

PROJECT SUMMARY

Overview:

PROJECT ELEMENTS:

New or renewal: Renewal of Previously Funded REU Site (DBI-8900580 through DBI-1358465)

Project Title: REU Site: Systematics and Evolutionary Biology for the 21st Century

Principal Investigator: Mark E. Siddall

Submitting organization: American Museum of Natural History

Other organizations involved: None

Location of proposed research: American Museum of Natural History.

Main fields and sub-fields: Evolution and Systematics, including molecular phylogenetics, morphological character study, population genetics, genomics, and conservation genetics.

No. of undergraduate participants per year: 10

Summer or Academic Year: Summer program

No. of weeks per year that students will participate: 10

Does project include international or RET component? No

Contact Persons: Mark Siddall (212-769-5638, siddall@amnh.org and Maria Rios (212-769-5017), mrios@amnh.org)

Website: <https://www.amnh.org/our-research/richard-gilder-graduate-school/academics-and-research/fellowship-and-grant-opportunities/undergraduate-fellowships/reu-biology-program/>

Over the course of 3 years, an additional 30 undergraduate students will be trained in the fields of systematics and evolutionary biology. This continues a highly successful 30-year tradition in which 80% continue in graduate school and an eventual 40% are currently in faculty positions. Students will be based at the American Museum of Natural History in New York City, where in addition to the 85 million natural history specimens in residence, they will have access to state-of-the-art equipment such as next-generation sequencers, three fully equipped molecular systematics laboratories, a Computed Tomography scanner, scanning electron microscopes, and two parallel computing clusters.

Intellectual Merit:

Eight undergraduate students per year will conduct original research projects in systematics and evolutionary biology. In addition to individualized research projects in which students have a firm role of planning and lead role in executing, each week, the students will receive lectures in core topics in systematics and evolutionary biology, attend lunchtime discussions of academic careers and scientific ethics, and tour each of the AMNH collection spaces. The students will participate in two relevant field trips over this period and will also have the opportunity to take a 2-day course in the principles and practice of CT scanning and/or next-gen sequencing. We will recruit both from the exceptionally diverse community of students at a variety of institutions in the NYC-tri-state metro area as well as nationally. Application and evaluation procedures are designed to attract students, match them with mentors and projects, gauge their progress through our program, and track their careers and the influence their participation in the REU Site program had. Students present their research at an end-of-summer symposium and prepare final reports, which are strongly encouraged to be adopted into peer-reviewed publications and attendance at national meetings.

Broader Impacts:

In addition to the 30 undergraduate students who will be trained, the program will also provide mentorship professional development opportunities for our postdoctoral scholars and graduate students at the AMNH and also form early research group opportunities for junior faculty. Shared mentorship among faculty, postdocs, and grad students in an operational lab ensures students will get intensive personal attention supporting their planning and execution of their individualized research project in a manner that fosters creative confidence will be fostered. Each of the students will be asked to conduct individual "broader impact" engagement with one of the K-12 summer programs conducted by the AMNH Education Department, and will be trained in various means of publicizing their research through outlets ranging from formal situations to social media. This, underscores the importance of communicating science and the critical importance of basic research literacy for our nation.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

SUBSTANTIAL DIFFERENCES FROM PRIOR AWARDS/APPLICATIONS

- 1) We are requesting funding for 10 interns for 10 weeks in each of 3 consecutive summers, which is 2 more each year than the 8 interns that we have taken historically. We have no concerns whatsoever about attracting or taking this number in light of our regularly receiving over 300 applicants per year. Indeed, in several summers we have already accommodated 9 or 10 in the program under special circumstances. We easily accommodated 10 in the interregnum funding year of 2019.
- 2) We are including an outreach component for our summer interns that has them intersecting with educational and public elements at the American Museum of Natural History (see response to reviewer comments).
- 3) We now are including a project title that will be structured to be included each year: “Computational analysis of language relationships: The Northwest Coast of Native North America” mentored by curators Ward Wheeler and Peter Whitely, and which will be targeted specifically to applicants of aboriginal (Native American) descent (see response to reviewer comments).
- 4) In light of increased next-gen sequence work, a bioinformatics component is being added to the curriculum.
- 5) The Slack collaborative work environment is being leveraged as a central point of contact for the sharing both of program and of enrichment activities: reviewers can use login amnhreubio2019@gmail.com and password \$ally0C0nnor (zeros for the first two O’s).
- 6) Post enrichment will include letter writing to congressional representatives.

RESPONSE TO REVIEWER COMMENTS

The review of last year’s submission which received an Excellent and two Very Good reviews, noted as strengths “a 30-year long REU Sites program” that “has a very strong research focus under an excellent collection of mentors. Strengths include the excellent tracking of past participants, many of whom are now faculty members/senior scientists at a variety of institutions. Although this program has existed for 30 years they have continued to update the themes and structure of the program based on thoughtful evaluation of the program.” Among the weaknesses were that “Potential improvements would include training in scientific ethics and collaboration, and public speaking and outreach” including specifically “more public outreach by participants given the vast number of visitors that pass through the museum each summer.”

In direct response to this concern, we have now established and successfully implemented in the interregnum year (summer 2019) of funding, a formal relationship with the museum’s Education Department (which covers all of K-12 education, teacher professional development, and the museum’s Public program group). On the education side, the AMNH summer programs running concurrently with the REU program include both “Summer Camp” structures as well the prestigious Lang Program in Science (which enrolls middle school students and keeps them through 12th grade). The PI (Siddall) did and will work intensively to identify which summer REU interns’ projects best matched the summer curriculum of specific Lang program research tasks (e.g., REU intern Samantha Miller working of fish parasites engaged for a whole afternoon of near-peer mentoring with about 20 Lang program enrollees in the 11th and 12th grade about the value-added by parasitological questions to the 5 years of fish collecting they had been doing in the NY City watershed area). In addition, on two separate occasions, 2 sets of 3 REU interns teamed up to address and be grilled by each of rising 11th graders and 12th graders about what college application processes are like and what college life is **really** like and how they each made their own personal decisions. The key point of contact in this regard is Brian Levine (see letter of commitment).

The summary also suggested while “Targeting recruits from local institutions, as proposed, is a good strategy. An additional strategy is for the PI to take more control over selecting students from the applicant pool.” As described, I can assert that the this would spell the end of this program. Were I to choose interns foist them on mentors, mentorship participation would wane. Instead, and beginning with summer 2020, I have invited 2 mentors (Wheeler and Whitely) working on “Computational analysis of language relationships: The Northwest Coast of Native North

America” to maintain that project in each of the 3 years on-going, and to target students from Native American colleges and ancestry. Already this project has been part of the program for 2 years and has generated great interest. The mentors agree that it is time to ensure that it is being informed by actual stakeholders.

Another weakness identified was that “a relatively larger proportion of students than desired has gone to medical school”. We believe that the nearly 40%, of whom 67% are women, who are in tenured or track faculty positions mitigates against this concern.

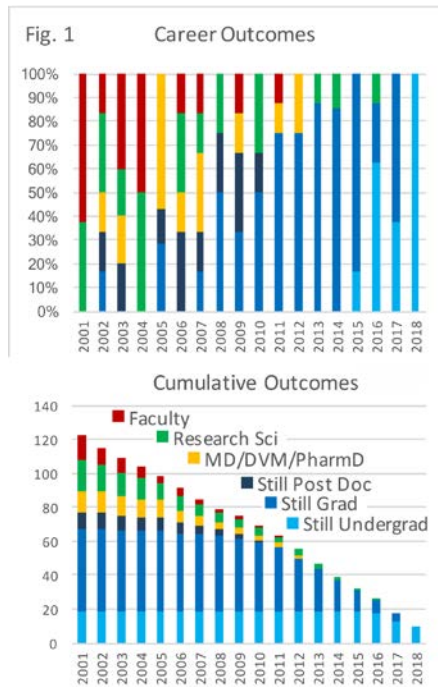
RESULTS OF PRIOR NSF SUPPORT

The American Museum of Natural History has successfully implemented NSF REU Site grants continuously since DBI-8900580 in 1989 through DBI-1358465. These awards established and have sustained undergraduate research in the area of Biological Systematics and Evolutionary Biology for 31 years. Drawing on the research and teaching expertise of the Museum's outstanding scientific staff, the program has continued to revolve around projects carefully designed to introduce undergraduate level students to the excitement and challenge of original research in evolutionary biology.

