Project Description

1. Brief Statement of Objectives and Rationale

Understanding the potential impacts of climate change, invasive species, and other large-scale factors on biological systems is a formidable task. It is not feasible to conduct randomized, replicated experiments at regional and continental scales. Instead we can use natural field experiments to study such phenomena (Hargrove and Pickering 1992). Herein we propose to develop a continental scale network for the rapid collection of vast quantities of specimen-level data to inventory and monitor field sites. We will use these data to take advantage of natural experiments. Our specific objectives are

- to develop the human and technical capacity across this network for researchers to collect, identify, integrate and analyze high-quality digital observations about organisms across geographical and temporal scales;
- to study the ecology of representative examples of plants, insects and other groups of organisms and model how weather and other large-scale factors affect their phenology, distribution, abundance and interactions.

2. Results from Previous NSF Support

2.1 Steve Stephenson
NSF Award DEB-0316284 - Planetary Biodiversity Inventories: Global Biodiversity of Eumycetozoans; Stephenson; University of Arkansas; $2,075,523; 2003-2009.

This project's overall goal was to expand, standardize, systematize and summarize all available information on the taxonomy, ecology and biogeography of eumycetozoans (myxomycetes, dictyostelids and protostelids). The primary objective was to survey for eumycetozoans in areas of the world where data were previously lacking. Secondary objectives included (1) compiling a major specimen database that would encompass both numerous "new" records obtained from the field surveys as well as the majority of the myxomycete collections in the world's herbaria and all available records of dictyostelids and protostelids and (2) developing a web site on eumycetozoans that would incorporate the specimen databases and world distribution maps for all of the 1,200 to 1,300 known and new species. During the course of the project, field surveys were carried out on all seven continents and in every type of terrestrial ecosystem. The total effort has considerably increased our understanding of patterns of eumycetozoan biodiversity on scales ranging from local to global. An extensive web site (http://slimemold.uark.edu) has been constructed that includes databases of nomenclature, specimen records [>213,000 thus far], published literature, images of particular species (>2,000 images that show habit, diagnostic features and ultrastructure) and educational materials on eumycetozoans. A linkage established with Discover Life (www.discoverlife.org) allows world distribution maps to be generated for each species. This aspect of the project represents the first effort to consolidate and make available to the scientific community and an even larger public audience the widely scattered information that exists on eumycetozoans.

Broader Impacts: The project funded by this grant has been a major collaborative effort involving scientists from all over the world. In addition, the grant provided support for five Ph.D. students, two MS students and 15 undergraduates (13 of whom are female). Numerous (ca >100) presentations have been made at international and national meetings, and >80 papers in peer-reviewed journals have been published thus far.

2.2 Nyree Zerega
NSF Award DBI 0648972 - REU Site: Plant Science and Conservation Biology from Genes to

Ecosystems; PI: Louise Egerton-Warburton, co-PI Nyree Zerega; Chicago Botanic Garden and Northwestern University; $252,960; 2008 - 2010.

The primary goals of the Research Experience for Undergraduates (REU) Program in Plant Biology and Conservation program were to: 1) provide a diverse group of undergraduate students with a stimulating interdisciplinary environment to address contemporary research issues in basic and applied plant conservation; 2) facilitate a unique research experience that promotes intellectual growth, analytical skills, and creativity; and 3) encourage students to pursue graduate school and professional careers in plant conservation and related disciplines.

Our REU program began with a weeklong field and laboratory workshop where students were introduced to interdisciplinary conservation practices through field sampling and census protocols, and laboratory methods in plant molecular biology, and soil chemistry and biology. This weeklong period encouraged collaborative learning, leadership, and the development of group identity as well as the collection, analysis, and interpretation of different data forms. After the first week, students worked closely with their mentors to complete an 8-week research project. At the close of the program, students presented their research both as a short oral presentation and poster. The research projects included both basic and applied conservation research, and comprised conservation genetics, systematics and evolution, molecular ecology, pollination ecology, restoration, aquatics, biogeochemistry, and plant-soil interactions.

Broader Impacts: Over the course of the three-year grant, 342 applications (19% came from minorities) were received, and 34 applicants (23% were minorities) were chosen. Currently, 16 of the REU students have now graduated from college, and 13 of them are either employed or in graduate school in the field of biological and environmental sciences or other STEM fields.

2.3 Gretchen LeBuhn
NSF Award DBI 0207090 - UMEB: Integrating Inquiry-Based and Cooperative Learning with Expanded Career Horizons in Environmental Biology; PI: Edward Connor, co-PIs Gretchen LeBuhn, V. Thomas Parker; San Francisco State University; $400,000; 2002 - 2007.

This UMEB (Undergraduate Mentoring in Environmental Biology) program was designed to encourage and prepare students from groups that are currently underrepresented in the sciences to choose careers in environmental biology. Over the four years, 23 undergraduate students were integrated into research labs pursuing research on the local projects. Most students participated for two years during which they acted as members of research teams in ongoing projects, and developed, executed, analyzed, interpreted, wrote-up, and presented a project of their own design with supervision of their mentor. The science conducted by students in the program focused on the impact of urbanization and agriculture via habitat loss, fragmentation, and degradation, but was not exclusively restricted to this area. Over the four years of the grant we had 43 applicants of which 31 were female and 14 were male. Our applicant pool included 7/43 or 16% minority students. From these applicants, we accepted 23 students (15 female and 8 male) of which 7/23 (30%) were minority students. Four graduate students, partially supported by the grant, assisted with program coordination. Of the graduate participants, all were female, and one was minority.

