**NRT: Next-Generation Biodiversity Training**

1. **List of Core Participants**

|  |  |  |  |
| --- | --- | --- | --- |
| 1. **Name** | **Project Role** | **Department and Institutional Affiliation** | **Discipline(s)** |
| **Brian O’Meara** | **PI** | **Ecology and Evolutionary Biology, UT** | **Phylogenetics, macroevolution** |
| **Charles Kwit** | **CoPI** | **Forestry, Wildlife and Fisheries, UT** | **Conservation, wildlife-plant interactions** |
| **Susan Kalisz** | **CoPI** | **Ecology and Evolutionary Biology, UT** | **Evolution, ecology, and conservation of plants** |
| **Meg Staton** | **CoPI** | **Entomology and Plant Pathology, UT** | **Plant pathology, genomic tools, and science communication** |
| **John Kevin Moulton** | **CoPI** | **Entomology and Plant Pathology, UT** | **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 conservation, agriculture, and communicating with the public. American graduate education programs do an excellent job training students for academic careers in biodiversity, but training students for careers in non-governmental organizations (NGOs), government agencies, and business remains low priority, often explicitly seen as merely an “alternate” to the normal path. The US clearly has an adequate (in terms of numbers, though not diversity) supply of students going to academic jobs [x], but we need a stream of well-trained students going into jobs outside academia, where they can also have immediate real world impact in a different way than is possible in many academic positions This project seeks to train biodiversity scientists for careers outside academia.

*Vision*

We will capitalize on the academic expertise at the University of Tennessee, Knoxville (UT) and engage with local and national partners to provide real-world experience to students through internships. The goal is to generate a culture change, which will generate biodiversity experts who will effectively face today’s societal and scientific grand challenges.

two

1. Create a workforce to fill the need for biodiversity expertise in the US.
2. Create a prototype for institutional culture change toward non-academic career paths.

*Understanding the Need*

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

While academia will always remain an important career path, especially for the creation and dissemination of new knowledge, it is increasingly being recognized by students as having some downsides as a career path.

Typical training often produces (1) researchers with deep taxonomic and evolutionary knowledge of one group but little training in how to broadly apply general biological principles, or (2) workers trained in applied details without sufficient depth of knowledge of evolutionary or ecological contexts. This leads to a lack of synergy: questions and approaches in one field, even within various fields of biology, only slowly diffuse to others. Even within the three departments on our campus, this is the first grant incorporating all of us, and the first interaction between many of the involved faculty. Further, traditionally narrow training paths yield graduates who lack skills in the latest technology revolutionizing their fields. Such skills include next-generation sequencing abilities allowing detection of organisms from wisps of DNA in a stream or sequencing entire viral genomes in a day, drones allowing remote sensing of biodiversity data, and geographic information systems allowing precise mapping and correlation of abiotic factors with responses of organisms. Moreover, potential leaders require training in skills such as project management.

*The Next-Generation Biodiversity Solution*

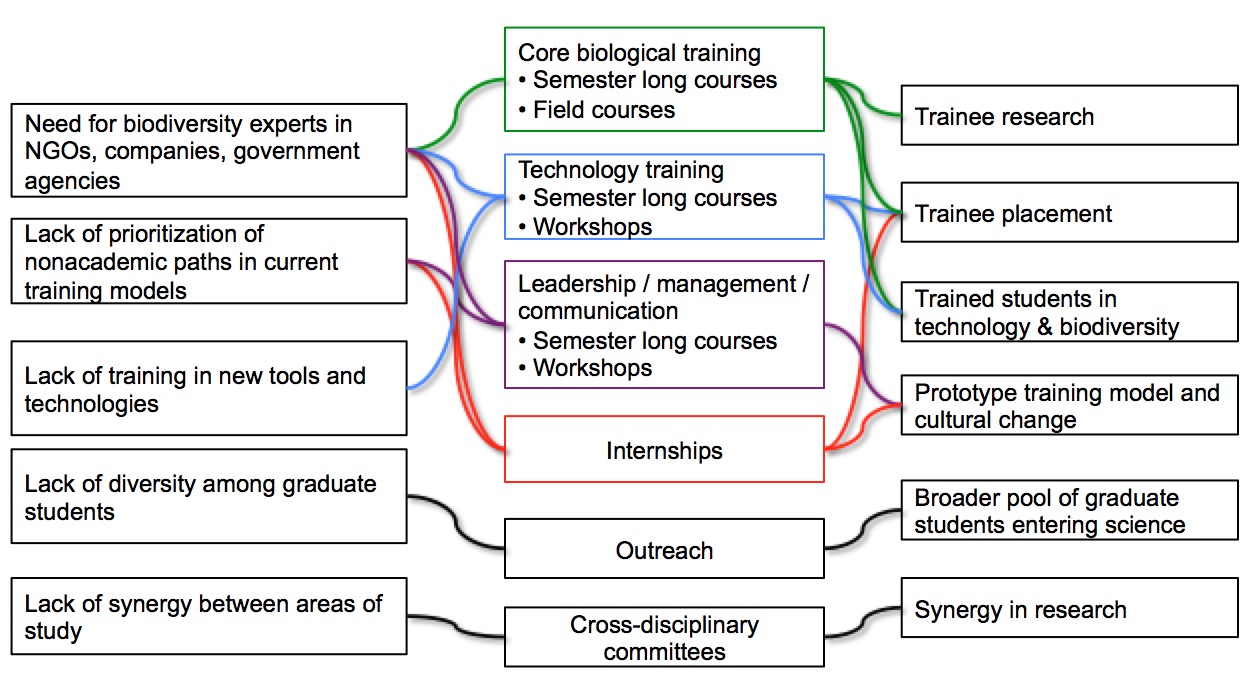
Our strategy is a training program for graduate students that combines interdisciplinary emphases and experiential learning to address current biodiversity-related challenges. This will pave the way for next-generation biodiversity scientists to enter careers in alternative academic paths in partner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

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

Our program covers five modular areas (Figure 1): (1) core biology training in an interdisciplinary approach including several academic disciplines, such as ecology, evolution, genetics, and natural history; (2) technological training in remote sensing, genomics, and GIS; (3) leadership and management training; (4) internships; (5) outreach. Through interdisciplinary research projects (described below), NRT trainees will use skills these modular areas to compete for top jobs. This model for graduate student training will be monitored as a prototype for building student awareness and faculty support for non-academic career choices.

