer herbivory.* Forest Ecology and Management, 2009. **257**(3): p. 1095-1103.

37. Heckel, C.D., N.A. Bourg, W.J. McShea, and S. Kalisz, *Nonconsumptive effects of a generalist ungulate herbivore drive decline of unpalatable forest herbs.* Ecology, 2010. **91**(2): p. 319-326.

38. Hale, A.N., S.J. Tonsor, and S. Kalisz, *Testing the mutualism disruption hypothesis: physiological mechanisms for invasion of intact perennial plant communities.* Ecosphere, 2011. **2**(10): p. 1-15.

39. Cantor, A., A. Hale, J. Aaron, M.B. Traw, and S. Kalisz, *Low allelochemical concentrations detected in garlic mustard-invaded forest soils inhibit fungal growth and AMF spore germination.* Biological invasions, 2011. **13**(12): p. 3015-3025.

40. Burke, D.J., M.N. Weintraub, C.R. Hewins, and S. Kalisz, *Relationship between soil enzyme activities, nutrient cycling and soil fungal communities in a northern hardwood forest.* Soil Biology and Biochemistry, 2011. **43**(4): p. 795-803.

41. Hale, A.N. and S. Kalisz, *Perspectives on allelopathic disruption of plant mutualisms: a framework for individual-and population-level fitness consequences.* Plant Ecology, 2012. **213**(12): p. 1991-2006.

42. Kalisz, S., R.B. Spigler, and C.C. Horvitz, *In a long-term experimental demography study, excluding ungulates reversed invader's explosive population growth rate and restored natives.* Proceedings of the National Academy of Sciences, 2014. **111**(12): p. 4501-4506.

43. Brouwer, N.L., A.N. Hale, and S. Kalisz, *Mutualism-disrupting allelopathic invader drives carbon stress and vital rate decline in a forest perennial herb.* AoB PLANTS, 2015. **7**: p. plv014-plv014.

44. Hale, A.N., L. Lapointe, and S. Kalisz, *Invader disruption of belowground plant mutualisms reduces carbon acquisition and alters allocation patterns in a native forest herb.* New Phytologist, 2016. **209**(2): p. 542-549.

45. Heckel, C.D. and S. Kalisz, *Life history trait divergence among populations of a non‐palatable species reveals strong non‐trophic indirect effects of an abundant herbivore.* Oikos, 2016.

46. Adler, P.H., M. Cherairia, S.F. Arigue, B. Samraoui, and B. Belqat, *Cryptic biodiversity in the cytogenome of bird-biting blackflies in North Africa.* Medical and Veterinary Entomology, 2015. **29**(3): p. 276-289.

47. Adler, P.H., Y.-T. Huang, W.K. Reeves, S.K. Kim, Y. Otsuka, and H. Takaoka, *Macrogenomic Evidence for the Origin of the Black Fly Simulium suzukii (Diptera: Simuliidae) on Okinawa Island, Japan.* PLoS ONE, 2013. **8**(8): p. e70765.

48. Adler, P.H., Y.-T. Huang, and H. Takaoka, *Nearctic–Palaearctic relationships of black flies (Diptera: Simuliidae): chromosomal and morphological evidence for the Prosimulium magnumspecies group in Japan.* Journal of Natural History, 2012. **46**(23-24): p. 1467-1475.

49. Adler, P.H., A. Inci, A. Yildirim, O. Duzlu, J.W. McCreadie, M. Kúdela, A. Khazeni, T. Brúderová, G. Seitz, H. Takaoka, Y. Otsuka, and J. Bass, *Are black flies of the subgenus Wilhelmia(Diptera: Simuliidae) multiple species or a single geographical generalist? Insights from the macrogenome.* Biological Journal of the Linnean Society, 2014. **114**(1): p. 163-183.

50. Adler, P.H. and G. Seitz, *Chromosomal characteristics and evolutionary relationships of the Palearctic black fly Simulium carthusiense (Diptera: Simuliidae).* European Journal of Entomology, 2014.