A total of 10 faculty mentors participated in the UMEB program as sole or as co-mentors of one of more student participants. Of the 20 undergraduate student participants who have graduated, 14 entered graduate programs in Biology, Mathematics, Medicine or Education (70%), 3 have obtained employment in biologically or environmentally related positions, and 3 are in unrelated fields or unemployed.

Four papers arising from the research conducted by the undergraduate participants and four papers arising from the graduate students have been published, accepted for publication, or submitted (see citations

under each student). The student participants have made a total of 15 presentations at local, regional, or national scientific meetings.

Broader Impacts: Over the four years of the grant we had 43 applicants.

2.4 Eric Nagy
NSF Award DBI 1005104 - REU Site: Independent Field Research in Ecology, Evolution and Behavior at Mountain Lake Biological Station. E. Nagy PI, E. Brodie co-PI, $509,238, 5/2010 - 4/2015.

This program has renewed NSF funding for 2005-2015. The 18-year-old NSF-funded REU-Sites program at MLBS is most closely related to this proposal. A list of all individual participants and their projects is archived on the mlbs.org website. During the past five-year period the program has hosted 56 undergraduate researchers from 40 different institutions; 71% are female, 34% from racial and ethnic groups underrepresented in science (up from 11% five years ago), and 36% from non-Ph.D.-granting institutions. 9% participated in the program with outside funding (e.g. Mentor support, home institution scholarship, REU Supplement, etc.). 47% have entered graduate programs or have already earned advanced degrees (participants from 2008 and 2009 programs not included). Eight of the eleven (73%) 2008 program participants plan to apply to Ph.D. programs in the next year. 13% of those entering graduate school do so with NSF Graduate Fellowships. 33% of minority participants from the same period are currently in graduate programs. Dawn O'Neil, an African-American woman whose first field experience was as an REU at MLBS (2001), returned to the program as an REU mentor in 2005 after initiating her Ph.D. work in the lab she worked in as an REU. Two other recent program alumni also returned as mentors during the currently funded project. Another measure of program success is publication and presentation rate. From student projects supported in the past 5 years, 11 papers have been published or are in press. At least three more will be submitted shortly. These 14 papers reflect the work of 38% of REU participants during the most recent award.

3. Objectives, Rationale, and Significance

3.1 **Capacity building**
We propose to study species and their interactions with teams of students at 95 field sites, building a powerful new multi-site framework for natural history research. It will allow us to address large-scale research questions (section 3.2) and mentor a new generation of field scientists.

Traditional methods of collecting and managing specimen-level data are neither economically nor functionally feasible for studying the driving forces of large-scale ecological phenomena. While required for systematics, processing physical specimens is too laborious and inefficient to yield sufficient replicates of comparable data across sites and over time. Faced with this problem, many studies have turned to citizen scientists to collect data rapidly and over extensive geographical areas (Crall et al. 2010). However, when data are strictly observational, they generally lack credibility and scientific rigor, because species identifications cannot be verified and are often wrong (Mumby et al. 1995, Ericsson and Wallin 1999, Barrett et al. 2002, Genet and Sargent 2003, Brandon et al. 2003).

To address these issues, Discover Life has designed a system to collect, identify, integrate and check large quantities of high-quality data using digital photography, web tools and rigorous protocols. Our experience with the Lost Ladybug Project shows that when image data are verified by experts they can be of very high quality. We are now ready to expand our system across a network of field sites and taxa, enabling researchers to answer ecological questions across scales ranging from local to continental.

3.2 **Research Questions**

Our initial work focuses on six questions. We will expand these to additional taxa as researchers join the network.

- 3.2.1 <u>How temperature drives the phenology of plants, insects and other taxa</u>
  Many taxa have shown a biological response to climate change (Parmesan and Yohe 2003, Walther et al. 2002, Root et al. 2003). Certain plants, birds and butterflies have shifted their geographic distributions (Grabherr et al. 1994, Thomas and Lennon 1999, Parmesan et al. 1999). In addition, some plants, birds, butterflies and amphibians have shifted their seasonal phenology (Fitter and Fitter 2002, Menzel et al. 2001, Bradley et al. 1999, Roy and Sparks 2000, Beebee 1995, Gibbs and Breisch 2001).

  Pickering, Hargrove, Creed, and Long are modeling satellite and weather data to understand variation in the timing and length of the growing season, using MODIS satellite images of the "green" signal from mid-latitude Mexico through southern Canada and NOAA's data from over 10,000 ground-based weather stations. These models, based on the methods of Hochberg et al. (1986), will predict the timing of spring and fall for plant communities across the continent based on weather data. To compare how weather drives phenology at the species level, we propose to collect specimen-level data and analyze species activity across study sites in a similar manner. We will develop our protocols in consultation with the National Phenology Network and tailor them with their standards.

  Climate change and phenology studies that focus on individual species tend to favor more extreme changes than those studies of groups of species (Parmesan 2007). Hence, we propose to collect data on many species from a phylogenetic array of plants, moths and other taxa to increase the strength and accuracy of our results. Because sampling frequency and population size can affect results from phenology studies (Miller-Rushing et al. 2008), we will collect data frequently and focus on species that are common across sites.

- 3.2.2 <u>Inventorying and predicting biodiversity and invasion across the continent</u>
  NEON has delineated 20 domains in the United States, defined by a multivariate analysis of temperature, precipitation, and soil moisture (Hargrove and Hoffman 2009; Field et al. 2006). These domains are defined solely by abiotic factors and not by the biological communities or species within them.