GRAPHIC CONCEPT, WORK IN PROGRESS:





Restructure this text to align with graphic. 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 a workshops that can draw interest from hundreds of applicants; by streaming these online, we can reach many more potential trainees. For leadership and management training we will capitalize on relevant courses in project management and team building, including coordinating with colleagues on the creation of new courses. In modular area 4, trainees will participate in at least one internship with our partners, which will help build their professional networks and expose them to the management of concrete issues. For outreach, we will capitalize on existing programs at our University, as well as train students in science writing and have them write and disseminate a short popular press article about their work.

*Outcomes*

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

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

*Context for Added Value*

Our programs track outcomes (see Fig. 2): for example, we have tracked placement of EEB Ph.D. and Master’s students for the past 16 years, and know placements for 127 of 135 graduates of that program. All the programs currently have a substantial proportion of graduates going on to academia, but there still are students (in red) who go outside academia.This baseline data will be useful in allowing us to measure the impact of this program. It also allows us to integrate program participants into alumni networks, especially with alumni outside academia. These data suggest that for our programs, academia remains the default outcome, with 83% of EEB Ph.D. graduates either in a faculty role or in some other academic research position (often postdoctoral positions, especially for recent graduates, with the intention of moving on to faculty positions) and 50% for EPP.

***Figure 2.*** *Graduate student placement (UT, 2016).*



**C. Education and Training**

The traineeship model has four main components at its disposal: (1) core coursework in ecology, evolution, statistics, GIS, and related areas,( 2) two-week field courses focused on particular groups of organisms, (3) intensive professional skill workshops, (4) internships, (5) science communication. We propose to use existing and new programmatic elements to enable students, in consultation with their Multidisciplinary Advisory Committee, to select appropriate courses and experiences from all four components (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.

The **core coursework** builds on these existing UT courses spanning three modular areas. Core biology courses are supported by traditional graduate student offerings across departments, spanning ecology, taxonomy, anatomy, physiology, evolution, and conservation. Existing technological training courses include ENVE 561 – Climate and Environmental Informatics, GEOG 517 – Geographic Information Management and Processing, and EPP 622 – Bioinformatic Applications. One course coming online soon includes FWF 530 – GIS for Natural Resources. Management and assessment courses include EDAM 560 – Grant Writing and Project Management, ENMG 536 – Project Management, and ENMG 541 – Managing Change and Improvement in Technical Organizations.

**Table TK:** TITLE

|  |  |  |
| --- | --- | --- |
| **Number** | **Course Title** | **Knowledge and Skills** |
| ***Technology Training Courses*** | | |
| ENVE 561 | Climate and Environmental Informatics | **.** |
| GEOG 517 | Geographic Information Management and Processing | **.** |
| EPP 622 | Bioinformatic Applications | **.** |
| FWF 530 | GIS for Natural Resources | **.** |
| ***Management and Assessment Course*** | | |
| EDAM 560 | Grant Writing and Project Management | **.** |
| ENMG 536 | Project Management | **.** |
| ENMG 541 | Managing Change and Improvement in Technical Organizations | **.** |

Trainees will pursue courses across each of the three types (ecology, technology, management/assessment). More targeted graduate courses, depending on the needs of the trainees, may also be utilized. Capitalizing on established courses helps make the program more sustainable after its funding runs out and exposes trainees to students and instructors from a variety of perspectives.

***Table 1.*** *Graduate education*

|  |  |
| --- | --- |
| Credit Hour Instruction | Totaling to 24 |
| Core Biology Credits | 9+ |
| Technology Credits | 3+ |
| Management/Communications Credits | 3+ |
| Field Courses Credits | 3+ |
| Experiences |  |
| Skills Workshop | 2 Ph.D.  1 Master’s |
| Internship | 1 |

**Field courses** are key ways to promote learning (McLaughlin and Johnson 2006), and UTK faculty have experience teaching in field courses for a variety of organisms. This constitutes a focal area of development. Efforts are currently underway to expand this effort at the graduate level (e.g. field courses integrating use of EEB’s field station outside Great Smoky Mountains National Park).

Each year, trainees will also have access to **technology skills workshops,** which are two to three days of intensive learning, usually with both lecture and practical exercises. The workshops will be available online through streaming them live and posting all teaching materials (slides, exercises, scripts) to an open website available to all. This successful model is used by O’Meara through several National Institute for Mathematical and Biological Synthesis (NIMBioS) tutorials on computing, phylogenetics, R, and genetics, as well as an NSF CAREER grant-sponsored course. For the biodiversity student trainees, O’Meara will offer two options based on tutorials he has run in the past: “High Performance Computing for Phylogenies” and “Computing in the Cloud: What Every Computational Life Scientist Should Know.” CoPI 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. 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. There will also be a workshop on science communication, taught in conjunction with the journalism department. As part of this, students will write a news release on their research.