This continuing 31-year program has now seen the mentorship of 259 undergraduates here at the Museum and continues to enjoy broad support from the scientific staff and the Museum's administration. With such a legacy, it is appropriate to track not only the results of this most recent award, but also give a sense of the impact the program has had for its duration. In terms of the first half (12

Table 1 Current faculty among AMNH REU interns (1989 - 2001)

Year Name	Faculty Position
1989 Erika Bach	New York University School of Medicine
1989 Joseph Alia	Chemistry & Biochemistry , Univ Minnesota -Morris
1990 Christopher Braun	Psychology, Hunter College, City University of New York
1990 Cynthia Gerstner (d.)	Columbia College of Visual Arts
1991 Jennifer Maltz	PACE University
1991 Jason Mezey	Biological Stistics and Computational Biology, Florida State Univ.
1992 Jim Bonacum	Biology - University of Illinois Springfield
1992 Frederika Kaestle	Anthropology, Indiana University
1992 Robert Hanner	Integrative Biology University of Guelph
1992 Judy Hull	Sarah Lawrence College
1993 Roland Kays	Director - North Carolina Museum of Natural Sciences
1994 Johnathon Geisler	New York Institute of Technology
1994 Briana Pobiner	Human Origins - Nat'l Mus Nat Hist -Smithsonian
1994 John Ascher	National University of Singapore
1995 Elizabeth De Santo	Franklin and Marshall College
1995 Sara Jacoby	University of Pennsylvania School of Nursing
1995 Matt Rockman	Biology - New York University
1996 Surangi Punyasena	Plant Biology - University of Illinois at Urbana Champaign
1996 Sushma Reddy	Biology - Loyola University Chicago
1996 Dan Moran	Biomedical Engineerin - Washington University St. Louis
1997 Johnathan Allen	Biology - College of William & Mary
1997 Leonardo Avilla	Universidade Federal do Estado do Rio de Janeiro
1998 John McCormack	Occidental College
1998 Courtney Babbitt	Biology - University of Massachusetts Amherst
1999 Prosanta Chakrabarty	Louisiana State University
1999 Jennifer Balch	Geography, Pennsylvania State University
1999 Denise Bookwalter	Dept of Art, Florida State University
1999 Taylor Maxwell	Human Genetics - University of Texas
1999 Anthony Catalano	St. John's University
2000 Kevin Strange	Director - Mount Desert Island Biological Laboratory
2000 Brian Trotta	Radiology - University of Virginia



years) of the AMNH REU Site grant, we have been able to track the current whereabouts of 77% of the participants. A stunning 41% of those tracked are in faculty positions at academic institutions (Table 1). There is not a single summer in those first 12 years that failed to produce a future faculty member in Academia.

In terms of more recent support, the PI (Siddall) assumed lead responsibility for the program beginning with award DBI-0097552 and has continued to for the ensuing 19 years. In that time from 2001 through this past summer's cohort, 90% of the participating interns have been tracked (Fig. 1). Among those that have completed their undergraduate education, 81% enrolled in graduate level education (either Masters, PhD or both), most of whom are still in their graduate programs or are in postdoctoral fellowships. Of those that have completed graduate school in the last 18 years, fully 39% are in tenure track faculty positions at academic institutions (Table 2). An unprecedented 5 of 8 interns from the summer of 2001 are now tenure track faculty: Meghan Avolio and Siobhan Cooke are both Assistant Professors at Johns Hopkins, Natalia Taft is an Assistant Professor at University of

Wisconsin, Jake Wintermute is faculty at Paris Descartes University and Jacob Egge is already tenured at Pacific Lutheran University. Five interns currently in tenure-track positions returned to the American Museum of Natural History for graduate studies after completing their bachelor degrees. These include California Academy of Sciences

Curator Lauren Esposito and Anna Phillips mentored to their doctorates by AMNH curators Lorenzo Prendini and Mark Siddall respectively, both through their adjunct appointments to City University of New York; as well as 3 AMNH summer interns mentored directly through the Museum's own PhD-granting Richard Gilder Graduate School: Assistant Professor at City University of New York Antonia Florio, Assistant Professor at New Jersey Institute of Technology Phil Barden, and Assistant Professor at University of North Georgia Lauren Oliver.

This success in terms of eventual academic placement of our past interns is only part of the success of the program as an additional 30% are presently in technical research positions in academia, 18% are medical or veterinary doctors, 11% work in the not-for-profit or NGO sectors and another 7% are K-12 teachers. Of the remainder, interestingly there is a preponderance of

Table 3. NSF Graduate Research Fellowship Program Awardees since 2001

REU yr	Name	GRFP	REU yr	Name	GRFP
2017	Emily Lau	2018	2010	Emily Pitcairn	2012
2015	Kyle DeMarr	2017	2009	Philip Barden	2012
2015	Devin Hoffman	2017	2009	Brandon Peacock	2011
2015	Michael Miyagi	2017	2008	Sweta Agrawal	2010
2015	Ashley Paynter	2017	2008	Jessica Guo	2012
2014	Alexandra Buczek	2017	2008	Alexandra Neinst	2012
2014	Grace Aveccilla	2016	2007	Antonia Florio*	2010
2013	Allison Bronson*	2016	2007	Caroline Storer*	2011
2013	Lucy Gill*	2017	2006	Keith Bayless	2008
2012	Benjamin Blanchard*	2016	2006	Natahn Butler	2008
2012	Adolfo Lara	2014	2006	Jennifer Hughes*	2009
2011	Ekaterina Larina	2013	2006	Grace wu	2011
2011	Lauren Oliver	2012	2002	Rebecca Budinoff*	2007
2011	Dan Paluh	2016	2002	Matthew Leslie	2006
2011	James Proffitt	2013	2002	Amy Turmelle*	2006
2011	Shan Kothari	2014	2001	Brian Webster	2007
2011	Christina De Jesus	2015	2001	Edwin Wintermute	2005
2010	Dallas Krentzel	2013		* honorable mention	

Publications appearing during the period (2014 – 2019) of the most recent award numbered twenty-two^[1-22] (interns' names in bold in the References cited section). This is nearly double the number of peer-reviewed publications witnessed during the previous award period (2009-2013).

Representation

Fifty-two percent of the student participants under DBI-1358465 were recruited from academic institutions where research opportunities in STEM are limited. In addition to a variety of undergraduate-only institutions, this included interns from each of University of Puerto Rico at Humacao, Northwest Indian College and two-year colleges in the New York City area (Laguardia Community College, Queens Community College, NY College of Technology)

The representation of women in our program was to 71% during the most recent 5 year funding period; and while representation of women in the REU program is not remarkable, the fact that

Table 2. Current faculty among AMNH REU Interns 2001-2018

Year	Name	Faculty Position
2001	Jacob Egge	Associate Professor Biology Pacific Lutheran University
2001	Natalia Taft	Assistant Professor Biological Sciences, University of Wisconsin Parkside
2001	Edwin Wintermute	Chargé de recherches Université Paris Descartes
2001	Siobhan Cooke	Assistant Professor Functional Anatomy, Johns Hopkins University
2001	Meghan Avolio	Assistant Professor Earth and Planetary Science, Johns Hopkins University
2002	Lauren Esposito	Assistant Curator, Schlinger Chair of Arachnology, California Academy of Sciences
2003	Jim Hayden	Curator of Lepidoptera-Florida State Collection of Arthropods
2003	Sandra Castelli	Assistant Professor of Clinical Medicine, New York Presbyterian
2004	Carla Staver	Assistant Professor, Yale School of Forestry
2004	Anna Phillips	Curator Invertebrates, NMNH, Smithsonian
2004	Michael Bush	Assistant Professor Concordia College
2006	Jennifer Wisecaver	Assistant Professor Biochemistry, Purdue University
2007	Antonia Florio	Assistant Professor Biology City University of New York
2009	Phillip Barden	Assistant Professor Biological Sciences New Jersey Inst. Technology
2011	Lauren Oliver	Assistant Professor Biology University of North Georgia

women represent 67% of our past interns getting tenure track faculty jobs is outstanding. The average number of minority students for the full 5-year period was 31% including 9 Hispanic, 3 African American (one of whom was male) and an American Indian woman.

INTELLECTUAL MERIT

Overview

This proposal requests continuing funding for ten REU interns for each of three years to conduct work at AMNH in the field of **Systematics and Evolutionary Biology**. Research projects cover the various fields of the systematic discipline from descriptive taxonomy to molecular systematics in both neontological and paleontological data sets. Students have the opportunity to engage in cutting-edge research in these fields in light of the infrastructure afforded them in the museum environment. Modern Systematics and Evolutionary Biology research programs weave a rich mixture of anatomical data obtained from advanced imaging techniques (like Scanning Electron Microscopy, Transmission EM, high resolution digital photography, and Computed Tomography all freely available through the museum's Microscopy and Imaging Facility) with equally advanced DNA sequence information (be it from amplified mitochondrial and nuclear genes or from next-generation sequencing methods for transcriptomics and genomics freely available through the museum's Institute of Comparative Genomics and our consortium membership in the New York Genome Center).