  How powerful are local versus large-scale factors in determining species distributions and patterns in biodiversity? How important are biotic versus abiotic factors in structuring communities at different scales, from individual sites, through NEON domains, to the biogeography of North American and surrounding areas?

  Researchers have yet to take advantage of the climatic and edaphic factors that define NEON domains in understanding biodiversity and predicting how it will change over the next century. To rectify this, we propose to inventory plants, lichens, slime molds, butterflies, moths, syrphid flies and amphibians at sites in each NEON domain and at 5 tropical sites in Central America. We will analyze our local inventories in conjunction with species checklists at the domain level that we will assemble from herbaria, museums, and other sources. We will extend the methods that we used in large-scale comparisons of biodiversity across regions (Bartlett et al. 1999, Skillen et al. 2000), compare alpha diversity (species richness within the domains) and beta diversity (rate of species turnover across domains) with data on species interactions, and better understand how regional flora and fauna are pieced together.

Our proposed inventories will detect novel invasions of non-native species at each site, and perceive general trends of invasive species across sites. With its partners at USGS National Biological Information Infrastructure (NBII) and referring to the USDA PLANTS database and APHIS information sources, Discover Life has assembled invasive species lists. These will be factored out when we try to understand how the climatic and edaphic variables have shaped the native species composition and biogeography of the domains. The invasive species lists will be factored in when we try to understand if certain domains are more susceptible to biological invasion than others.

- 3.2.3 <u>Between-year variation in pollinator abundance across sites and disruption of pollination seasonal synchrony</u>
  Changes in climate may have both direct and indirect effects on plant reproduction. For those plants that rely on an animal pollinator, changes in the phenology of that pollinator that do not correspond with changes in phenology of the host plant may have dire consequences for both. Recent work in alpine environments suggests that plant phonologies are changing asynchronously leading to novel communities where formerly tightly co-adapted relationships may be disrupted (Forrest et al. 2010) and there is increasing asynchrony between some plants and their pollinators leading to declines in reproductive success of those plants (Thomson 2010). Using data collected in this project, we plan to ask three questions:
  - o Can we detect disruptions in synchrony between pollinator emergence and plant flowering times?
  - o Are these disruptions significant enough to decrease plant fertility or pollinator abundance?
  - o Does climate influence the amount of synchrony in pollinator and plant communities?

- 3.2.4 <u>How climate affects local and regional fruiting of selected mushroom species</u>
  It has long been known that the phenology of macrofungi (mushrooms) is influenced by both precipitation and temperature (Stephenson 2010), and that there is already some change in phenology due to warming winter temperatures (Kauserud 2008, Kauserud et al. 2010). Because mushroom fruiting is more closely tied to weather responses than to photoperiod or day length, their phenology is both harder to predict and more sensitive to climate (Kauserud et al. 2010). We aim to determine how weather affects the phenology of individual species in this somewhat climate-sensitive and unpredictable group.

  The Fungimap project in Australia has demonstrated the feasibility of using citizen scientists to document the occurrence of mushrooms on a continental scale and will serve as a model for our mushroom component of the proposed project. We will make identification keys, images and information relating to approximately 100 "target" species on Discover Life in a manner similar to that developed by Co-PI Stephenson on www.mushroom.uark.edu and www.ncrfungi.uark.edu.

  We plan to answer how rainfall and temperature affect local and regional fruiting of mushrooms.

- 3.2.5 <u>Large-scale factors affecting slime mold biogeography, local diversity, and ecology</u>
  Slime molds (myxomycetes) generally occur on some of the same substrates (e.g., decaying wood and forest floor litter) as mushrooms. Although the fruiting bodies produced by slime molds are smaller than those of mushrooms, those of most species tend to be produced in groups or clusters that can be documented (i.e., with digital images) in the same way as mushrooms. Co-PI Stephenson wrote the text of the only true field guide (Stephenson and Stempen 1994) available for slime molds and has developed educational materials (see www.slimemold.uark.edu) that will serve as the starting point for this component of our project.

We aim to answer the following questions about the influence of climate change on species abundance and association of species of myxomycete with particular vegetation types.

- *Species abundance and climate change.*
  There is little question that some species of myxomycetes are common while others are rare (Stephenson and Stempen 1994). Are changes in levels of abundance occurring (i.e., common species declining and certain rare species becoming more evident)? If so, can this be related to weather patterns? Do some species actually become locally extinct?
- *Association of species of myxomycete with vegetation type.*
  There is some evidence that the overall biodiversity of the assemblage of species of myxomycetes associated with a particular vegetation type is related to the biodiversity of the plants (particularly the woody plants) present, but this has never been evaluated on a regional or continental scale. To what extent does this linkage exist?

These studies will also provide baseline data for use by other researchers to answer novel questions about this group.

- 3.2.6 <u>Lichen diversity and growth rates as bio-indicators of pollution and drought</u>
  Lichens are good bioindicators of air pollution, and in some cases yield more accurate results than those from air particulate matter analysis (Rossbach et al. 1999, Garty 2001). Since 1994, the US Forest Service has been using lichens (fia.fs.fed.us/lichen/background) to monitor for air quality as part of the Forest Health Monitoring program. However, these studies focus on species richness and do not provide fine-grained data about lichen growth patterns. We also do not fully understand the potential effects of drought and other weather conditions on lichen growth rates and species richness (Ellis et al. 2007).