Trainees at the Master’s level will participate in at least one workshop prior to graduation, and Ph.D.-level trainees will attend at least two. Courses will be updated yearly or replaced with new material to reflect state of the art approaches in biodiversity and the particular research needs of the trainees. Further options will be available through NIMBioS, which sponsors workshops for faculty, staff and students. Examples from the past two years include “Evolutionary Quantitative Genetics,” “Game Theoretical Modeling of Evolution in Structured Populations,” “Current Issues in Statistical Ecology,” and “Using R for HPC.” 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.

**Internships** will allow students to build networks outside academia and learn about the skills necessary for careers at places such as federal and state agencies, environmental consulting agencies, and more. Currently, FWF has well-established internship opportunities for its undergraduate majors, including opportunities with some of our partner organizations. At the graduate level, this constitutes a focal area of development, though a number of potential partners have expressed interest.

*STEM Graduate Population to Be Served*

This grant will serve four audiences. The first are the **core students**: 15 Ph.D. or Master’s students funded with $34K stipends (plus tuition and benefits) for two years each. These students will make up the core of the program. The next is the set of **affiliated students**: other degree-seeking UT graduate students in the affiliated EEB, FWF, and EPP departments, as well as students in related groups such as Earth and Planetary Sciences, Genome Sciences and Technology, and Geography. These students will participate in one or more of the field courses or skills workshops; over the five-year life of the grant; we anticipate training between 30 and 100 students. The third set consists of external participants who would attend a field course or skills workshop. These participants include academics, especially graduate students, from other institutions, and land managers, biocontrol workers, agency employees, and other non-academics. These experiences will deepen connections between the program and the broader community, and importantly expose core and affiliate students to professionals outside academia. The fourth tier is for people remotely making use of teaching materials. The audience size for this is uncertain, but available metrics indicate it could be quite large: NIMBioS online video tutorials can have hundreds of views, and O’Meara’s course website for his NSF-sponsored flipped phylogenetics methods course, launched in January, 2016, has had 6,136 visitors to date from 94 countries.

*Internships*

A major aspect of training is placing students in internships. We have communicated with the following organizations for potential internships for our students and what training needs they see: 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 various independent environmental consultants. Moreover, we will be receiving assistance from \_\_\_\_\_ of the Tickle College of Engineering, who has coordinated with USGS for internships for their students (See Letter of Support).

**D. Major Research Efforts**

There project will catalyze three areas of research. The first will be research performed by students while studying at the university, both while funded as part of this grant and, for Ph.D. students, while funded from other sources. The second will be research enabled through cross-disciplinary interactions fostered through this project. The third will be published research based on assessments of the program.

Students in this program will pursue research-based dissertations in areas relating to modern biodiversity. Most notably, the world faces a biodiversity crisis: human activities are driving some species to extinction, invasive species are a major economic risk ($70.4 billion for the agriculture in the US alone (Paini et al. 2016)), and the skills to identify critical species are being lost (Agnarsson and Kuntner 2007). Student projects depend on an overlap in interest between the student and her or his potential advisor. Some possible research programs include:

**Kaliz lab:** The evolutionary and ecological research in this lab investigates forces that shape individual phenotypes and genomes, drive population level fitness and speciation, and alter standing levels of biodiversity within native communities. Possible graduate projects will investigate mechanistic hypotheses centered on how anthropogenic factors, including habitat disturbance and overabundant deer, alter species interactions in forests and drive exotic plant species invasion and native species declines.  Current effort focuses on mechanism underpinning invasive species disruption of native plant mutualisms (i.e. AMF, pollination), physiological, and demographic responses to invasion and the maintenance of native biodiversity.  These projects leverage databases from GSMNP and other long-term field sites to address important conservation and management issues at national and regional scales. This can lead directly to careers in conservation organizations, state parks, and national parks.

**Kwit lab:** Research interests include plant-animal interactions and bioenergy sustainability. Connections with partner organizations include common interests in assessing landscape change and silvicultural practices on pollination. Graduate students could assist such efforts with field identification skills of pollinators interested in identifying pollen to species via DNA sequencing approaches to quantify pollen communities of specific pollinators. So, too, could graduate students with DNA sequencing skills interested in identifying insects. These students could move on to careers in federal or state agencies or agricultural businesses.

**O’Meara lab:** Research in this lab group uses phylogenetic methods to address key questions in macroevolution and ecology. Most notably, one focus of O’Meara and colleagues has been development and use of approaches to delimit species (O'Meara 2010), including cave fishes of the Eastern US (Niemiller et al. 2011) and North American bats (Jackson et al. 2016). Such skills are key to being able to identify biodiversity, especially cryptic biodiversity that is of grave conservation concern. Students working on such projects could pursue careers in conservation, at non-governmental organizations or in state or federal conservation agencies.

**Staton lab:** This group builds software for developing websites that store genotype and phenotype data (the open source Tripal project). Dr. Staton 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. Graduate students interested in programming could help with software development, while field courses and student research projects could be used as test bed for the application. These students could move onto careers identifying genes of potential agricultural significance.