Our program enjoys broad support among the curatorial staff and more generally in the New York City tri-state area, especially in the City University system, the major source for post secondary education in the City's 5 boroughs especially as it concerns minorities in the tri-state (New York City, New Jersey, Connecticut) area. Moreover, our program has a proven success rate in terms of students continuing education in graduate school in terms of scientific productivity and, more pointedly, in terms of producing the next generation of tenure-track faculty (see results of Prior Support). The AMNH REU site is coordinated by the PI with strong administrative and logistical support from the office of sponsored research and the Richard Gilder Graduate School (see next paragraph) and with broad involvement of museum curators and scientists as mentors for the incoming students. Students arrive in the last week of May, conduct research throughout June, July and into August with a final symposium of all student participants showcasing the summer's results. Recruitment and participation are coordinated with the other REU Site here in Physical Sciences.

The coming year, 2020, represents the 31th anniversary of the AMNH-REU program that began with DBI-8900580. This last granting period under DBI-1358465 coincided with those years in which the Museum's own degree granting PhD program under the Richard Gilder Graduate School (RGGS) saw its alumni achieve tenure track faculty positions at Universities and Museums. In 2007, the New York Board of Regents took the unprecedented step of conferring degree-granting status on the American Museum of Natural History. *The consistent success of our REU Site program was central to their decision.* Among the select few (4 or 5) that are admitted to museum's PhD program each year, 7 have been previous AMNH REU interns, the first 3 of which (Florio, Barden and Oliver) are in tenure track faculty positions. Adolfo Lara (AMNH REU 2012) and Allison Bronson (AMNH REU 2013) just defended their dissertations whereas Jeremy Frank (AMNH REU 2013) and Alexandra Buczek (AMNH REU 2014) are in the midst of their programs here. Insofar as AMNH has no undergraduate curriculum, the continued presence of an REU Site program is fundamental to the pedagogical goals we have for the RGGS Comparative Biology program. During the last 5 years of this REU Site, we involved RGGS doctoral students in project planning, intern mentorship and specifically in the instructional portion of weekly Systematic theory and practice instruction in a manner that enhances the 10 wk summer program and the internship experience.

The Research Environment

The American Museum of Natural History is an inspirational place for young scientists to work, and an REU program is a wonderful way for us to bring a critical mass of bright young scholars into our departments and expose them to the challenge and excitement of an original

research program. In entering the Museum community, students are offered an extraordinary opportunity to step outside of their immediate university environments, broaden their experience of biological disciplines, and participate in the highest caliber research at a premier academic institution, and one that is now a university in its own right, with the formation and accreditation of the Richard Gilder Graduate School. Our program provides students with a coherent, hands-on introduction to research in systematics and comparative evolutionary biology, areas in which few undergraduates have a solid grounding, and serves a critical role in attracting, inspiring and educating undergraduate students in the fundamental importance of these biological disciplines. The American Museum of Natural History is one of only a handful of REU sites with a principal focus on systematics, taxonomy, phylogenetics, biodiversity and collections-based curatorial research; and the only such Site on the East Coast. In addition to the specific research projects that REU interns will have available to them, the institution at large is dedicated to enriching this experience through its various divisions and exhibits.

There are more than 40 curators at the American Museum of Natural History spread through five divisions as well as the Sackler Institute for Comparative Genomics and the Center of Biodiversity and Conservation. The quality of our collections is in many cases unsurpassed anywhere in the world. Of the 85 million specimens in the museum, the entomological collection includes over 20 million specimens and is the largest in the world for termites, spiders, bees, bugs (Hemiptera), fruit flies and gall-wasps. The herpetological collections (with over 300,000 computerized records) entails 80% of the world's genera and more than half the world's known species of amphibians and non-avian reptiles. These are just examples of the collection-based resources we have in invertebrates as well as birds, mammals and fishes. Complementing these outstanding collections is the largest Research Library in the Western Hemisphere with nearly a half million volumes, journals and other material reaching back to the 15th century.

Researchers who have expressed their continuing interest in the REU program, and the institution more generally, have available to them all of the research facilities and equipment that makes for front-line exciting research in systematics and evolution. This includes a fully equipped Tissue Histology Laboratory, three state-of-the art molecular core facilities complete with dozens of modern PCR machines, three ABI 3730 automatic sequencers running 96 capillary arrays, next-generation sequencers and ancillary equipment (e.g. Bioanalyzer, Q-bit) and raw computational power in the form of an Argus supercomputing cluster of 260 high-speed processors running in parallel. The Museum's Microscopy and Imaging Lab has a low-energy CT scanner (capable also of micro-CT), a confocal microscope, a high-resolution scanning electron microscope, a low-pressure environmental SEM and a transmission electron microscope. The AMNH recently is a member of the New York Genome Center, a non-profit organization based in Manhattan that gives our scientists access to deeply discounted next generation pyrosequencing as well as bioinformatics and data-storage services.

The PI has extensive experience working with undergraduate researchers. Siddall has been the director of this REU program for 19 years now and has a strong and consistent record of publishing with his undergraduate students in leading journals (see Biographical Sketch). As this site program has been in place for 31 years now, many of the faculty at AMNH are extremely adept at mentoring students each summer. We have encouraged new curatorial hires to get involved in their first summers at the AMNH and these have served as valuable means to involve students in their labs. Brian Smith, in the Department of Ornithology and Melanie Hopkins in the Department of Paleontology each were hired as curators at AMNH in the last 5 year period of this grant and each took on summer REU interns. Along with the faculty curators, typically half of our projects have involved postdoctoral researchers and Research Associates and it is our intention to continue this practice should we be fortunate enough to be renewed (see project descriptions below). The postdoctoral fellows have been extremely enthusiastic, conscientious and dedicated mentors to the students, involving them provides each with extremely valuable mentorship experience as part of their professional development at the AMNH.

As a means of providing training for our mentors, there is an informational and instructional workshop for all potential mentors, including postdoctoral mentors, just prior to the point where

we solicit project descriptions for advertisement. In this session, care is taken to make sure that they all understand the broad goals of the REU program both in terms of recruitment priorities and in terms of the sets of experiences and skills that students should walk away with. This also serves as an intersection point for members of our Education Department's Professional Development staff to join the discussion and provide current pedagogical practices for research-based learning.

NATURE OF STUDENT ACTIVITIES

The AMNH has long been a center for undergraduate and graduate training. Beginning in 2008, this was formalized with the establishment of the Richard Gilder Graduate School, which adds 16 to 20 Ph.D. students in residence at any time, which are in addition to the roughly equal number in residence who are matriculated at our partner programs at Columbia University and the City University of New York. Our REU program has now had a history of 30 successful years and these undergraduates have become a regular part of our summer activities and schedules. The faculty at AMNH use this opportunity to engage with undergraduates to do smaller "side projects" that they've been considering, to test out new methods and collect preliminary data for future research endeavors, and to work closely with postdoctoral trainees on their research. Faculty commit to engaging the students throughout the ten-week program and actively participate in their training in the laboratory. We very honestly tell the students that these are not "canned" lab exercises, like the ones that they might have done as part of their undergraduate courses, but rather real research projects, with the expected failures and disappointments, but ultimately insights, new ideas, and results, including presentations and publications, that happen with perseverance and creativity. We actively engage the undergraduates in trouble-shooting throughout the course of their projects.

Most importantly both the students' projects and the ancillary engagements with them on a weekly basis by the PI are intended to generate a strong focus on thinking and scientific inquiry. The brown-bag luncheons always begin with REU's self-evaluations of progress and then shared determinations of how to overcome or merely manage hurdles and failures. Structure of the research environment is such that students will have significant creative contribution to their own work. Shared mentorship among faculty, postdocs, and grad students in an operational lab also makes it very likely students will get intensive personal attention supporting their project, and that their creative confidence will be fostered; these are the people who can reassure them that there is no mistake or failure that hasn't been made already by one of them.

Examples of Undergraduate Research Projects

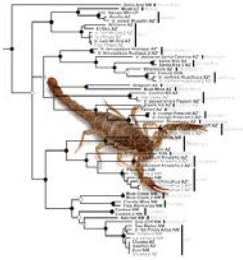
Following are examples of research projects that may be advertised in the coming cycle of this program. Each contains background of the significance of the project as well as learning objectives for the undergraduate researcher involved.