We aim to answer how weather and air quality affect lichen growth rates.

4. Methods

4.1 Capacity Building

- 4.1.1 <u>Computer technology</u>
  Discover Life has the databasing tools, storage space, and processing capacity to run the proposed network. Its users can (1) upload images and manage associated data, (2) build and use identification guides customized by location and time of year, and (3) map, analyze, search and disseminate specimen records and information about taxa. Discover Life will provide this capacity and associated technical support to the network at no cost to the NSF. Two consecutive 5-year cooperative agreements with NBII make this possible (see Annie Simpson's letter of cooperation).

  Over 100 museums, herbaria, universities and other organizations have contributed to Discover Life. Together their databases provide information on over 1.2 million species. Through its relationships with GBIF, the Integrated Taxonomic Information System (ITIS), and other contributors, the site integrates data from nearly 10,000 original sources. These include over 150 large specimen-level datasets, including several NSF Planetary Biodiversity Inventory (PBI) and Partnerships for Enhancing Expertise in Taxonomy (PEET) projects, 500 identification guides and checklists, and 300 photographic albums, which together contain 225,000 images. In August 2010, it served 24.7 million pages and images to 316,000 IP addresses. Since 1998, it has served a total of 720 million pages and images.

- 4.1.2 <u>Workflow</u>
  This is geared to large-scale data collection and management, while maintaining rigid quality control in all the following steps:
  - o 4.1.2.1 *Data Collection*
    We will provide research projects with new means to collect verifiable observations on specimens, accurately documenting time, location, and species information with digital photography, GPS units, and cell phones. In addition to recording specimen-level events rapidly, this technology greatly enhances our ability to record and track plant-pollinator, predator-prey, and other species interactions. We will use on-line videos to explain all aspects of data collection, uploading, and management.

  - o 4.1.2.2 *Species Identification*
    By integrating technology and human expertise, the network will determine large numbers of specimens rapidly and accurately without overwhelming taxonomists. Our hierarchical identification procedures include customized local online guides, automated flagging of unusual events, and oversight by taxonomists (see below). Certain species cannot be identified from photographs and require physical specimens. We will generally not identify such species but instead, for efficiency, focus on ones for which we can ensure high-quality, standardized determinations from photographs. We will continue to accept specimen data on all species.
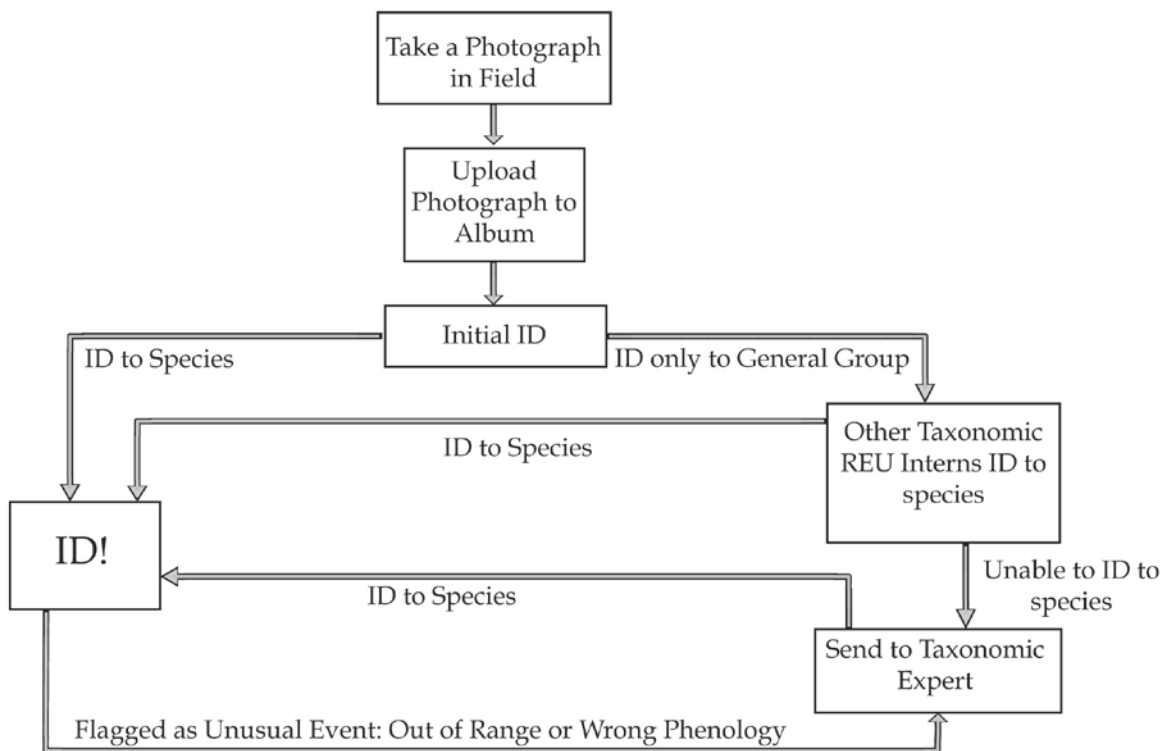
Pickering is building guides to moths as part of the cooperative agreement with NBII. We request funds to build identification guides to target species of lichens (Beeching), slime molds and mushrooms (Stephenson), plants (Zerega), and other taxa (see letters of collaboration).