**E. Broader Impacts**

It is increasingly recognized that graduate programs in sciences should not focus on just churning out future faculty (Nature Editorial Board 2014), but few are configured for broader career outcomes. This project builds connections between graduate students and professionals outside academia while training students for a wide variety of positions focused on biodiversity. The addition of necessary practical skills such as project management, science communication, and program assessment will position graduates to be strongly competitive and ultimately more successful in industry or academia. The open nature of the training pushes scientific knowledge into the public domain where professionals can learn from it, fulfilling a classic role of land grant institutions. Sponsored student research projects will span a variety of biodiversity questions, likely ranging from alpha taxonomy, to modeling population movement with climate change, to studies of urban ecology. Our approach is radically different: with this program, the “alternate” career is academia – our goal is to get our students out into the world working with real world biodiversity questions. Both the academic and non-academic paths have great value, but the latter needs much more emphasis. The triumphs and failures of this program, which will be communicated throughout the grant, will help create a prototype that other programs can adopt when they choose to bring the same rigor and attention to non-academic paths as to academic ones.

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

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

**F. Organization and Management**

The faculty involved in this grant as PIs and Co-PIs will comprise the Leadership Team. They already are well-connected (for example, Kwit spans two involved departments; O’Meara has served on committees for Ph.D. students of Moulton and Kalisz; Staton, Kalisz, and O’Meara are all affiliated with NIMBioS). As PI, O’Meara will ensure the project meets its goals. Kwit will serve as a bridge between the various academic communities, both on and off campus. Kwit’s recent research spans areas from warbler winter habitat management in the Bahamas, bioenergy sustainability of switchgrass as a biofuel crop, oak savanna restoration, and animal-mediated seed dispersal, much of which has utilized collaborative support from state and federal agencies and NGOs. He has a joint appointment in the Department of Forestry, Wildlife, and Fisheries in UT’s College of Agricultural Sciences & Natural Resources and the Department of Ecology and Evolutionary Biology in UT’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. We will hire a half-time staff person to serve as Project Coordinator, who will report to Kwit and O’Meara, and would be responsible for overseeing steady progress of the students and handling connections between them and internship opportunities. Staton will lead the development of tutorials and workshops, given her experience with this in the past, assisted by O’Meara. Evaluations will be handled by East Main Evaluation and Consulting, LLC; Dr. Barbara Heath will lead this group, assisted by staff or interns within her group.

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

Students in our program will be full members of one of the three collaborating departments. Our plan is that each department receives at least 25% of all students. We will only admit students if we can assure them of funding until graduation (as long as they meet adequate progress guidelines). For EEB, this means that after their NRT funding expires, Masters and Ph.D. students will continue on guaranteed TA or RA lines until graduation, a model already used for trainees in our NIH PEER program. For EPP and FWF, which have few TA lines, most admitted students will be Master’s students expected to graduate in two years unless their advisor has other sources of funding, and Ph.D. students would require stipend, benefits, tuition, and fees to be covered by their advisor.

*Coordination with Administrators*

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

We will coordinate with higher level administrators in two ways. The first is informal: we will invite them to our two annual social events so they can form connections with our students and our external partners. The second is through an annual joint meeting with heads of the three collaborating departments, grant personnel, the Dean of the Graduate School, the Associate Dean for Academic Programs at the College of Arts and Sciences, and the Associate Dean at the College of Agricultural and Natural Resources. One week before the meeting, all the involved parties will receive a written report listing grant goals for the previous year, delivery of those goals, goals for the next year, University, College, and Department policies or procedures that have helped or hindered the achievement of those goals. For example, our Office of Institutional Research Assessment currently does a poor job tracking graduate outcomes; while the involved departments are compensating for this individually, this is an institution-wide problem that should be addressed.

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

*Project Roles*

* *Project Coordinator*: half time position for a staff member. She or he will be involved in matching students to internships, tracking progress, and preparing reports. A half time position should be adequate for the program’s scope, plus promotes sustainability in the future.
* *PI O’Meara*: He will oversee the project to make sure it delivers on its goals, as well as teach in workshops.
* *Co-PI Kwit*: He will be the key contact person for students and external members. He can fluidly move between the worlds of academia and applied work.
* *Co-PI Staton:* She will arrange for and teach in skills workshops, as well as identify curricular holes that will need to be filled with new courses.
* *Co-PIs Moulton, and Kalisz*: They will teach in workshops. Their involvement is part of UT’s investment for sustainability. They are both fairly senior faculty (Kalisz also currently serves as EEB department head).
* *Affiliate faculty*: Faculty who seek to enroll students through this program will have to go through a training session on alternative academic careers and cross-mentoring. The need to do this before students can be accepted will be an inducement to widespread training in this area.
* *Core students*: These are the funded students who will engage with the program.
* *Affiliate students*: These are other degree-seeking students at UT who will take classes through this NRT.
* *External particpants*: These are members of the community who will take NRT workshops or field courses.
* *Remote participants*: Those who will use our information from all over the world, but not formally enroll in a course.
* *External internship mentors*: Partners at local companies, NGOs, and government agencies who will host students.
* *East Main Evaluation and Consulting, LLC*: Assessment of project outcomes.
* *Advisory Board*: The project’s advisory board will provide significant guidance and an outside perspective on the progress of the training. This board will consist of one member each from a private company, NGO, and government agency, two alumni from the affiliated departments, and a current student who is not affiliated with the program. This group will meet by teleconference twice per year to review reports and respond to questions posed by the leadership team.

*Sustainment Plan*

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

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

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

*Recruitment*

This NRT program will work closely with UT’s Graduate School, which supports 55 doctoral degree and 76 master’s degree programs, to recruit a diverse population of students. We will join Graduate School representatives as they participate annually in graduate school fairs across the Southeast and at national conferences such as the annual Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) conference, which has 3,600 attendees from a wide variety of backgrounds, as well as professional conferences. In addition, we will provide printed and online promotional materials about the NRT Traineeship, which will be disseminated in these venues and others. Our focus on training students for careers outside academia, which can result in higher starting salaries (\_\_\_\_\_\_) and far less uncertainty in career outcome and locale after graduation (\_\_\_\_), will help broaden our set of participants (\_\_\_\_\_\_).