51. Adler, P.H. and Ü. Şirin, *Cytotaxonomy of the Prosimulium(Diptera: Simuliidae) of Western Asia.* Zoological Journal of the Linnean Society, 2014. **171**(4): p. 753-768.

52. Adler, P.H. and Ü.D. Sirin, *A New Species of Black Fly in the Prosimulium hirtipes (Fries) Group (Diptera: Simuliidae) from Western Turkey.* Proceedings of the Entomological Society of Washington, 2015. **117**(2): p. 85-94.

53. Cherairia, M., P.H. Adler, and B. Samraoui, *Biodiversity and Bionomics of the Black Flies (Diptera: Simuliidae) of Northeastern Algeria.* Zootaxa, 2014. **3796**(1): p. 166.

54. Courtney, G.W., *A new genus and species of net-winged midge from Madagascar (Diptera: Blephariceridae: Blepharicerinae).* Zootaxa, 2015. **4052**(1): p. 107.

55. Cranston, P.S., *Some proposed emendations to larval morphology terminology.* CHIRONOMUS Journal of Chironomidae Research, 2012(25).

56. Cranston, P.S., N.B. Hardy, G.E. Morse, L. Puslednik, and S.R. McCluen, *When molecules and morphology concur: the ‘Gondwanan’ midges (Diptera: Chironomidae).* Systematic Entomology, 2010. **35**(4): p. 636-648.

57. Cranston, P.S. and M.N. Krosch, *DNA sequences and austral taxa indicate generic synonymy of Paratrichocladius Santos-Abreu with Cricotopus Wulp (Diptera: Chironomidae).* Systematic Entomology, 2015. **40**(4): p. 719-732.

58. Cranston, P.S. and M.N. Krosch, *Nomenclatural corrections to Australian species of Cricotopus (Wulp) (Diptera; Chironomidae).* Zootaxa, 2015. **3980**(2): p. 298.

59. Curler, G.R., J.K. Moulton, and R.I. Madriz, *Redescription of Aposycorax chilensis (Tonnoir) (Diptera, Psychodidae, Sycoracinae) with the first identification of a blood meal host for the species*Zootaxa, 2015. **4048**(1): p. 114.

60. Drayson, N., P.S. Cranston, and M.N. Krosch, *Taxonomic review of the chironomid genus Cricotopus v.d. Wulp (Diptera: Chironomidae) from Australia: keys to males, females, pupae and larvae, description of ten new species and comments on Paratrichocladius Santos Abreu.* Zootaxa, 2015. **3919**(1): p. 1.

61. Fasbender, A. and G.W. Courtney, *Case 3664 Tipula contaminata Linnaeus, 1758 (currently Ptychoptera contaminata; Insecta, Diptera): proposed conservation of prevailing usage through designation of a neotype.* The Bulletin of Zoological Nomenclature, 2014. **71**(4): p. 237-243.

62. Huang, Y.-T. and P.H. Adler, *Chromosomal relationships of Simulium suzukii, an Old World member of the Simulium tuberosum species group (Diptera: Simuliidae).* Medical Entomology and Zoology, 2011. **62**(1): p. 23-30.

63. Jacobson, A.J., G.R. Curler, G.W. Courtney, and J.K. Moulton, *New species of BlephariceraMacquart (Diptera: Blephariceridae) from eastern North America, with a discussion of the phylogenetic relationships and biogeography of all Nearctic species.* Systematic Entomology, 2011. **36**(4): p. 768-800.

64. Khazeni, A., P.H. Adler, Z. Telmadareiiy, M.A. Oshaghi, H. Vatandoost, S.M. Abtahi, and A. Lotfi, *The Black Flies (Diptera: Simuliidae) of Iran.* Zootaxa, 2013. **3694**(1): p. 67.

65. Krosch, M. and P.S. Cranston, *Not drowning, (hand)waving? Molecular phylogenetics, biogeography and evolutionary tempo of the ‘Gondwanan’ midge Stictocladius Edwards (Diptera: Chironomidae).* Molecular Phylogenetics and Evolution, 2013. **68**(3): p. 595-603.