Computational analysis of language relationships: The Northwest Coast of Native North America

With Ward Wheeler through the Division of Anthropology. The Northwest Coast is the second most diverse area of Native North America linguistically (after California). Numerous proposals have been made over the years about potential relationships among distinct languages, e.g. of Tlingit or Haida with "Na-dene" languages—but with no resolution. To date, these 2 remain "isolates" though with clear relationships to each other in some elements of vocabulary. Overall there are 2 recognized "families": Wakashan and Salishan, as well as a series of small linguistic entities—Tsimshian, Haida, Heiltsuk, and Tlingit. All share a common culture in numerous practices, including economic adaptation, ritual, and instituted social hierarchy. We have initial Swadesh word-list data for a small number of languages and will expand this data set to encompass a more adequate sampling of the group. The data for this study come from a diversity of sources (e.g. PDFs, transcribed field notes, online public databases). The REU student will work on developing tools

to compile Swadesh lists (and probably other vocabulary; species names, for example) in a common orthography. This will involve creating data scraping and encoding tools. The compiled data will then be subjected to phylogenetic analysis using the phylogenetic analysis program POY^[23] in a related fashion to a previous study concerning Uto-Aztecan and Bantu^[24,25]. The scientific problem is whether we can develop better measures of linguistic relatedness, and whether there are indicators of horizontal transfer linguistically (obviously, there are culturally), similar to another study relating to Pueblo languages in the Southwest. The REU student is expected to learn aspects of computational linguistics to apply to an analytical problem. *We will be targeting students from Tribal Colleges in the area to both build on their experience and share our work with local researchers and other interested people.*



Living Fossils: Systematics and Evolution of Scorpions with Dr. Lorenzo Prendini (Division of Invertebrate Zoology)

Scorpions are among the most ancient of arthropods—derived from aquatic ancestors that lived in the Silurian, more than 425 Mya. Scorpions occur on all continents except Antarctica, in a diverse array of environments, from tropical rainforests to hot deserts, from sea level to 4600 m elevation, and from the intertidal zone to some of the world’s deepest caves. They are also increasingly threatened by habitat destruction and harvesting for the exotic pet trade. Many are also

extremely habitat specific and range-restricted, exacerbating their risk of extinction due to human activities. The task of inventorying their diversity and distribution is a priority if steps towards their conservation are to be implemented. The REU intern will undertake assessing the taxonomy and phylogeny of particular groups of scorpions involving (1) morphology, microscopy and imaging scorpion specimens, (2) isolation and sequencing of scorpion DNA, and (3) mapping and GIS analysis of scorpion distributions.



Slow Loris Evolution, Ecology and Conservation with Dr. Mary Blair (Center for Biodiversity and Conservation)

Slow lorises are small nocturnal primates threatened by the illegal wildlife trade in South and Southeast Asia. This project will utilize the Museum’s primate and frozen tissue collections to distinguish among unique evolutionary lineages of lorises using genetic information, morphological characters, and ecological preferences. The REU student will have the opportunity to extract, sequence, and

analyze DNA from slow loris Museum specimens, and learn how to build ecological niche models from Museum specimen occurrence data. The results of the project will not only improve our understanding of the diversity and evolution of this poorly known group, it will also help to inform conservation management and enforcement of wildlife trade policies.



Adaptation and diversification in the radiation of modern and recently extinct crocodiles with Dr. Evon Hekkala (Sackler Institute of Comparative Genomics)

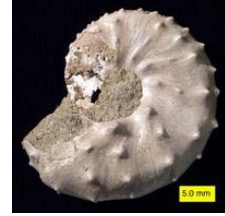
In this project, we plan to erect a new phylogenetic framework to identify genomic mechanisms of post Miocene adaptation and diversification with the genus *Crocodylus*. Using whole mitogenomes and targeted resequencing of exons from extant and recently extinct crocodiles we will explore evidence for selection on genes associated

with osmoregulation and thermal tolerance as mechanisms of adaptation to global environmental change. This project will take advantage of existing genomic resources for crocodylians and collect new data from AMNH’s valuable historical collections of crocodylians.

Declining or thriving? Unraveling the mass extinction of ammonites at the Cretaceous-Paleogene (K-Pg) boundary with Dr. Neil Landman (Division of Paleontology)

Ammonites are shelled cephalopod molluscs related to modern squid and octopus, and among the most common fossil invertebrates in marine sedimentary deposits. Having dominated the oceans for over 300 million years, they went extinct 66 Mya during the Cretaceous-Paleogene

(K-Pg) mass extinction that caused the demise of non-avian dinosaurs. Details of this event are still the subject of intense debate; whether the primary cause was a sudden, catastrophic extraterrestrial bolide impact, or a slow decline over a longer timescale with climate changes or volcanism playing roles. The REU student will examine new collections of ammonite fossils from K-Pg boundary sites along the Gulf Coast, USA to look at the patterns of abundance and diversity prior to the K-Pg extinction and to better test hypotheses of the cause (and effect) of this event.



Developing new methods to monitor fine-scale movement of wildlife in Black Rock Forest with Drs. Suzanne Macey (Center for Biodiversity and Conservation), Christopher Raxworthy (Dept. Herpetology)

Black Rock Forest, a living laboratory for field-based research approximately an hour north of NYC, is installing 20 self-powered “nodes” for a new “wire-less mesh” network. These low-cost cutting-edge networks will provide researchers with real-time data from their existing environmental monitoring stations, but can also provide an opportunity to

test the network’s ability to accurately monitor fine-scale movements of animals. In this project, our goal is to monitor the movements of understudied and often rare terrestrial animals (such as Eastern Box Turtles) in a comparative way across species. The participating student would be based at Black Rock for part of the internship and acquire skills relating to field and data analysis methods involved in movement ecology and demographic studies of wildlife.



Assessing population genomic patterns in near-shore squid across the Indo-Pacific

with Dr. Samantha Cheng (Center for Biodiversity and Conservation, Invertebrate Zoology).

Cephalopod fisheries in Southeast Asia and the Coral Triangle constitute a major source of income and protein to thousands of coastal communities. However, little basic information is known about these fisheries, much less about their evolution and population dynamics. Differences in life history, particularly in dispersal life history, is a major factor in driving different patterns of connectivity, or the exchange of genes, over space and time. Understanding patterns of connectivity is vital to informing spatial management of these squid stocks, particularly as they range over the fishing regions of multiple nations. Using genome-wide markers, this summer project would contribute new data to this ongoing study of the population structure over the Indian and Pacific Oceans - identifying important processes shaping both genetic and demographic connectivity in two co-distributed species of big fin reef squid (*Sepioteuthis lessoniana*). This project would include substantial lab work and could include field work (potential field sites include Israel or Tanzania).



Wing spurs are a poorly known but exceedingly interesting feature of avian Pugilistic Flycatchers: Wing spurs in the bird family Tyrannidae with Dr. Brian Smith (Dept. of Ornithology)

Wing spurs are a poorly known but exceedingly interesting feature of avian external anatomy present in only a few groups of large birds. Wing spurs are generally bony, large, sharp, and used for fighting or defense in a similar way to the antlers of deer or antelope. While prevalent in some large bodied bird families, wing spurs are almost unheard of in small songbirds except in the family Tyrannidae (Tyrant Flycatchers)

and suggests a fascinating and completely unknown world of combat among these small birds. This project will entail a systemic survey of specimens of Tyrannidae at the AMNH to determine the phylogenetic distribution of spurs. Morphometric analysis with digital photo morphometrics and computed tomography (CT) using the state of the art facilities at AMNH. The student working on this project will learn digital morphometrics, CT imaging, morphometric and phylogenetic analyses coding in R.



Mitogenomics of the Order Antipatharia (Black Corals): Are Increased Substitution Rates Linked to Gene Rearrangement Events?

With Dr. Mercer Brugler (Sackler Inst Comparative Genomics) Basal metazoans (Placozoa, Porifera & Cnidaria) are unique in that their mitochondrial genome is subject to frequent gene rearrangement events. We are seeking to test whether mitochondrial gene rearrangement events are linked with rapid bursts of nucleotide substitutions, particularly at synonymous sites. Black corals are one of

the longest living deep-sea organisms (at 4,265 years old) and hold the record for the deepest occurring coral (at 8,600m). Using a recently published phylogeny of the Order Antipatharia we will select twelve black corals that encompass the full range of branch lengths (i.e., substitution rates) on the phylogeny and sequence their mitogenome using an Illumina MiSeq. While several mechanisms have been proposed to explain how gene rearrangement events occur, Brugler & France discovered a rearrangement that can only be explained by invoking recombination, which goes against one of the basic tenets of mitochondrial evolution. By elucidating additional gene arrangements, we can better understand the mechanism(s) behind these events and begin to infer the selective advantage of a given arrangement (e.g., adaptation to extreme temperature and/or pressure).