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

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

*Mentoring and Retention*

Mentoring and retention will build on the strengths of our programs. For example, EEB has tracked long-term placement of our graduate students over the past 16 years; out of the Masters students, 27 (52%) have gone on to careers outside colleges and universities, at jobs ranging from the US Forest Service to education coordinator at the Jackson Zoo to program director at the New York City Parks Department to high school biology teacher. The EEB department has also created its own tracking software to monitor grad student progress towards degree and to automatically highlight potential issues while building up a long term, secure, database of progress and outcomes. Data-intensive approaches such as these can identify problems early while also making programmatic assessment more rigorous for reports to grant agencies or higher administrative levels within the University. Core trainees will be mentored through standard committee structures but also through annual meetings with the Project Coordinator (one of the core faculty). The initial meeting will involve the creation of an individual development plan with concrete goals; this plan will be re-evaluated every year. Students will also be mentored through the informal networks fostered by their internships in their second year of grant funding.

Co-PI Kwit will oversee trainees’ mentoring activities, to be developed collaboratively with Dr. Brothers, who also oversees the Office of Graduate Training and Mentorship within the Graduate School. One of these activities is a weekly discourse session, modeled on a PEER initiative to increase the number of exceptional underrepresented students graduating with doctoral degrees in STEM disciplines at UT. Another activity will help students develop an individual development plan and monitor their progress toward accomplishing their goals.

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

**H. Performance Assessment / Project Evaluation**

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

The evaluation of this NRT will follow a process-and-outcome framework. This approach provides a comprehensive model to continue to analyze the project activities while gathering data on the program effects. Within this framework, a logic model (see tables) is used to represent the sequence of steps between program services and outcomes (Rossi, Lipsey, and Freeman 2004). The evaluation tables represent the logic model developed for the proposed NRT program. The outputs and outcomes shown include identified performance measures and expected competencies that are anticipated effects of the project activities.

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

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

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

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

***Table 2.*** *Evaluation and assesment*

|  |  |  |  |
| --- | --- | --- | --- |
| **Goal 1: Create a workforce to fill the need for biodiversity expertise in the US.** | | | |
|  | **Output** | **Outcome** | **Data Method** |
| **Course work** | # and description of courses offered pre/post program  # students enrolled in each course each semester  # students completing each course each semester  # trainees completing comprehensive examination  # 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 * Increase graduate student retention rate * Trainees secure related career post-graduation * Faculty and institution undergo paradigm shift * Increase in department collaboration | * Document review * Trainee survey (semester) * Trainee exit interview * Trainee follow-up survey * Faculty survey (semester) * Department Chair survey or interview |
| **Two-week field course** | # and description of field courses  # students enrolled in each course each semester  # students completing each course each semester  # of faculty teaching program courses  # of departments collaborating | * Trainees are satisfied with field course * Trainees gain understanding of field methods * Faculty and institution undergo paradigm shift * Increase in departmental collaboration | * Document review * Trainee survey (semester) * Trainee exit interview * Faculty survey (semester) * Department Chair survey or interview |
| **Workshops and Tutorials** | # and description of workshops and tutorials offered  # of streamed workshops and tutorials  # of workshop participants  # of tutorial views  # workshop instructors | * Trainees are satisfied with workshops * Trainees gain technological skills * Trainees gain domain knowledge * Expand program reach through streaming | * Document review * Post workshop survey |
| **Internships** | # students accept internship  # students complete internship  # students placed in internship companies  # companies offering internships  # interns hired | * Trainees increase professional network * Trainees gain skills needed for career outside academia | * Document review * Intern survey |
| **Trainee Research** | # completed theses  # completed dissertations | * Trainees successfully defend their thesis or dissertation | * Document review |
| **Cross-disciplinary Committees** | # of committees | * Committees are diverse | * Document review |
| **Publications** | # published manuscripts  # journals  # non-academic publications  # collaborations per paper | * Disseminate findings to broad audience | * Document review |
| **Outreach** | # events  # people reached | * Dissemination of idea that science careers are more than just faculty positions. * Communication of the power of biodiversity studies | * Document review |

|  |  |  |  |
| --- | --- | --- | --- |
| **Goal 2: Create a prototype for institutional culture change toward non-academic career paths.** | | | |
| Strategy | Output | Outcome | Data Method |
| Document program implementation over 5 years (including revisions) | # leadership team meetings  Timeline  Leadership meeting minutes  # significant revisions made to program  Description of rationale for changes  Updated timeline  # and description of advisory committee  # advisory committee meetings  Advisory committee meeting minutes | * Narrative description of program implementation | * Document review * Leadership team interviews * Meeting attendance |
| Disseminate program results via publications and presentations | # and description of presentations  # and description of publications | * Prepare and submit publication for peer review * Prepare and present results at conferences | * Document review |