66. Krosch, M.N., A.M. Baker, P.B. Mather, and P.S. Cranston, *Comparison of intraspecific genetic structure among related chironomids (Diptera) from New Zealand and Patagonia: disparity between potential and realized dispersal.* Freshwater Science, 2012. **31**(4): p. 1105-1120.

67. Krosch, M.N. and P.S. Cranston, *Non-destructive DNA extraction from Chironomidae, including of fragile pupal exuviae, extends analysable collections and enhances vouchering.* CHIRONOMUS Journal of Chironomidae Research, 2012(25).

68. Krosch, M.N., P.S. Cranston, A.M. Baker, and S. Vink, *Molecular data extend Australian Cricotopusmidge (Chironomidae) species diversity, and provide a phylogenetic hypothesis for biogeography and freshwater monitoring.* Zoological Journal of the Linnean Society, 2015. **175**(3): p. 496-509.

69. Lambkin, C.L., B.J. Sinclair, T. Pape, G.W. Courtney, J.H. Skevington, R. Meier, D.K. Yeates, V. Blagoderov, and B.M. Wiegmann, *The phylogenetic relationships among infraorders and superfamilies of Diptera based on morphological evidence.* Systematic Entomology, 2012. **38**(1): p. 164-179.

70. Madriz, R.I. and G.W. Courtney, *The Neotropical tanyderid Araucoderus gloriosus (Alexander) (Diptera, Tanyderidae), with description of the egg, larva and pupa, redescription of adults, and notes on natural history.* Zootaxa, 2016. **4158**(3): p. 325.

71. Moulton, J.K., *The true identity of Dixa modesta Johannsen (Diptera: Dixidae) resolved: synonymy of Dixa similis Johannsen, designation of the Dixa ubiquita species group, and description of three new eastern Nearctic species.* Zootaxa, 2017. **4216**(3): p. 247.

72. Petersen, M.J., M.A. Bertone, B.M. Wiegmann, and G.W. Courtney, *Phylogenetic synthesis of morphological and molecular data reveals new insights into the higher-level classification of Tipuloidea (Diptera).* Systematic Entomology, 2010. **35**(3): p. 526-545.

73. Pfrender, Michael E., Charles P. Hawkins, M. Bagley, Gregory W. Courtney, Brian R. Creutzburg, John H. Epler, S. Fend, Leonard C. Ferrington, Paula L. Hartzell, S. Jackson, David P. Larsen, C.A. Lévesque, John C. Morse, Matthew J. Petersen, D. Ruiter, D. Schindel, and M. Whiting, *Assessing Macroinvertebrate Biodiversity in Freshwater Ecosystems: Advances and Challenges in DNA-based Approaches.* The Quarterly Review of Biology, 2010. **85**(3): p. 319-340.

74. Pivar, R.J., J.K. Moulton, and B.J. Sinclair, *A new species of Austrothaumalea Tonnoir from Australia (Diptera: Thaumaleidae).* Zootaxa, 2016. **4132**(4): p. 594.

75. Reeves, W.K. and P.H. Adler, *Colonization of Pacific Islands by Black Flies (Diptera: Simuliidae).* Proceedings of the Entomological Society of Washington, 2011. **113**(3): p. 371-376.

76. Schneeberg, K., F. Friedrich, G.W. Courtney, B. Wipfler, and R.G. Beutel, *The larvae of Nymphomyiidae (Diptera, Insecta) – Ancestral and highly derived?* Arthropod Structure & Development, 2012. **41**(3): p. 293-301.

77. Senatore, G.L., E.A. Alexander, P.H. Adler, and J.K. Moulton, *Molecular systematics of the Simulium jenningsi species group (Diptera: Simuliidae), with three new fast-evolving nuclear genes for phylogenetic inference.* Molecular Phylogenetics and Evolution, 2014. **75**: p. 138-148.

78. Sinclair, B.J., *Rediscovered at last: a new enigmatic genus of Axymyiidae (Diptera) from western North America.* Zootaxa, 2013. **3682**(1): p. 143.

79. Sinclair, B.J., *A New Species of Afrothaumalea Stuckenberg, 1960 (Diptera: Thaumaleidae) from the Western Cape (South Africa) and First Description of the Pupa of this Genus.* African Invertebrates, 2015. **56**(1): p. 161-166.