Molecular systematics and species delimitation of the clownfish sea anemones

with Dr. Estefania Rodriguez (Division of Invertebrate Zoology) The clownfish-sea anemone symbiosis is an icon of tropical coral reefs of the Indo-West Pacific and one of the most recognizable symbiotic relationships on the planet. There are 30 described species of clownfishes, but only 10 nominal species of host anemones. Why have the host anemones not

undergone a radiation similar to the clownfishes? However, no genomic research focusing on population level questions of clownfish sea anemone host species exists to date. Using high-throughput sequencing (e.g. RADseq, transcriptomics), molecular and morphological species delimitation, and a comparative phylogeographic framework, we will search for cryptic species and reconstruct the evolutionary histories of the clownfish sea anemone host species. REU students involved in this project will participate on genomic and morphological aspects of this research focused on our ecological speciation hypotheses.



Madagascar Biodiversity Through the Gut of Leeches

with Dr. Mark Siddall (Division of Invertebrate Zoology) Recently a remote forest protected from fires and human influence by steep cliffs was discovered in the central part of Madagascar south of Ihoay. Estimating taxonomic diversity of and its distribution is a central challenge for conservation. Camera-trapping and non-invasive (e.g., scat) sourced genomics are heavily biased toward large mammals, missing the majority of vertebrate biodiversity in protected

areas: small mammals, reptiles, amphibians, birds. The use of iDNA (residual host DNA inside of invertebrate ectoparasites), especially leeches, allows for rapid, inexpensive biodiversity monitoring of forests (where the terrestrial leech families Haemadipsidae and Xerobdellidae reside). To date, our research has evaluated the relative efficacy both of Sanger sequencing (individual leeches) and next-gen (pooled spatiotemporal sets) from each of Bangladesh, Cambodia, Southern China, and PN Ranomafana Madagascar. The REU intern will work with hundreds of leeches collected from that recently discovered forest in Madagascar. Laboratory work will include DNA Isolation and genomic sequencing efforts (traditional and amplicon based next-gen) both to identify the resident leech species as well what animals those leeches most recently fed upon. Should new species of leech be apparent from DNA sequence data, specimens will be subject to micro-CT scanning so as to investigate their internal taxonomic characters.

Summer Program Curriculum and Other Activities

The primary objective of the 10-week program is for students to have the opportunity to conduct independent research projects under the mentorship of AMNH faculty, research associates, and postdoctoral fellows. Thus, the bulk of the students' time will be spent actively collecting relevant data, becoming familiar with the relevant background literature, analyzing the data, and preparing it for both oral and written presentations that are asked of them. However, we also augment their research experiences with other learning objectives, and quite frankly it being New York, social objectives, throughout their ten weeks. *At the request of the summer interns of 2019*, the bulk of the curriculum and sundry activities have been managed through the Slack collaborative environment.

Formal lectures

We aim to have each student leave our program having the same basic competency in systematic biology and this is primarily achieved through a series of weekly formal lectures (Table 4) for about 45 minutes each. In the course of the last two granting cycles and going forward that has been provided by an AMNH RGGS graduate student teaching assistant for the summer. More often than not, this has been a former REU intern who is now enrolled in the museums RGGS graduate School including each of Allison Bronson (AMNH REU 2013), Jeremy Frank (AMNH REU 2013), and those now in tenure track positions like Phil Barden (AMNH REU 2012). These lectures cover principles of characters and homology, introduce them to phylogenetic inference, its history, its context and terminology so as to engender fluency, expose the students to the various optimality criteria for constructing phylogenies but more importantly cover the ways in which phylogenies can be interpreted and used for downstream questions. These lectures are frequently supplemented by short "lab-like" demonstrations and coding exercises and will now formally include bioinformatics pipelines for phylogenetic work.

Table 4. Curriculum

Week	Topic
1	Orientation and information session
2	History and tasks of Systematics
3	Specimen and data collection
4	Species, populations, characters
5	Sequence alignment and Parsimony
6	Maximum likelihood
7	Bayesian inference
8	Evolutionary patterns & Tree thinking
9	Historical Biogeography
10	Practice talks

Brown-bag Discussions

Once a week, we will also have a more informal, hour-long, brown-bag discussion at lunchtime. These sessions will address many of the ancillary activities involved in research, museum science and pursuing a career in science, not the least of which are ethical considerations. As part of these sessions, we will also provide a standard basis of scientific ethics for our students and so use one of these sessions to engage the students in a series of case studies meant to provoke them into delving into issues concerning matters of scientific ethics, which range from grad school application procedures, scientific authorship, data accessibility, privacy, and personal conduct.

Table 5. Brown Bag Luncheons

Week	Topic
1	Collections tour
2	Permitting (feat. USFW officers)
3	Data integrity
4	Media Outreach (feat. Kendra Snyder)
5	Careers in Science
6	Presentation Skills and Style
7	How to write and publish
8	Sterling Hill with Phys Sci REU program
9	GRFP & grant writing (feat. RGGS student)

Individualized course instruction

We have will continue to offer a two-day crash course instruction in each of computed tomography (CT) and next-generation DNA sequencing for interns whose research projects require it and yet also for other interested students. Each course is taught by one of the RGGS graduate students who has been using these technologies in their dissertation research, and is accomplished in coordination with our Microscopy and Imaging Laboratories manager or Sackler Institute of Comparative Genomics manager. Each course gives students an introduction into the history and principles of the relevant technology, how this technology is leveraged in every day research at the AMNH, as well as how they can use it in their own REU projects. The second day is focused on pipeline: students are taught how to go from start to

finished product how to analyze their data and issues of post-processing. After these two days, each student is allotted time either on the CT machine or scheduled for next-gen runs at the NY Genome Center.

Collection tours

In the very first week of the program our interns are imbued with the notion that Natural History Museums are Libraries of Biodiversity representing the breadth of life in space and time. This is accomplished through tours of the various AMNH collections, given by the collection managers in the various departments and typically last about 30-45 minutes. If current students are conducting research using the collection that is being toured, they are asked to relate this to the rest of the students at that time. These tours are meant to give all of our students the chance to go behind the scenes across our various disciplines and to observe the breadth of these enormous (85 million scientific specimens) as well as the various ways in which specimens are stored and databased, depending on the organism. No student leaves without touching a giant squid and a coelacanth or without seeing Ernst Mayer's bird collections from the Pacific, etc.). While instructional, this also augments their sense of belonging to the natural history community; to our community of scientists.

Field trips

Two distinct behind the scenes tours of other institutions occur each summer. One of these is either a day-trip to the Bronx Zoo campus or to the New York Aquarium campus of the Wildlife Conservation Society. There, they hear a lecture detailing research projects and conservation priorities that are the hallmark of WCS's mission. The students are then free to spend the rest of the day at the Zoo or Aquarium as they please, going to see the various exhibits. Through our internal partnership with the NSF funded REU site program in physical sciences, we also take the Systematics students to the Sterling Mine in New Jersey: the single largest aggregate of fluorescent and phosphorescent minerals on the planet.

Student Symposium & Final Reports

At the conclusion of the program, we host a symposium in which each student presents a 15-minute talk describing their research accomplishments to an open audience that includes the entire museum community. These are attended by our AMNH scientific staff and students (in particular by the summer Lang Science program for high school students), affiliates, and very often the family and friends of the students as well. One week prior to the symposium, students submit an abstract that are peer-critiqued during our weekly meetings and then distributed in final symposium program. We do a complete run-through of their talks the day before as a group on the stage but without a full audience, with the students providing constructive peer-feedback to each other. The symposium itself occurs in the spacious Kauffman Theater, is recorded and students receive digital copies of the whole symposium. Students also compile the results of their 10-week research experience in the form of a final report. These are intended to form a rough draft for an eventual publication and thus are asked to be formatted in the style of a journal of their choice.

Summer in the City

The American Museum of Natural History obviously provides a unique and compelling research opportunity for our summer undergraduate interns in terms of the available advanced technology and highly regarded team of curators and scientists.

But the Museum itself is much more than this - it is the most frequently visited cultural institution in New York City. An entire day is insufficient time to fully explore even the permanent exhibition halls. The highlights include the Dinosaur halls, Primitive Mammals, Biodiversity, the Hall of Ocean Life, iconic African, Asian and North American Mammal halls, the Hall of Planet Earth, the Hall of Human Origins and the Rose Center and Hayden Planetarium. But, there's also the Hall of Gems and Minerals, of Meteorites, Birds of the World, Reptiles and Amphibians, and eight separate cultural anthropology halls covering the peoples of the world. Beyond even this are rotating



temporary exhibitions featuring live animals in “The Butterfly Conservancy”, “Frogs a Chorus of Colors”, “Lizards and Snakes: Alive!” and “Spiders Alive!” as well as our award winning travelling exhibitions. The latter have recently included “Senses”, and “Unseen Oceans”. Our summer interns have all of this freely at their disposal, not only for themselves but also for their family and guests.