*Evaluation Timeline*

TBD

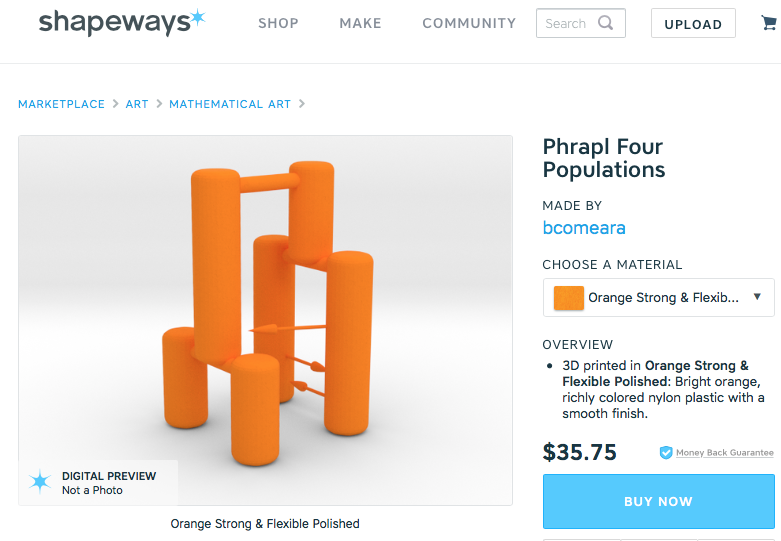
**I. Recent Student Training Experiences**

Over the past five years, PI O’Meara has had four graduate students in his lab. All are still currently enrolled: two are on schedule to receive their Ph.D. in ecology and evolutionary biology as well as a Masters in statistics this semester, another recently received a DDIG award and is on track for graduation on schedule, 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 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 also serves on approximately one-third of graduate student committees in the Ecology and Evolutionary Biology department and has also served on student committees in Entomology, Earth & Planetary Sciences, Microbiology, and Genome Sciences and Technology. O’Meara has also 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 ecology and evolutionary biology, another is a co-advised natural resources Ph.D. candidate in FWF, and a fourth is pursuing a Master’s 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 co-PI Kwit’s graduate students identify as women. Over the past two years, co-PI Kwit and one of his EEB graduate students have served as undergraduate mentors at the University of Virginia’s Mountain Lake Biological Station, a NSF-funded Research Experience for Undergraduates program. Kwit currently serves on graduate student committees in FWF, EEB, Plant Sciences, and at other universities.

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

**J. Results from Prior Support**

**B. O’Meara:** DEB-1257669: Collaborative Research: Phylogeographic Inference Using Approximated Likelihoods, $340,000, Feb. 28, 2013 – Feb 28, 2017. Intellectual merit: we developed, implemented, and tested models for examining phylogeographic structure of populations or species. These models can allow for gene flow between populations, speciation events, and population size changes. We also created models to allow inference about species delimitation (whether a set of populations should be treated as one species or multiple species). We have published two papers about this approach (Jackson et al. 2016, Morales et al. 2016), have two more in press, and are working on a general review paper about model comparison in phylogeography. We have run workshops in Ohio and Louisiana with travel support for students to train them in phylogeography, and students are already using our software in their research. To aid in communication and outreach, our software allows creation of 3D models, which can be embedded in presentations or even 3D printed using an output file from the open source software R (see figure). The postdoc involved in the grant chose to take a position in cancer research outside academia. We have also created a website and discussion group to promote long term use of the software, which is open source.

**S. Kalisz**

**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 understudied dipteran families Blephariceridae, Chironomidae. Dixidae, Psychodidae, Simuliidae, and Thaumaleidae, resulting in descriptions of many species. The eastern Nearctic fauna of Blepharicera was revised to include 23 species, six of which were described as new to science. Several species of moth flies (Psychodidae) previously unknown to science were discovered in the southeastern US. A multifaceted approach used molecular, cytogenomic, and traditional morphological techniques applied to black flies (Simuliidae) from around the world to obtain new global understanding. Researchers constructed the first phylogeny for the Thaumaleidae family, and 40 species of Thaumaleidae were sequenced for two genes, with a total of 10 new species discovered from Australia, Chile and the US. The first evolutionary tree depicting relationships between the world genera was constructed, yielding results that provide a new understanding about how the genera are related and insight into where the family may have originated. Broader Impacts: This multi-institutional collaboration of researchers provided mentoring to the next generation of taxonomic specialists (i.e., systematists) for several families of lower Diptera identified as being in need of young specialists capable of providing taxonomic expertise for the next several decades. These new systematists received hands-on training in field research and traditional morphology-based and molecular systematics, including phylogenetics. This award provided training to nine international visiting scholars, one technician, three postdoctoral researchers, 10 graduate students (7 Ph.D. & 3 M.S.), 9 undergraduate students, and one high school student. Synergistic activities through the Iowa State University Insect Zoo (e.g., development of outreach programs focused on the role of aquatic Diptera in medical entomology and in the biomonitoring of aquatic ecosystems) and the Iowa State Insect Collection (e.g., collection-improvement projects, initiation of a database system, and digitization of slide- and fluid collections) further enhanced the impact of the project. Lucid keys to Chirnomidae 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, two books, seven book chapters, and 46 peer-reviewed articles [X-XX], and several more are forthcoming. 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**

**C. Kwit** does not have prior NSF support over the past five years.

**References**

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

Editors. 2014. Editorial: There is life after academia. Nature **513**:5.

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

McLaughlin, J. S., and D. K. Johnson. 2006. 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 **13**:65-85.

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

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

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

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

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. 2014. Natural History's Place in Science and Society. BioScience **64**:300-310.

**Evaluation citation:**

Rossi, P.H., Lipsey, M.W., & Freeman, H.E. (2004). Evaluation: A systematic approach. Thousand Oaks, CA: Sage.

**Moulton’s Prior NSF citations:**

BOOKS (2)

Courtney, G.W. 2011. "Way cool Mountain Midges". Editor(s): J. Li & M. Barbour. Wading for Bugs: Exploring Streams with the Experts. Oregon State University Press, Corvallis.

Gullan, P.J. & P. S. Cranston (2014). The Insects: An Outline of Entomology 5th. Wiley-Blackwell. ISBN: 978-1-118-84615-5.

