NSF Pollinator Portfolio

Overview: NSF funds basic research in all areas of science and engineering, except medicine, through competitive merit review of grant proposals submitted primarily by U.S. universities, and research institutions. Other government agencies, universities and corporations use basic scientific research supported by NSF to develop applied solutions and new technologies.

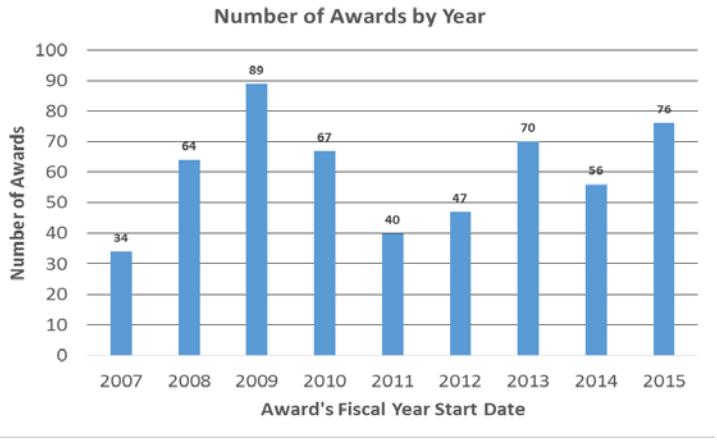

Figure 1: Number of pollinator-related grants made per year 2007-2015.

This thematic portfolio of NSF-supported research and education programs relevant to the National Pollinator Health Strategy and Pollinator Research Action Plan is an example of how NSF-funded projects advance and promote science in the U.S. and worldwide. There is no single NSF funding program focused on pollinators. The majority of awards related to pollinators are made through the Directorate for Biological Sciences, but pollinator research is supported throughout NSF, including in the social, behavioral, and economic sciences, mathematical sciences, engineering, and computer science directorates. As part of the National Pollinator Health Strategy, NSF committed to an analysis of the NSF-wide pollinator portfolio to identify the strengths of current support and areas that would benefit from future investments. Descriptions of the awards highlighted in this analysis are available at http://www.nsf.gov/awardsearch/simpleSearch.jsp.

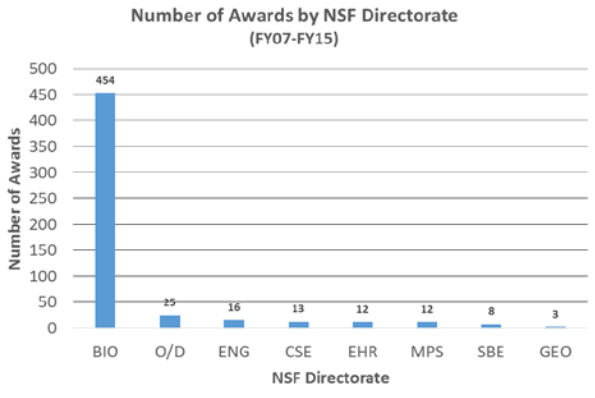

Figure 2: Number of grants awarded for pollinator - related research by directorate. BIO= Directorate for Biological Sciences; O/D = the Office of the Director including the Office of International Science and Engineering and the Office for Integrative Activities; ENG= Directorate for Engineering; CSE = Directorate for Computer and Information Science and Engineering; EHR = Directorate for Education and Human Resources; MPS= Directorate for Math and Physical Sciences; SBE= Directorate for Social, Behavioral and Economic Sciences; GEO= Directorate for Geosciences

Results: From fiscal years 2007-2015, NSF made 543 grants for research related to pollinators. There is no clear trend in the number of awards per year over this period (see Fig. 1). The largest number of awards was made in 2009, due to the availability of American Recovery and Reinvestment Act (ARRA) funds, which increased the number of awards NSF-wide. Of the 543 awards, 324 have ended and 219 are ongoing. All projects range from 1 to 5 years in length, with an average duration of 39 months, or just over 3 years. While the majority of these were awarded by the Directorate for Biological Sciences, all 7 directorates within NSF provided support for pollinator-related research (see Fig. 2).

These 543 awards went to 177 U.S. colleges and universities, 44 of which were primarily undergraduate institutions that participate in the Research in Undergraduate Institutions (RUI) program. Another 10 were designated as minority serving institutions, as defined by § 365(3) of the Higher Education Act (20 U.S.C. § 1067k(3)). The 177 institutions were in 45 of the 50

states (see Fig. 3). There are currently 26 states and 2 territories participating in the Experimental Program to Stimulate Competitive Research (EPSCOR) and 114 of the 543 pollinator awards went to institutions in EPSCOR states. These 543 grants involved 861 unique individual scientists as principal or co-principal investigators.