Table 6. Sampling of summer events NYC

Date	Event
27-May	Loisaida Fest
29-May	World Science Fest
01-Jun	Red Hook Fest
02-Jun	Governor's Ball
02-Jun	Multicultural Fest
09-Jun	Big Apple Barbeque
10-Jun	Puerto Rican Day
12-Jun	Museum Mile
16-Jun	Mermaid Parade Coney Island
17-Jun	Egg Rolls & Empanadas (LES)
17-Jun	Jazz Age Lawn Party
22-Jun	Swedish Misummer Fest
24-Jun	Pride Day
30-Jun	International African Arts Fest
04-Jul	Macy's Fireworks
14-Jul	Bastille Day
16-Jul	Go Africa Hwarlem fest
17-Jul	Blues Brunch Bryant Park
20-Jul	Fire Island Dance fest
21-Jul	OZY Fest
29-Jul	Panorama Fest
30-Jul	Mostly Mozart at Lincoln Center

Ongoing

- Shakespeare in the Park
- Midsummer Night Swing
- 20 years of Piers
- David Bowie Is- Brooklyn Museum
- Tiffany Lamps- New York Historical Society
- Central Park Summer Stage
- Georgia O'Keeffe - New York Botanical Garden
- Smorgasburg - eat, eat, and eat

What’s more, because the Museum is one of many significant New York cultural institutions, every intern, simply by showing their AMNH photo-ID, can gain access for themselves and a guest to the Metropolitan Museum of Art, the Guggenheim, the Museum of Modern Art, the Whitney Museum of American Art, the New York Historical Society, the Museum of the Moving Image, the Intrepid Air and Space Museum, the New York Botanical Gardens, and several other cultural sites around the 5 boroughs.

We encourage our interns to fully avail themselves of the rich opportunities at their disposal in the summer (Table 6), and remind their mentors that this is as important an experience as is their completing a skillful research project.

Each year the PI, in coordination with one or more of the local interns, amasses all of the weekly city events and sharing them with the group. Though the REU program typically begins around Memorial Day weekend in May (when all of our interns move in *en masse* as a cohort to Columbia Student Housing), nonetheless the PI begins communicating with the admitted interns in March about what to expect both scientifically and culturally.

STUDENT RECRUITMENT AND SELECTION

The Summer REU internship programs (both this one and the Physical Sciences program) are administered through the Richard Gilder Graduate School of the American Museum of Natural History and are navigated to easily from the RGGGS website. Both REU Site programs and application materials at the museum can be found there.

Our recruitment and selection process has been refined over the years and is as follows. Each fall, we will solicit from our faculty, a set of research projects in the form of titles, short descriptions, and a research related image for advertisement through the RGGGS website with a goal of December 15th for distribution. Once the projects are up on the site, we will begin to market the program via both scientific channels as well as through broader communication outlets. We post a message announcing that applications are being accepted on academic listservs such as EvolDir and the Society of Vertebrate Paleontology with a request for faculty to post on their undergraduate listservs and email to potential students.

Efforts to reach students at institutions that lack strength in STEM fields have seen us forge new partnerships that take advantage of the large number of such schools within our own metropolitan area. While these local institutions include Hostas Community College, (primarily Hispanic and African American), Queensborough Community College in Queens, Lehman College in the Bronx, Guttman Community College, Borough of Manhattan Community College, Long Island University - Brooklyn, and Hudson County Community College, this year will initiate a new recruitment strategy with La Guardia Community College in Queens. Specifically, we have learned that making blanket offerings and notifications are not likely to lead to successful recruitment. At the suggestion of Dr. Jaqueline Brashears, faculty and mentor at LGCC, we will bring first year community college students to visit the AMNH both in the summer months, when REU interns are in place, as well as in the autumn. It is anticipated that by familiarizing

community college students with the institution in a manner that allows them to see themselves as a good fit, we would successfully recruit individuals into the following summer program.

The PI maintains a partnership with the University of Houston - Downtown (UHD), which has encouraged students from their NSF-funded UBM program to apply one of whom (Adolfo Lara) was later admitted to RGGS and defended his dissertation this past summer *in front of* the summer's cohort of REU students one of whom was himself from U-Houston-Downtown! This is an apt example of a successful pipeline in training a minority students and attracting them to a career in evolutionary biology.

A new partnership this year engages the AMNH REU program with Northwest Indian College (travel to which funds are requested in each of 3 years). This last granting cycle saw Na'ta'ne Morningsong Miles admitted to the AMNH REU program working with the PI on an invasive species taxonomic problem in relation to NY State Parks Commission. Siddall (the PI) learned an enormous amount about the wants, needs, and expectations of American Indian students from Tawnie (who later presented her work in Washington DC and is now co-author on a paper submitted for publication). Siddall has since initiated conversations with faculty mentors at NWIC, Rachel Arnold and Brian Compton. Unlike our standard procedure of advertising projects and selecting applicants to those, it has become clear that in relation to students at NWIC what is more likely to be successful is finding out first what various students' interests are and then seeing if one or more prospective mentors at AMNH might be able to tailor their research goals into a project that a NWIC student finds compelling (see for example the proposed project above by Ward Wheeler and others in the division of Anthropology). This is an entirely new strategy and one that the PI believes will be best met by visiting every other year and engaging students at NWIC directly.

In addition to our local base and targeted partnerships, the announcement will be forwarded to scientific colleagues on a national scale who teach undergraduates in their evolution, phylogenetics, and paleontology as well as other organismal courses such as herpetology, entomology and parasitology, posted to the REU project solicitation website on Facebook and Twitter, both via the personal accounts of each PI as well as involvement in other pages (e.g. American Society of Parasitologists, Association for Women in Science, Systematic Biology and the Willi Hennig Society).

The fact remains that in recent years, the average number of applications we received for 8 positions was well in excess of 300. It is plain that the AMNH REU site has no difficulty attracting applications already from a wide and diverse array of prospective interns.

In the past, our program had asked applicants to provide essays for the two top priority projects that they wanted to work on and to provide a personal statement in the form of an essay that described their motivation for pursuing a summer research opportunity such as ours. The PI determined that this long-form application disadvantaged some of those we had hoped to recruit. As such, the application has moved from the longer, essay-type statement to a series of shorter questions. These include: What attracts you to doing research this summer at the AMNH? What attracts you most to your top choice project? What attracts you most to your second choice project? What types of research opportunities have you had in the past? What are your career aspirations? Of the biology courses you have taken, which one was your favorite and why? What other skills do you have that might be relevant for research, including coding, art, graphics, knowledge of languages other than English? What skills do you hope to acquire by doing this summer research program? and What other types of experiences do you hope to have during the research program? It has become apparent that these short questions help our faculty to get a better sense of each student's background, motivation, and unique qualities, in a manner that does not bias selection toward Ivy League prospects. WE DO NOT ASK FOR OFFICIAL TRANSCRIPTS, though we do ask students which courses they have taken best prepare them for a summer with us.

Once the application deadline has passed, the applications are distributed to the faculty mentors using the same system we use for our graduate school and small grants applications at the AMNH. This password-protected website allows for secure distribution of PDFs of all application materials and opportunities for online commenting by faculty reviewers for their

personal or group information purposes. Mentors are provided too with a spreadsheet of all applicants and their most recent year of undergraduate education completed, and their home institution. Applications from our partnered institutions (UH-D, NWIC, LGCC) get a first reading by the mentors and each is asked first whether there is a suitable candidate from that preliminary pool. Only after that is the full slate of applicants released to the mentors. Approximately two weeks after the applications are distributed there is meeting of the mentors. At this meeting, each mentor is asked to identify their top three choices for students. If more than one mentor both pick the same student as their top choice, then a discussion of strategy will be initiated. If we have not identified approximately half of the students to come from under-represented groups in science and/or from non-STEM schools, then we will revisit the applicant rankings and see which applicants may deserve a higher priority.

EVALUATION AND REPORTING

The PI intensively evaluates the students' progress throughout the 10-week program at the brown-bag luncheon sessions and then beyond the program once they return to their home institutions. There is a pair of "Goal and Objective Worksheets": one for each mentor to fill out before the summer program begins and another for each student to fill out prior to beginning the program. The purpose of these is conceptualizing the project from both parties point of view and initiating a conversation that will set the mentor-student pair off in the right direction with a shared understanding of expectations and goals. While the PI engages each intern in exit interviews, the RGS student teaching assistant does as well insofar as the PI typically takes a student himself.