- o 4.1.2.3 *Data Integration*
  Discover Life assigns unique, permanent record identifiers to each observation. It will use these identifiers to integrate our specimen-level and species-interaction data with historical information from the literature, collections, and other reliable sources. It uses automated programs, taxonomic authority lists, geographic gazetteers, human feedback and other means to detect and correct errors. It will integrate the biological data with information from satellite, aerial photographs, weather stations, and NEON's air quality and other physical monitoring.

- o 4.1.2.4 *Data Analysis*
  We will make the data that we collect readily available to researchers using Discover Life's automated programs that index and tabulate records and build summary files of them each night. We will put data into standard formats that can be easily imported into spreadsheets, databases and analysis software. Thus, we will provide the data to the research community in a timely fashion so they can be modeled and used to answer questions at different scales of analyses.

- o 4.1.2.5 *Dissemination*
  Our goal in building capacity is not to write traditional publications per se, but to provide researchers, land managers, policy makers and the general public with up-to-date, high-quality biological data. We assert that these data should be made readily and rapidly available in a manner similar to the way in which weather data are currently collected and distributed, as a public service. Using search tools and other web programs, we will freely disseminate the data as HTML pages, text files and in other formats, as we collect and analyze them in real time. Participants will take photographs, identify specimens, integrate, analyze and disseminate data to the world, as a cooperative endeavor and public service. Photographers will retain ownership and copyright to their images but will allow Discover Life to make them available to the world for non-commercial use as specified by Discover Life's copyright policy and terms of use (www.discoverlife.org/ap/copyright.html).

- 4.1.3 Data collection teams
  We propose to employ undergraduate teams, who will work at field stations, and high school teams, who will collect data in their county throughout the year. Our outreach programs will collect supplemental data through the web by working with schools and the general public.

  In summer 2010, we evaluated our methods with eight students. Their experience level ranged from a high school sophomore with no prior natural history experience to an individual with a masters degree in plant taxonomy. In total, they took over 10,000 photographs, database where and when they took them, and identified nearly 700 plant, insect, and lichen species. We have designed our teams based on the relative productivity of these individuals.

  - o 4.1.3.1 *Undergraduate teams*
    As we phase in study sites, we will employ from 42 to over 100 undergraduates annually. At each participating field station, we propose a team of two students with support equivalent to REU awards, working with a faculty mentor and local expert naturalists.
    - ▪ Recruitment: We will make every effort to recruit from underserved communities, including from the individuals in our high school teams who go to college. We will encourage students to return year-after-year and gain experience comparing multiple field sites. If some become graduate students, we will

support their continued participation. We hope this mentoring and jobs over five years will convince more students to choose STEM careers.

- ▪ Training: Students will be trained by their mentors and, after the first year's cohort, by experienced peers who have worked with the network for a summer or longer. We will supplement training with online videos and remote technical and taxonomic support.
- ▪ Responsibilities: At temperate sites the undergraduates will work for 9 weeks between May and September. We will staff our tropical sites (Hawaii, Puerto Rico, South Florida, Costa Rica, Panama) year-round with our more experienced undergraduates, in assignments of 4-6 months. We will employ local expert naturalists to work with the team periodically to acquaint them with their site's natural history. The students will spend half their time on an independent project and the other half inventorying and monitoring the site as a team. They will photograph insects, plants, and mushrooms; mark and measure lichens, collect and rear slime molds, and manage data and identify specimens online. They will study additional taxa as researchers join the network and expand its taxonomic breadth. The undergraduates will learn general identification skills and, under the remote supervision of our taxonomists, each will become an expert at identifying a genus or family. Thus, they will collect data for a number of projects, including their own, and provide identification support for other people across the network.

- o 4.1.3.2 *High school teams*
  To monitor biodiversity for entire field seasons, we will employ high school teams of a teacher and three students. In year-1 we propose 9 teams in Georgia. By year-3 we propose to add one high school team in each of the other 36 eastern states, for a total of 45 teams. We will write a supplemental proposal in year-3 to fund high school teams in western states and increase their density across all regions starting in year-4.

  - ▪ Recruitment: We are partnered with the Young Scholars Program at the University of Georgia. This program's mission is to recruit minorities to STEM. They will recruit minority and other under-served students into our high-school teams. In year-1 Young Scholars will recruit in Georgia and surrounding states. By year-3 they will recruit throughout the eastern United States. See letter of collaboration from their Associate Dean and Director, Dr. Ronald Walcott. We will also recruit high school teachers at Annual AP Biology exam reading sessions, where over 400 of the most qualified biology teachers in the country assemble to grade AP exams. The teachers who join our project will help us recruit students from their county and then oversee a team. Ideally, once recruited, teachers will work with us for multiple years. See letter of collaboration from AP Biology teacher Stella Guerrero. We will recruit young science teachers through the PI's work with the College of Education at the University of Georgia (see letter of collaboration from Dr. Mike Mueller).
  - ▪ Training: High school teachers will attend a one-week course in their region. Our staff will cover the objectives of the project, teach skills in photography, our web tools, research protocols, identification, and natural history. Teachers will then train their students, oversee their work using our web tools, and supervise their science fair projects.
  - ▪ Responsibilities: Students in the high school teams will collect data at sites in their county. In the fall, they will be focused on collecting data on arthropods associated with goldenrod and lichens. In the spring, they will collect data on plant and mushroom phenology. In addition, the teams will monitor moths at

lights nightly at their homes for an hour just before dawn for 6 to 10 months, depending on their latitude and elevation. In year-1 they will bracket sampling to assure getting the earliest and latest flying species. After year-1 we will determine each site's moth sampling dates based on their past results, that year's local temperatures, and our phenology models.