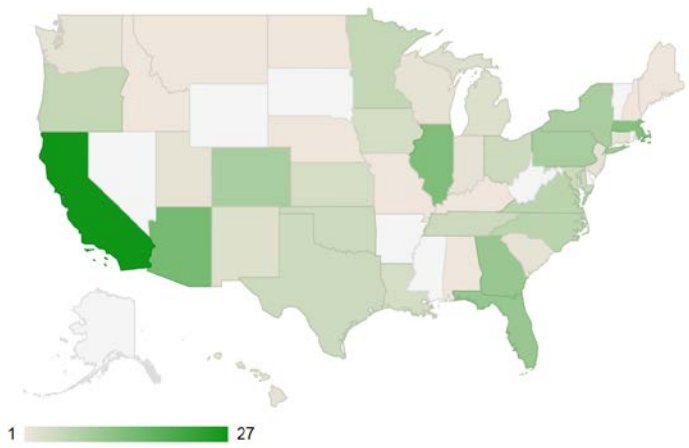

Figure 3: Distribution of pollinator-related grants from FY 2007-205 by state. Grants were made to researchers in 45 of 50 states plus the District of Columbia and Puerto Rico.

We identified 21 major themes (see Fig. 4) spanning the intellectual merit and broader impacts criteria. The themes focused on butterflies and honey bees specifically, but also native pollinators as well as pollinator-relevant studies more broadly.

Research under the theme, monarch butterflies (in the upper right of Fig. 4), for example, represents the basic descriptive information about how monarchs live, reproduce, and grow, as well as where they are found and what they do. For example, an ongoing project from Dr. Leslie Ries and colleagues at the University of Maryland (Award #1147049) is developing tools to share large databases of butterfly monitoring data, account for issues specific to this kind of data, and visualize and analyze the data. These tools will allow scientists in the U.S and other countries to share data across projects with different research designs for a more comprehensive view of butterfly distributions. Additionally, this research will provide public access to the data over the web and encourage the public's participation in butterfly monitoring as citizen scientists.

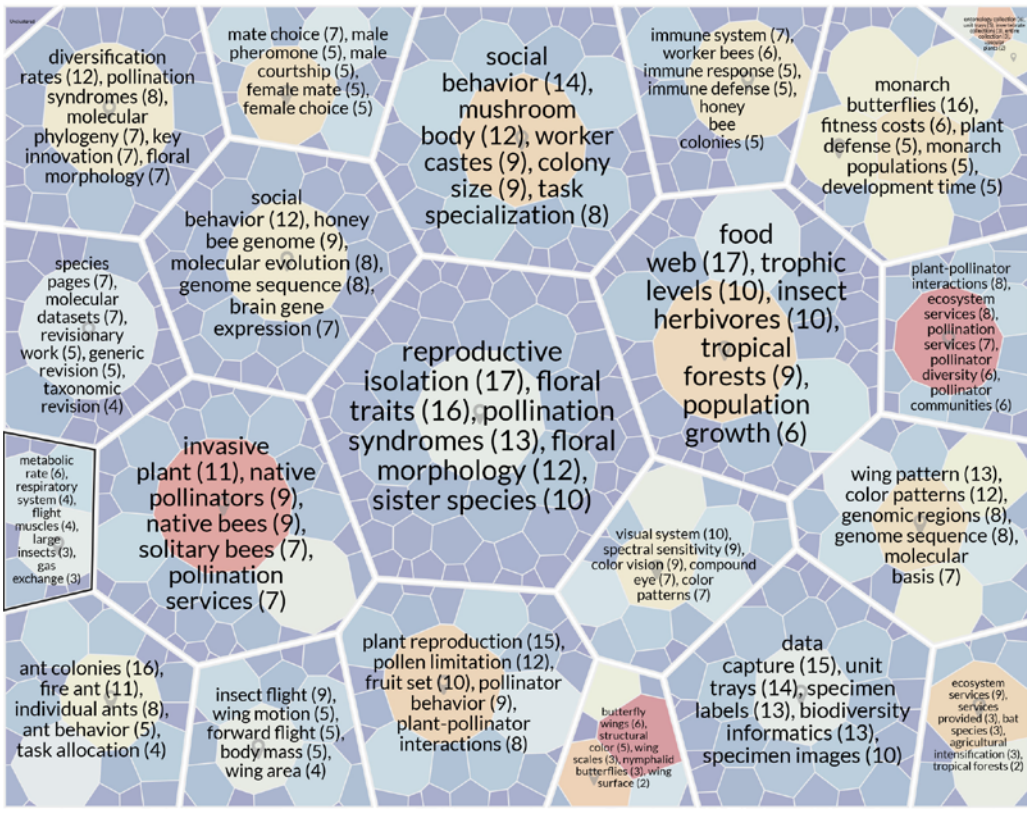

Figure 4: Themes for the full set of 543 pollinator-related research grants awarded from Fiscal Years 2007-2015 by NSF.