A modified URSSA questionnaire is applied formally and strategically in its entirety (within a month of completion of the summer program) but also in terms of selected URSSA questions each of one-month prior to arriving at AMNH for the summer program as well as at the first and second anniversary of their completion of the 10-week research experience at AMNH. For those of our interns that have previously had a summer or academic year research experience (about half) it has proven valuable to get their standing impressions of answers to question series 6.1 through 6.10, 7.1 through 7.5, and 8.1 through 8.8, both in advance and in relation to their most recent research experience (if there was one) so as to compare the trends in answers afterwards in a way that accounts for such prior experience. For distinct reasons, questions 16.1 through 16.10 are queried at the entry stage for all summer interns rather than at the end of the summer insofar as they serve the students' premise for applying to any research program, as opposed to for example flowing from the AMNH summer experience itself. In this same suite of URSSA questions are some that pertain to scientific products like publications, presentations at professional meetings and awards received for presentations (e.g., 6.1 - 6.10). It is quite unlikely that many of these will have materialized within a month of completion of the summer program at AMNH. It is, however, much more likely given our continued focus on publications and presentations by our interns, that much of this will be emergent at the one-year and two-year mark, when we follow up with scheduled surveys. Application of URSSA questions (6.1 - 6.10 and 7.1 - 7.5) one year and two years after the fact will necessarily be brief in terms of scope so as to encourage the rate of return from interns no longer local.

For our purposes, we implement several modifications to the URSSA. Question 1.8 is generally not applicable to us as we do not have an academic year program of our own. Furthermore, the diversity of data analysis our interns apply go far beyond the strictly "statistical," suggesting "advanced computation and coding" in place of "statistics" in question 3.8. As well, and given the expansive enrichment opportunities associated with a summer in the city of New York, we would add to "research experience" (5.1 - 5.7) questions relating to a) the interns' perceptions of the relevance of those extracurricular opportunities to their overall summer experience, b) whether they felt they had appropriate opportunities to engage in them, c) did they feel as though their mentor well-understood that this was relevant to the summer experience and d) did they feel sufficiently informed of such enrichment possibilities?

Our program has seen extraordinary success not only in the proximal goals associated with achievement by past interns in acquiring rewarding graduate school research opportunities, but

even long-range outcomes seeing past interns now in tenure track and equivalent academic positions. The historical span of the AMNH Biology REU internship program stands at 30 years. Of some interest too would be knowing whether and how these one-time-interns, now colleagues are incorporating undergraduate and high school students into their own research programs. In this coming 5 yr period post-enrichment will include interns learning strategies for writing to their elected representatives both at-home and at-college addresses.

Data assimilation and management for our program has long been under the oversight of Maria Rios, Assistant Director for Student Affairs and Fellowships for the RGGGS. She also serves a critical on-boarding role as the interns arrive, ensuring they are properly placed and properly paid. We are fortunate to have this level of “institutional memory”, one that even extends beyond the point (18 years ago) when the PI assumed his role in the program. Ms. Rios is critical to our reporting structure insofar as she serves as the fulcrum point when we annually collate reports on Activities and Findings and on demographic breakdowns for the previous year’s interns. Beyond these NSF-required annual (and final) grant reports, the summer REU internship program now falls under the academic umbrella of the RGGGS academic program with Dr. John Flynn as its Dean. Dean Flynn (at least quarterly) reports on the activities of the school, including this REU program that predates the inception of RGGGS. These reports are made to the Vice President and President of AMNH, and notably also on a regular basis to the Curatorial Senate - a body that comprises every tenured and tenure-track faculty member of the Museum. In that context, the REU program sees as much scrutiny and oversight as does any other academic program here.

BROADER IMPACTS

The most obvious broader impact of any REU Site award is to provide 30 undergraduate students with a unique opportunity to experience first-hand what it is like to conduct actual scientific research. Our recruitment process, already proven to be successful in attracting students from a wide variety of backgrounds and undergraduate institutions, will be enhanced in this next round to allow us to target an even deeper array of students who may not have had access to research experiences as of yet. In particular this coming 3 years will specifically target Native Americans to an ongoing project.

In the coming 3 year period the summer interns will be provided structured opportunities to share their research experiences at the museum community, and share their own personal trajectory in science with the many summer K-12 programs offered by the Museum’s Education Department. These include the Lang Science Program, Adventures in Science, Bridge Up, Urban Advantage and Science Alliance.

In addition to our undergraduate students each summer, training is also provided to several RGGGS graduate students via the REU Site program. Each summer, one of the RGGGS Comparative Biology Ph.D. program students serves as the teaching assistant for the program and delivers lectures to the REUs and helps the directors coordinate the program. A second graduate student is involved in the ancillary courses for CT scanning or next gen sequencing. Occasionally, graduate students also participate as mentors to the undergraduates, with the supervision of their advisors.

Postdoctoral fellows are also trained via this program to the extent that they frequently serve as mentors alongside their faculty sponsors and can serve as the primary mentors for the undergraduate students if their supervisors agree.

REFERENCES CITED

Names of REU interns in bold and underlined.

1. Barrowclough, G.F., Groth, J.G., **Bramlett, Elizabeth K.**, Lai, J.E. and Mauck, W.M., 2018. Phylogeography and geographic variation in the Red-bellied Woodpecker (*Melanerpes carolinus*): characterization of mtDNA and plumage hybrid zones. *Wilson J. Ornithology*. 130(3):671-83
2. **Bronson, Alison W.**, Mapes, R.H. and Maisey, J.G., Chondrocranial morphology of *Carcharopsis wortheni* (Chondrichthyes, Euselachii incertae sedis) based on new material from the Fayetteville Shale (upper Mississippian, middle Chesterian). *Papers in Palaeontology*. 4(3):349-62
3. Burbrink, F.T. and **Futterman, I.**, 2019. Female- biased gape and body- size dimorphism in the New World watersnakes (tribe: Thamnophiini) oppose predictions from Rensch's rule. *Ecology and Evolution*. doi.org/10.1002/ece3.5492
4. Clouse, R.M., Janda, M., **Blanchard, Benjamin**, Sharma, P., Hoffmann, B.D., Andersen, A.N., Czekanski- Moir, J.E., Krushelnycky, P., Rabeling, C., Wilson, E.O. and Economo, E.P., 2015. Molecular phylogeny of Indo- Pacific carpenter ants (Hymenoptera: Formicidae, *Camponotus*) reveals waves of dispersal and colonization from diverse source areas. *Cladistics*, 31(4), pp.424-437.
5. Clouse, R.M., **Blanchard, Benjamin D.**, Gibson, R., Wheeler, W.C. and Janda, M., 2016. Taxonomic updates for some confusing Micronesian species of *Camponotus* (Hymenoptera: Formicidae: Formicinae). *Myrmecological News*, 23, pp.139-152.
6. Galen, S.C., **Nunes, R.**, Sweet, P.R. and Perkins, S.L., 2018. Integrating coalescent species delimitation with analysis of host specificity reveals extensive cryptic diversity despite minimal mitochondrial divergence in the malaria parasite genus *Leucocytozoon*. *BMC evolutionary biology*, 18(1), p.128.
7. Groth, J.G., **Arbisser, Ilana**, Landman, N.H. and Barrowclough, G.F., 2015. The mitochondrial genome of *Allonautilus* (Mollusca: Cephalopoda): base composition, noncoding-region variation, and phylogenetic divergence. *American Museum Novitates*, (3834), pp.1-13.
8. Heiss, A.A., Heiss, A.W., **Lukacs, Kaleigh** and Kim, E., 2017. The flagellar apparatus of the glaucophyte *Cyanophora cuspidata*. *Journal of phycology*, 53(6), pp.1120-1150.
9. **Iwama, Rafael E.**, Oceguera-Figueroa, A., De Carle, D., Manglicmot, C., Erséus, C., **Miles, Na'ta'ne M-S.** Siddall, M., Kvist, S. Broad geographic sampling and DNA barcoding do not support the presence of *Helobdella stagnalis* (Linnaeus, 1758) in North America. In Press
10. Kim, E., Lin, Y., Kerney, R., **Blumenberg, Lilli** and Bishop, C., 2014. Phylogenetic analysis of algal symbionts associated with four North American amphibian egg masses. *PloS one*, 9(11), p.e108915.
11. **Larina, Ekaterina**, Garb, M., Landman, N., Dastas, N., Thibault, N., Edwards, L., Phillips, G., **Rovelli, Remy**, Myers, C. and Naujokaityte, J., 2016. Upper Maastrichtian ammonite biostratigraphy of the Gulf Coastal Plain (Mississippi Embayment, southern USA). *Cretaceous Research*, 60, pp.128-151.
12. Miyagi, M. and Wheeler, W.C., 2019. Comparing and displaying phylogenetic trees using edge union networks. *Cladistics*. 10.1111/cla.12374
13. Metzger, M.J., **Paynter, Ashley N.**, Siddall, M.E. and Goff, S.P., 2018. Horizontal transfer of retrotransposons between bivalves and other aquatic species of multiple phyla. *Proceedings of the National Academy of Sciences*, doi.org/10.1073/pnas.1717227115