- o 4.1.3.3 *Outreach programs*
  We will augment the data collected by these teams with data submitted by the general public and assembled through a growing consortium of websites and outreach programs associated with our network. These include Discover Life, Great Sunflower Project, Mushroom Observer, Encyclopedia of Life, Floral Report Card / Project Bud Burst, Pollinator Live, and Lost Ladybug Project (see letters of collaboration).

- 4.1.4 <u>Field sites</u>
  Ultimately, we envision building a dense network of study sites across the continent. We propose to start with 95 sites that are both stratified and clustered regionally. Together they will enable us to make statistically meaningful comparisons across time and space to address large-scale ecological questions. They will provide the data that we need to design a network with enough replication across sites to yield strong conclusive results.

  We propose to staff teams at 41 temperate field stations and other institutional sites, such at the Los Angeles County Museum. These sites are likely to sustain for decades, and hence, could support long-term ecological research beyond the scope of our 5-year proposal. They include two stations in each of the 18 temperate NEON domains, a cluster of 6 field stations in the Northeastern domain, and 3 in the Appalachians, for a total of 41 temperate sites. We will also staff 9 tropical field stations: Hawaii (2), southern Florida, Puerto Rico, Costa Rica (4), and Panama. In addition, we propose to have 45 high school teams in the 37 states east of the Rocky Mountains, one per state, with the exception of Georgia, where we will have a cluster of 9 counties (3 Appalachian, 3 Piedmont, and 3 Coastal Plain).

  At temperate field stations, undergraduate teams will collect data and build customized local identification guides during the summer. At the tropical ones, they will do the same year-round. At the county sites in the eastern United States, the high school teams will collect data throughout the growing season.

  We have recruited 23 biological field stations and other sites that wish to join the network, representing 11 NEON domains. In year-1 we will staff these and the 9 Georgian counties. By year-3 we propose to have all 95 sites staffed. Thus, by the end of the project we will have 3-5 years data per site, allowing us to analyze across year differences.

    Participating field stations -- Contacts (* indicates letter of collaboration included)
    1. Arizona -- <u>Merriam-Powell Research Station</u> -- Amy Whipple*
    2. Arizona -- <u>Southwest Research Station</u> -- Dawn Wilson*
    3. California -- <u>Los Angeles County Museum</u> -- Brian Brown*
    4. Colorado -- <u>Rocky Mountain Biological Laboratory</u> --Ian Billick*
    5. Florida -- <u>Archbold Biological Station</u> -- Hilary Swain*
    6. Indiana -- <u>IU Research and Teaching Preserve</u> -- Keith Clay*
    7. Iowa -- <u>Iowa Lakeside Laboratory</u> -- Peter van der Linden*
    8. Maine -- <u>Shoals Marine Lab</u> -- Willy Bemis*
    9. Massachusetts -- <u>Worcester, Harvard Forest</u> --David Foster
    10. Massachusetts -- <u>Nantucket Field Station</u> --Sarah Oktay*

11. Michigan -- <u>W.K. Kellogg Biological Station</u> -- Tom Getty*
12. Michigan -- <u>University of Michigan Biological Station</u> -- Knute Nadelhaffer*
13. Montana -- <u>Yellowstone Ecological Research Center</u> -- Bob Crabtree*
14. New York -- <u>Adirondack Ecological Center</u> -- Stacy McNulty*
15. New York -- <u>The Huyck Preserve</u> -- Chad Jemison*
16. New York -- <u>Black Rock Forest</u> -- Bill Schuster*
17. North Carolina -- <u>Highlands Biological Station</u> -- Jim Costa*
18. North Carolina -- <u>Turnipseed Tract, Wake County</u> -- Chris Snow*
19. North Carolina -- <u>Balsam Mountain Preserve</u> -- Michael Skinner*
20. Oregon -- <u>H.J. Andrews Experimental Forest</u> -- Mark Schulze*
21. Virginia -- <u>Mountain Lake Biological Station</u> -- Edmund Brodie*
22. Puerto Rico -- <u>El Verde Field Station</u> -- Nick Brokaw*
23. Costa Rica -- <u>La Selva Biological Station</u> -- Deedra McClearn*
24. Costa Rica -- <u>UGA Costa Rica at San Luis de Monteverde</u> -- Quint Newcomer*

4.1.5 <u>Organizational structure and governance</u>

o 4.1.5.1 *Polistes Foundation*
The Polistes Foundation (www.discoverlife.org/polistes) is a 501-c-3 non-profit organization based in Massachusetts. It is the legal and fiduciary umbrella of Discover Life, works virtually, and has very low overhead costs. Weick and Talmadge will administer this proposal through Polistes. As a new, efficient way of managing research, Polistes will charge no indirect costs to the NSF on this proposal. All our costs are specified as direct ones.

o 4.1.5.2 *Executive Committee*
Within the legal framework of the 501-c-3, the five PI's will serve as the network's Executive Committee. To minimize travel, they will coordinate our activities via regular Skype conference calls and other electronic means. They will attend professional meetings to seek advice from the larger scientific community and coordinate our activities with their members. These meetings will include Botany (Nyree), Ecology (LeBuhn), Entomology (Pickering), Mycology (Stephenson), OBFS (Nagy), and NSTA (Lowe).