BOOK CHAPTERS (7)

Courtney, G.W. & P.S. Cranston. 2015. Section VIII: Phylum Arthropoda – Subphylum Hexapoda. 40. Diptera. pp. 1043-1058 In J.H. Thorp, D.C. Rogers, & K. Tockner (editors). Thorp and Covich’s Freshwater Invertebrates Volume I: Ecology and General Biology.

Courtney, G.W., T. Pape, J.H. Skevington & B.J. Sinclair. Biodiversity of Diptera. In R.G. Foottit & P.H. Adler (editors). Insect Biodiversity: Science and Society. Second Edition. John Wiley & Sons, Chichester, UK. [in review].

Courtney, G.W. 2016. 16. Blephariceridae (Net-winged Midges or Torrent Midges). In A. Kirk-Spriggs & B. Sinclair (editors). Manual of Afrotropical Diptera. South African National Biodiversity Institute. Pretoria, South Africa.

Fasbender, A. 2016. 27. Ptychopteridae (Phantom Crane Flies or Fold-winged Crane Flies). In A. Kirk-Spriggs & B. Sinclair (editors). Manual of Afrotropical Diptera. South African National Biodiversity Institute.

Madriz, R.I. (2015). 15. Tanyderidae (Primitive Crane Flies). In A. H. Kirk-Spriggs and B. J. Sinclair (editors). Manual of Afrotropical Diptera. South African National Biodiversity Institute. Pretoria, South Africa.

Marshall, S.A. & G.W. Courtney. 2015. Diptera. In C. Griffiths (editor). Field Guide to Freshwater Life in Southern Africa. Random House/Struik (Field Guide Series).

Sinclair, B.J. (2015). 33. Thaumaleidae (seepage midges or trickle midges). In A. H. Kirk-Spriggs & B. J. Sinclair (editors). Manual of Afrotropical Diptera. South African National Biodiversity Institute. Pretoria, South Africa.

THESES/DISSERTATIONS (4)

Fassbender, A.A. 2014. Phylogeny and diversity of the phantom crane flies (Diptera: Ptychopteridae). Ph.D. Dissertation. Iowa State University, Ames, Iowa. 867 pp.

Gleason, K.L. 2012. Cytogenetic biodiversity in the Simulium johannseni species group (Diptera: Simuliidae). M. S. Thesis. Clemson University, Clemson, South Carolina. 73 pp.

Pivar, R.J. 2015. Morphological and molecular systematics of Nearctic and World Thaumaleidae (Diptera). M. S. Thesis. University of Tennessee, Knoxville, Tennessee. ??? pp.

Swanson, D.A. 2012. Ecology and phylogeny of the biting-midge genus Culicoides (Diptera: Ceratopogonidae). Ph.D. Dissertation. Clemson University, Clemson, South Carolina. 182 pp.

REFEREED JOURNAL ARTICLES

Published (46)

1. Adler, P.H., Y.T. Huang & H. Takaoka. 2012. Nearctic-Palearctic relationships of black flies (Diptera: Simuliidae): chromosomal and morphological evidence for the Prosimulium magnum species group in Japan. Journal of Natural History 46:1467-1475.

2. Adler, P.H., Y.T. Huang, W.K. Reeves, S.K. Kim, Y. Otsuka & H. Takaoka. 2013. Macrogenomic evidence for the origin of the black fly Simulium suzukii (Diptera: Simuliidae) on Okinawa Island, Japan. PLOS ONE 8(8): e70765. doi:10.1371/journal.pone.0070765.

3. Adler, P.H. & G. Seitz. 2014. Chromosomal characteristics and evolutionary relationships of the Palearctic black fly Simulium carthusiense (Diptera: Simuliidae). European Journal of Entomology 111: 469-474.

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

5. Adler, P.H., M. Cherairia, S.F. Arigue, B. Samraoui & B. Belqat. 2015. Cryptic biodiversity in the cytogenome of bird-biting black flies in North Africa. Medical and Veterinary Entomology 29: 276-289.

6. Adler, P.H., A. Inci, A. Yildirim, O. Duzlu, J.W. McCreadie, M. Kúdela, A. Khazeni, T. Brúderová, G. Seitz, H. Takaoka, Y. Otsuka & J. Bass. 2015. 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 114: 163-183.

7. Adler, P.H. & Ü.D. Şirin. 2015. A new species of black fly in the Prosimulium hirtipes (Fries) group (Diptera: Simuliidae) from Western Turkey. Proceedings of the Entomological Society of Washington 117: 85-94.

8. Cherairia, M., P. H. Adler & B. Samraoui. 2014. Biodiversity and bionomics of the black flies (Diptera: Simuliidae) of northeastern Algeria. Zootaxa 3796: 166-174.

9. Courtney, G.W. 2015. A new genus and species of net-winged midge from Madagascar (Diptera: Blephariceridae: Blepharicerinae). Zootaxa 4052(1): 107–116.

10. Cranston, P.S. 2012. Some proposed emendations to larval morphology terminology. Chironomus 25: 35-38.

11. Cranston, P.S., Hardy, N.B., Morse, G.E., Puslednik, L. & McCluen, S.R. 2010. When morphology and molecules concur: the 'Gondwanan' midges (Diptera: Chironomidae). Systematic Entomology 35: 636-648.

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

13. Cranston, P.S. & Krosch, M.N. 2015. Nomenclatural corrections to Australian species of Cricotopus Wulp (Diptera: Chironomidae). Zootaxa 3980: 298–300.

14. Curler, G.R., & J.K. Moulton. 2010. Descriptions of three new species of Nearctic Psychodidae (Diptera). Zootaxa 2524: 51-62.