80. Sinclair, B.J. and H. Huerta, *A new species of Androprosopa from Mexico (Diptera: Thaumaleidae).* The Canadian Entomologist, 2010. **142**(05): p. 443-447.

81. Swanson, D.A. and W.L. Grogan, *A New Predaceous Midge in Brachypogon ( Brachypogon ) from Alabama and Florida, U.S.A. and New Distibution Records for Brachypogon woodruffi Spinelli and Grogan (Diptera: Ceratopogonidae).* Proceedings of the Entomological Society of Washington, 2011. **113**(4): p. 531-540.

82. Swanson, D.A. and W.K. Reeves, *New records of biting midges (Diptera: Ceratopogonidae) from Guam Island, USA.* Check List, 2016. **7**(3): p. 313.

83. Teles, C.B.G., R.A. Freitas, A.F.J. De Oliveira, G.M. Ogawa, E.A.C. De AraÚJo, J.F. Medeiros, F.A.C. Pessoa, and L.M.A. Camargo, *Description of a new phlebotomine species (Diptera: Psychodidae, Phlebotominae) and new records of sand flies from the State of Acre, northern Brazil.* Zootaxa, 2013. **3609**(1).

84. Wihlm, M.W. and G.W. Courtney, *The Distribution and Life History of Axymyia furcata McAtee (Diptera: Axymyiidae), a Wood Inhabiting, Semi-Aquatic Fly.* Proceedings of the Entomological Society of Washington, 2011. **113**(3): p. 385-398.

85. Wihlm, M.W., R.B. Sam, and G.W. Courtney, *Morphology of Axymyia furcata (Diptera: Axymyiidae), including scanning electron microscopy of all life stages.* The Canadian Entomologist, 2012. **144**(02): p. 273-290.

86. Wipfler, B., G.W. Courtney, D.A. Craig, and R.G. Beutel, *First μ-CT-based 3D reconstruction of a dipteran larva-the head morphology of protanyderus (tanyderidae) and its phylogenetic implications.* Journal of Morphology, 2012. **273**(9): p. 968-980.

87. Farnsworth, E.J., M. Chu, W.J. Kress, A.K. Neill, J.H. Best, J. Pickering, R.D. Stevenson, G.W. Courtney, J.K. VanDyk, and A.M. Ellison, *Next-generation field guides.* BioScience, 2013. **63**(11): p. 891-899.

88. Huang, Y.T., P.H. Adler, and H. Takaoka, *Polytene chromosomes of Simulium arakawae, a pest species in the Simulium venustum group (Diptera: Simuliidae) from Japan.* Tropical biomedicine, 2011. **28**(2): p. 376-381.

89. Curler, G.R. and J.K. Moulton, *Descriptions of three new species of Psychodidae (Diptera) from the southeastern United States.* Zootaxa, 2010. **2524**: p. 51-62.

90. Mills, N., F. Feltus, and W. Ligon, *Maximizing the Performance of Scientific Data Transfer by Optimizing the Interface Between Parallel File Systems and Advanced Research Networks.* Future Generation Computer Systems, 2016. **Preprint**.

91. Watts, N.A. and F.A. Feltus, *Big Data Smart Socket (BDSS): a system that abstracts data transfer habits from end users.* Bioinformatics, 2016.

92. Wytko, C., B. Soto, and S.P. Ficklin, *blend4php: a PHP API for galaxy.* Database-the Journal of Biological Databases and Curation, 2017.

93. Watts, N. and A. Feltus, *BDSS*. 2017.

94. Developers, *Tripal.* 2017.

95. Soto, B. and S. Ficklin, *blend4php*. 2017.

96. Chen, M. and M. Staton, *Tripal Docker.* 2017.

97. Chen, M. and M. Staton, *Tripal Galaxy Workflows.* 2017.

98. Chen, M. and M. Staton, *Tripal Elasticsearch Module*. 2017.

99. Cheng, M. and M. Staton, *Docker Galaxy dibbs*. 2017.