o 4.1.5.3 *Organization of Biological Field Stations, OBFS*
Through our co-PI Eric Nagy, a past President and board member of OBFS, we are working closely with OBFS to recruit field stations and mentors. We have received enthusiastic support from OBFS members and will use their annual meetings as a central element in coordinating our activities across sites. At the OBFS meeting in September 2010, we plan to recruit a second cohort of stations.

o 4.1.5.4 *International Center for Public Health and Environmental Research, PHER*
Polistes founded PHER in 2007 (www.discoverlife.org/research). PHER now has 75 researchers who work together virtually on their mutual goals. Its members will provide the backbone of scientific expertise in ecology and taxonomy that the network will use. They will help advise the Executive Committee and mentor students. As researchers join the network, PHER will invite them to join, thus formally expanding their participation.

o 4.1.5.5 *Workshop*
To launch the network, brainstorm, seek early feedback and train the first cohort of mentors, we will host a workshop at Elmira College, New York, in June, 2011. To get broad input, participants will include an eclectic crowd of theoretical ecologists, field biologists, taxonomists, statisticians, modelers, web developers, government agencies, NGOs, educators, and land managers.

4.2 **Methods to answer research questions**

For our analysis we will select species that are readily identifiable from photographs, are relatively easy to find, and occur across multiple sites and years. Based on our work photographing and identifying moths, plants and lichens over the past two years, we estimate that the network will process an average of over 10,000 specimens identified to species per year at each site. Once we build custom identification guides to the sites, each verified identification will require approximately one minute of human time.

- 4.2.1 <u>How temperature drives the phenology of plants, insects and other taxa</u>
  To limit costs, we will confine this study to the eastern United States, where we already have built partnerships with study sites and have begun building customized guides. For monitoring, we will select 100 species of plants from at least 10 different families, including both woody and herbaceous plants. Similarly, we will select 100 species of moths from at least 10 families. The high school teams will collect daily data on moths and weekly data on plants. We will analyze these data with satellite and weather data to understand the effects of temperature on phenology of individual species, as well as on possible cascading effects within communities.

- 4.2.2 <u>Alpha and beta diversity of NEON domains</u>
  Plants will be a primary group because they are important in defining ecosystem types and are designated as a Fundamental Sentinel Unit (FSU) for NEON. We will also inventory moths, syrphid flies, mushrooms, lichens, slime molds, and other taxa.

- 4.2.3 <u>Between-year variation in pollinator abundance across sites and disruption of pollination seasonal synchrony</u>
  All our teams will photograph pollinators as they inventory and monitor flowering plants. High school teams will monitor pollinators and other insects on goldenrods in the east. Outreach and citizen science projects such as Great Sunflower Project may augment these data by contributing data between sites.

  We will then identify syrphid flies, butterflies and some other groups. We will analyze these specimen-level data with weather data from NEON sites and NCDC stations to determine how temperature and wetness influence pollinator abundance, diversity and seasonal synchrony.

  To determine whether seasonal asynchrony is reducing pollinator services, we will select species of early-flowering plants that occur at a minimum of 15 sites and are readily identifiable from photographs. For these species, we will not only capture image data on flower phenology and regular sampling of their pollinators, but will also supplement our image data by measuring seed set during the fruiting months.

- 4.2.4 <u>How rainfall affects local and regional fruiting of selected mushroom species</u>
  We will monitor transects at all sites for macrofungi. We will select approximately 100 species that are common across many sites and readily identifiable from photographs. We will augment these data with data collected between sites through outreach with the Mushroom Observer and regional clubs of expert amateur mycologists in Connecticut, Maine, New York, North Carolina, Illinois, Michigan and other states. The Mushroom Observer will help identify images of non-target species.

  Because mushroom fruiting times are usually brief, herbarium collections can yield fairly accurate phenology records (Primack et al. 2004; Lavole and Lachance 2006; Kauserud 2008). Therefore, we will compare our contemporary data with historical collections. By comparing

these phenological data to weather data, we will be able to better predict the effects of climate change on individual species of fungi.

- 4.2.5 <u>Large-scale factors affecting slime mold biogeography, local diversity, and ecology</u>
Using standard sampling protocols (described in Stephenson and Stempen 1994) which have been well tested with high schools and other outreach partners, we will use macro digital photography to collect specimen-level data and will customize local guides to identify species of myxomycetes. By analyzing these data with weather data, we will determine whether changing climate will have an impact on myxomycete phenology.

  To understand myxomycete relationships to the flora, we will compare plant checklists at sites with myxomycete checklists to discern patterns of association with particular vegetation types. This has never been done except on a very local scale (e.g., Stephenson 1989).

- 4.2.6 <u>Lichen diversity and growth rates as bio-indicators of pollution and drought</u>
We will inventory lichen species at all sites, identify them, select both sensitive and tolerant species for monitoring, mark selected species, and measure once a year. These will provide baseline data for a longitudinal study. Eventually, researchers will be able to use these data to analyze lichen growth rates with weather and pollution data from weather stations and NEON monitoring.

5. Broader Impacts

- 5.1 **Encouraging diversity in STEM**
For our undergraduate teams, we will recruit students from historically black colleges and universities, tribal colleges, and community colleges. We will recruit high school teams in partnership with the Young Scholars Program, which has a strong record of recruiting minority students to STEM research.

  Four of our initial field stations are in EPSCoR states. As our network grows, we will strongly encourage participation from field stations and students at schools in these and other EPSCoR states.