14. **Paynter, Ashley N.**, Metzger, M.J., Sessa, J.A. and Siddall, M.E., 2017. Evidence of horizontal transmission of the cancer-associated Steamer retrotransposon among ecological cohort bivalve species. *Diseases of aquatic organisms*, 124(2), pp.165-168.
15. Ruane, S., Myers, E.A., Lo, K., Yuen, S., Welt, R.S., Juman, M., **Futterman, India**, Nussbaum, R.A., Schneider, G., Burbrink, F.T. and Raxworthy, C.J., 2018. Unrecognized species diversity and new insights into colour pattern polymorphism within the widespread Malagasy snake *Mimophis* (Serpentes: Lamprophiidae). *Systematics Biodiversity*, 16(3), pp.229-244.
16. **Rubin, Margaret**, Lamsdell, J.C., Prendini, L. and Hopkins, M.J., 2017. Exocuticular hyaline layer of sea scorpions and horseshoe crabs suggests cuticular fluorescence is plesiomorphic in chelicerates. *Journal of Zoology*, 303:245-253.
17. Siddall, M.E., **Rood-Goldman, Rebecca, Barrio, Amalie** and Barboutis, C., 2013. The eyes have it: long-distance dispersal by an intraorbital leech parasite of birds. *The Journal of parasitology*, 99:1137-1139.
18. Siddall, M.E., **Barkdull, M.**, Tessler, M., Brugler, M.R., Borda, E. and Hekkala, E., 2019. Ideating iDNA: Lessons and limitations from leeches in legacy collections. *PLoS one*, 14(2), p.e0212226.
19. Soto-Centeno, J.A., **O'Brien, Maggie** and Simmons, N.B., 2015. The importance of late Quaternary climate change and karst on distributions of Caribbean mormoopid bats. *American Museum Novitates*, (3847), pp.1-32.
20. Tessler, M., **Barrio, Amalie**, Borda, E., **Rood- Goldman, Rebecca**, Hill, M. and Siddall, M.E., 2016. Description of a soft-bodied invertebrate with microcomputed tomography and revision of the genus *Chthonobdella* (Hirudinea: Haemadipsidae). *Zool. Scripta*, 45:552-565.
21. Velazco, P.M., **Buczek, Alexandra J.** and Novacek, M.J., 2017. Two New Tritylodontids (Synapsida, Cynodontia, Mammalia) from the Upper Jurassic, Southwestern Mongolia. *American Museum Novitates*, 3874:1-35.
22. Witts, J.D., Landman, N.H., Garb, M.P., Boas, C., **Larina, Ekaterina, Rovelli, Remy**, Edwards, L.E., Sherrell, R.M. and Cochran, J.K., 2018. A fossiliferous spherule-rich bed at the Cretaceous–Paleogene (K–Pg) boundary in Mississippi, USA: Implications for the K–Pg mass extinction event in the Mississippi Embayment and Eastern Gulf Coastal Plain. *Cretaceous Research*. 91:147-67
23. Wheeler, W. C., N. Lucaroni, L. Hong, L. M. Crowley, and A. Varón. 2015. POY version 5: Phylogenetic analysis using dynamic homologies under multiple optimality criteria. *Cladistics* 31:189-196.
24. Wheeler, W. C. and P. M. Whiteley. 2015. Historical Linguistics as a Sequence Optimization Problem: Uto-Aztecan Language Evolution and Biogeography. *Cladistics* 31:113-125. 2018
25. Whiteley, M. Xue, and W.C. Wheeler, 2018, Revising the Bantu Tree. *Cladistics*. (Early view 8-31-2018).

BIOGRAPHICAL SKETCH: MARK EDWARD SIDDALL, PH.D.

Department of Invertebrate Zoology
American Museum of Natural History
Central Park West at 79th St.
New York, NY 10024

212-769-5638
siddall@amnh.org

PROFESSIONAL PREPARATION

University of Toronto, Toronto, Canada	Microbiology, B.Sc.	1988
University of Toronto, Toronto, Canada	Parasitology, Ph.D.	1994
Virginia Inst. Mar. Sci., Gloucester Point, VA	Postdoctoral	1994 -1996

PROFESSIONAL APPOINTMENTS

American Museum of Natural History, New York, NY; Curator & Professor 07/99 -
Columbia University, New York, NY; Adjunct Professor, 09/01 -
City University of New York, New York, NY; Adjunct Professor, 04/00 -
University of Michigan, Ann Arbor, MI; Ass't Prof and Michigan Soc Fellow, 08/96-04/99

PUBLICATIONS (REU interns underlined>

- Siddall, M.E., Barkdull, M., Tessler, M., Brugler, M.R., Borda, E. and Hekkala, E., 2019. Ideating iDNA: Lessons and limitations from leeches in legacy collections. *PLoS one*, 14(2), p.e0212226.
- Metzger, M.J., Paynter, AN., Siddall, M.E. and Goff, S.P., 2018. Horizontal transfer of retrotransposons between bivalves and other aquatic species of multiple phyla. *Proceedings of the National Academy of Sciences*, doi.org/10.1073/pnas.1717227115
- Paynter, A N., Metzger, M.J., Sessa, J.A. and Siddall, M.E., 2017. Evidence of horizontal transmission of the cancer-associated Steamer retrotransposon among ecological cohort bivalve species. *Diseases of aquatic organisms*, 124(2), pp.165-168.
- Tessler, M., A Barrio, E Borda, R Rood- Goldman , M Hill, ME Siddall. 2016. Description of a soft-bodied invertebrate with microcomputed tomography and revision of the genus *Chtonobdella* (Hirudinea: Haemadipsidae). *Zoologica Scripta* DOI: 10.1111/zsc.12165 – Amalie Barrio is enrolled in a PhD program at Washington University, St. Louis, MO
- Kvist, S, Ocegüera-Figueroa, AF, Fuks, BB, and Siddall, ME. 2011. Phylogenomics of *Reichenowia parasitica*, an alphaproteobacterial endosymbiont of the freshwater leech *Placobdella parasitica*. *PLoS ONE* 6(11): e28192.
- Kvist., S., Montanari, S., Yi, H., Fuks, B., and Siddall, M. E. 2011. Teaching Biodiversity and evolutionary biology in a North American marine coastal environment. *American Biology Teacher*, 73(2):72-77.
- Siddall ME, Trontelj P, Utevsky SY, Nkamany M, Macdonald III, KS. 2007. Diverse

molecular data demonstrate that commercially available medicinal leeches are not *Hirudo medicinalis*. Proc R Soc Lond B Biol Sci 274:1481-1487.

Hughes, J.L., and Siddall, M.E. 2007. A new species of leech from the New York Metropolitan Area. American Museum Novitates, 3578. – Jennifer Hughes (now Wisecaver) is an Assistant Professor of Biochemistry at Purdue University

Siddall, M. E, **Budinoff, R. B.**, and Borda, E. 2005. Phylogenetic evaluation of systematics and biogeography of the leech family Glossphoniidae. Invertebrate Systematics, 19: 105-112. –

Oceguera-Figueroa, A, Kvist, S, Watson, SC, **Sankar, DF**, Overstreet, RM, and Siddall, ME 2010. Leech collections from Washington State, USA, with the description of two new species of Placobdella.

FIVE SYNERGISTIC ACTIVITIES

Exhibition Curation – The Power of Poison, <http://www.amnh.org/exhibitions/current-exhibitions/the-power-of-poison>: exploring the nature of venoms and poisons in the natural world, human relationship to toxicity from literature to forensics; and the ways we leverage toxins as pharmaceuticals.

Exhibition Curation – Life at the Limits, 2013-2020

<https://www.amnh.org/exhibitions/life-at-the-limits> exploring the diverse and sometimes jaw-dropping strategies animals and plants employ to find food, fend off predators, reproduce, and thrive in habitats many would find inhospitable, even lethal. From bizarre mating calls, to extraordinary examples of parasitism and mimicry, and other amazing means of survival, using specimens, videos, interactive exhibits, and models, the scope of adaptation to the natural world is examined.

Course Instruction: Next Generation DNA Sequencing Lab Course Richard Gilder Graduate School, AMNH 2013, 2014.

Public Outreach at The National Academy of Sciences Entertainment Exchange.

H. B. Ward Medal for research in parasitology American Society of Parasitologists, 2002.