15. Curler, G.R. 2011. Records of phlebotomine sand flies (Diptera, Psychodidae, Phlebotominae) with a description of a new species of Sergentomyia. Franca & Parrot from Khao Yai National Park, Thailand. Zootaxa 2806: 60-68.

16. Curler, G.R., J.K. Moulton, R.I. Madriz. 2015. Redescription of Aposycorax chilensis (Tonnoir) (Diptera, Psychodidae, Sycoracinae) with the first identification of a blood meal host for the species. Zootaxa 4048(1): 114–126.

17. Drayson, N., Cranston, P.S. & Krosch, M.N. 2015. 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 3919 (1): 1–40.

18. Farnsworth, E.J., M. Chu, W.J. Kress, A.K. Neill, J. Pickering, G.W. Courtney, J.K. VanDyk, & A.M. Ellison. 2013. Next-generation field guides. Bioscience 63: 891-899.

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

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

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

22. Jacobson, A.J., G.R. Curler, G.W. Courtney, & J.K. Moulton. 2011. New species of net-winged midges of the genus Blepharicera Macquart (Diptera: Blephariceridae) from eastern North America. Systematic Entomology 36: 768–800.

23. Khazeni, A., P.H. Adler, Z. Telmadareiiy, M.A. Oshaghi, H. Vatandoost, S.M. Abtahi & A. Lofti. 2013. The black flies (Diptera: Simuliidae) of Iran. Zootaxa 3694: 67-74.

24. Krosch, M.N. & Cranston, P.S. 2012. Non-destructive DNA extraction, including of fragile pupal exuviae, extends analysable collections and enhances vouchering. Chironomus 25: 22-27.

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

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

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

28. Lambkin, C.L, B.J. Sinclair, T. Pape, G.W. Courtney, J.H. Skevington, R. Meier, D.K. Yeates, V. Blagoderov, & B.M. Wiegmann. 2013. The phylogenetic relationships among infraorders and superfamilies of Diptera based on morphological evidence. Systematic Entomology 38: 164-179.

29. Madriz, R.I. & 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 ecology. Zootaxa. 4158(3): 325-51. doi: 10.11646/zootaxa.4158.3.2.

30. Moulton, J.K. 2017. 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 4216 (3): 247–260.

31. Moulton, J.K. 2016. The Dixa inextricata Dyar & Shannon (Diptera: Dixidae) species group, with two new cryptic species from the eastern Nearctic Region. Zootaxa 4121(4): 458–472.

32. Petersen, J.D., M.J. Petersen, & G.W. Courtney. 2012. Description of a new subgenus Neophylidorea (Diptera: Tipulidae) and a new species. Zootaxa 3555: 40-54.

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

34. Pfrender, M.E., C.P. Hawkins, M. Bagley, G.W. Courtney, B. R. Creutzburg, J.H. Epler, S. Fend, L.C. Ferrington, Jr., P.L. Hartzell, S. Jackson, D.P. Larsen, C.A. Lévesque, J.C. Morse, M.J Petersen, D. Ruiter, D. Schindel, and M. Whiting. 2010. Assessing macroinvertebrate biodiversity in freshwater ecosystems: Advances and challenges in DNA-based approaches. The Quarterly Review of Biology 85: 319-340.

35. Pivar, R.J., J.K. Moulton, B.J. Sinclair. 2016. A new species of Austrothaumalea Tonnoir from Australia (Diptera: Thaumaleidae). Zootaxa 4132(4): 594–597.

36. Reeves, W.K. & P.H. Adler. 2011. Colonization of Pacific islands by black flies (Diptera: Simuliidae). Proceedings of the Entomological Society of Washington. 113(3): 371-376.

37. Senatore, G.L., E.A. Alexander, P.H. Adler & J.K. Moulton. 2014. Molecular fingerprinting of black flies in the Simulium jenningsi species group (Diptera: Simuliidae): phylogenetic and practical implications. Molecular Phylogenetics and Evolution 75: 138-148.

38. Sinclair, B.J. & H. Heurta. 2010. A new species of Androprosopa from Mexico (Diptera: Thaumaleidae). The Canadian Entomologist 142: 443–447.

39. Sinclair, B.J. (2013) Rediscovered at last: a new enigmatic genus of Axymyiidae (Diptera) from western North America. Zootaxa 3682(1): 143–150.

40. Sinclair, B.J. (2014). A new species of Afrothaumalea Stuckenberg from the Western Cape (South Africa) and first description of the pupa of this genus (Diptera: Thaumaleidae). African Invertebrates 56(1): 161-166.

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

42. Swanson, D.A. & W.K. Reeves. 2011. New records of biting midges (Diptera, Ceratopogonidae) from Guam Island. Check List 7: 313-14.

43. Swanson, D.A. & W.L. Grogan, Jr. 2011. A new predaceous midge in the genus Brachypogon (B.) from Alabama and Florida, USA and new distribution records for B. woodruffi Spinelli and Grogan (Diptera: Ceratopogonidae). Proceedings of the Entomological Society of Washington 113(4): 531-540.

44. Wihlm, M.W. & G.W. Courtney, 2011. The distribution and life history of Axymyia furcata McAtee (Diptera: Axymyiidae), a wood inhabiting, semi-aquatic fly. Proceedings of the Entomological Society of America. 113: 385-398.

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

46. Wipfler, B., G.W. Courtney, D.A. Craig & R.G. Beutel. 2012. First µ-CT based 3D reconstruction of a dipteran larva - the head morphology of Protanyderus (Tanyderidae) and its phylogenetic implications. Journal of Morphology 273: 968-980.