- 5.2 **Building skills in ecology research**
Students will learn the importance of adherence to rigorous protocols for collecting reliable data. To assist high school students with science fair projects, we will set up web pages and provide technical support. Faculty mentors will oversee undergraduates in the completion and presentation of an independent project at the end of their term. Undergraduate students will each adopt a small taxonomic group in which they will gain expertise, using our online identification guides under the mentorship of taxonomic experts.

  By paying students rather than relying on volunteer data collectors, we will provide student jobs. Students will gain confidence, earn respect from their peers, and be able to envision science research as a viable career path.

- 5.1.3 **Tools for field stations and land managers**
Field stations and other sites that join our network will benefit from our identification guides and checklists. The guides will help researchers at those sites work in areas outside their area of expertise. Our identification guides will provide sites with environmental education tools for outreach to the local community.

Our inventories will alert site managers to the presence of invasive species so that they can respond rapidly and minimize further invasions. By comparing checklists across sites and integrating field data with air quality and other data, land managers can better predict and plan how their local species may respond to factors such as pollution and land use.

- 5.1.4 **Data sharing**
  We will make all data publicly and freely available via Discover Life and GBIF. It is our vision that the data and web tools will be heavily used by other researchers and students outside the network. Thus, we will provide opportunities for many other research projects besides the ones with whom we have direct contact and whose work we can measure.

- 5.1.5 **Building capacity for large scale ecological research**
  Our methods implement a new paradigm for collecting data on species and their interactions. Until now, it has been almost impossible to assemble the large data sets necessary to answer large-scale environmental questions. For over two decades, the PI has been developing and testing technology and protocols needed by biologists who wish to work at a regional or continental scale. We will train network participants to use these powerful methods. Beyond that it is our vision that the network, its technology, and methods will grow far beyond our initial network and will become widely accepted as a methodology for working on local- to global-scale ecology.

6. Collaborator Contributions

Our Methods and Budget Justification specify the PI's and co-PIs' contributions. We list the letters of collaboration from field sites in section 4.1.4. Below we list the other individuals who sent letters of collaboration, their institutions, and roles. A supporting document presents all letters together alphabetically.

1. John Ascher, <u>American Museum of Natural History</u>, taxonomic support, bees
2. Brian Brown, <u>Los Angeles County Natural History Museum</u>, taxonomic support, flies (also a field site)
3. Bill Buck, <u>New York Botanical Garden</u>, taxonomic support, mosses and lichens
4. Gerry Cassis, <u>University of New South Wales</u>, <u>Atlas of Living Australia</u>, ecological theory, species interactions
5. Theresa Crimmins, <u>National Phenology Network</u>, coordination with other projects
6. Paul Davison, <u>University of North Alabama</u>, taxonomic support, mosses and bryophytes
7. Patty Gowaty, <u>University of California, Los Angeles</u>, ecological theory, evolution and behavior
8. Wendy Gram, <u>National Ecological Observatory Network</u>, data sharing
9. Stella Guerrero, <u>Cedar Shoals High School</u>, teacher, education advisor, high school recruitment
10. Bill Hargrove, <u>USDA Forest Service</u>, ecological theory, data analysis
11. Richard Harris, <u>New York Botanical Garden</u>, taxonomic support, lichens
12. James Hogue, <u>California State University</u>, taxonomic support, syrphid flies
13. Jason Hollinger, <u>Mushroom Observer</u>, web technology, fungal and lichen identification
14. Steve Hubbell, <u>University of California, Los Angeles</u>, ecological theory, biodiversity
15. Dan Kjar, <u>Elmira College</u>, ecological theory, technical support, hosting meetings
16. Robert Luecking, <u>Field Museum</u>, taxonomic support, lichens
17. Mike Mueller, <u>University of Georgia</u>, teacher recruitment
18. Zack Murrell, <u>Appalachian State University</u>, taxonomic support, plants
19. Cynthia Parr, <u>Encyclopedia of Life</u>, website partner
20. Jennifer Schwarz, <u>Chicago Botanic Garden</u>, <u>Floral Report Card</u>, website partner

21. Annie Simpson, <u>US Geological Survey</u>, computer support, identification guides
22. Ben Swecker, <u>Prince William Network</u>, video editing, webcasts
23. Matt von Konrat, <u>Field Museum</u>, taxonomic support, liverworts
24. Ron Walcott, <u>University of Georgia Young Scholars Program</u>, student recruitment
25. Nathan Wilson, <u>Encyclopedia of Life</u>, <u>Mushroom Observer</u>, taxonomic support, fungi

7. Schedule of Research

- **2011**
  All year: Guide building, video production; June: Workshop; mentor training
  June - August: Undergraduates at field stations; July: High school student and teacher training
  August - October: High schools on goldenrods; November: High schools on lichens, trees
- **2012**
  All year: Guide building, video production; February - October: High schools on moths;
  Spring: High schools on wildflowers, leafout, pollinators, mushrooms;
  May - June: Mentor training; June - August: Undergraduates at field stations;
  July: High school student and teacher training; August - October: High schools on goldenrods;
  November: High schools on lichens, trees
- **2013-2015**
  All year: Guide building; February - October: High schools on moths;
  Spring: High schools on wildflowers, leafout, pollinators, mushrooms;
  May: High schools on lichens; May - June: Mentor training;
  June - August: Undergraduates at field stations;
  July: High school student and teacher training courses;
  August - October: High schools on goldenrods; November: High schools on lichens, trees
- **2016**
  January - May: Guide building;
  Spring: High schools on wildflowers, leafout, pollinators, mushrooms;
  May: High schools on lichens