Pollinators by definition have a close relationship to the plants they pollinate. Other major themes include *plant reproductive isolation*, *plant-pollinator interactions*, and *ecosystem services*. In 2009, pollination services were estimated to add more than $15.2 billion to U.S. crop production profits each year[2]. Pollination services are also critical to the balance of natural ecosystems. NSF-funded scientists are involved in quantifying the role and value of ecosystem

services provided by various pollinators. A recently supported project by Dr. Laura Lopez Hoffman at Arizona State University (Award # 1518359) investigates how conditions at one location affect the ability of migratory species to provide ecosystem services at a second location post-migration. This research could be used to create a model to inform conservation and land-use decisions by policy makers. In another project, Dr. Claire Kremen of University of California, Berkeley (Award # 0919128), with colleagues from California, Maryland, and Illinois, studies pollinators in California's Central Valley, one of the nation's most extensive agricultural areas. Dr. Kremen and colleagues combine field observations and experiments to understand how restoring patches of natural pollinator habitat can help sustain diverse communities of pollinators. The team also assesses the economic value to agriculture of pollination as an ecosystem service. The information from these projects can inform agricultural and conservation policy.

Several other themes that resulted from the portfolio analysis relate to *insect physiology* such as *metabolic rate*, *insect flight*, *insect vision* and *insect immunity*. For example, Dr. Marla Spivak, of the University of Minnesota-Twin Cities (Award # 1256992) studied how honey bees collect tree resin and deposit it in the hive where it is called propolis. A propolis envelope lines the inner walls of the hive and acts as an antimicrobial layer surrounding the colony. This ongoing project investigates how this resin layer benefits bee immune defenses and colony-level social immunity. Dr. Spivak received a McArthur Award in 2010 for her earlier NSF supported work on honey bee behavior, genetics, and group immunity and has an ongoing grant for this work.

Three of the themes, including the terms *entomology collection*, *data capture,* and *specimen labels*, involve projects related to digitizing natural history collections. The set contains 21 awards specifically focused on collections care and digitization. Natural history collections have great scientific value related to documenting where and when species of pollinators were found and public science education. These types of projects are connected to collections-based efforts by our sister agencies like the Smithsonian Institution. One of these projects, headed by Drs. Rebecca Irwin and Ian Billick, involved digitizing the bee collection at the Rocky Mountain Biological Laboratory (RMBL) (Award # 1016025). RMBL has a long history of studying pollinator biology and the RMBL Bee Collection holds 2682 bee specimens from five of the seven major families (Andrenidae, Colletidae, Halictidae, Apidae, and Megachilidae). Digitization of a collection allows easier access to the collection by scientists around the world, and allows an online public audience to view the collection. To further increase general access to collections, a collaboration between the University of Maryland and SR2Group, a small business, will use robotic imaging and data capture to create technologies for high-throughput-digitization of insect specimens by museums. Many museums have tens of thousands of specimens to digitize, and doing so by hand literally takes years for multiple individuals. This technology would speed that process. This project, headed by Dr. Jeffrey Sieracki (Award # 1143119), is part of the Small Business Innovation Research program which supports collaborations between small businesses and scientists to facilitate private sector commercialization of scientific and technological innovations.

The themes in Figure 4 involving *diversification rates*, *taxonomic revision*, and *reproductive isolation* include projects that investigate how species evolve, how they are related to one another, and how species diverge and lineages are maintained over time. In an ongoing project, Dr. Wenheng Zhang and colleagues at Virginia Commonwealth University (Award # 1355109) are investigating the phylogeny of 1300 species of plants in the acerola family, Malpighiaceae, their distribution worldwide, changes in floral structure over time, and changes in associated pollinators, specifically related to speciation events.

We looked at the change in themes over time. Specifically, we looked at periods at the beginning (FY 2007-2008), the middle (FY 2011-2012) and the end (FY 2014-2015) of the data set. Some themes are constant, such as *honey bees*, *life history*, and themes involving the genes underlying organisms' traits, such as *candidate genes*, *gene flow*, and *genetic basis*. Other themes from the previous years are lost; for example, *sequence data* is lost because over time fewer projects focused on sequence data due to the number of genomes that

have been sequenced since the price of sequencing dropped significantly. New themes emerge over time. *Citizen science* emerges as a theme in the FY 2011-2012 thematic groups, and it is also under the larger theme of *ecosystem services* in 2014-2015. NSF currently supports more than 300 citizen science projects. Examples of citizen science projects in the area of pollinator research include the work of Dr. Karen Oberhauser from the University of Minnesota-Twin Cities (Award # 1417777). In this project, high school students and their teachers participate in citizen science projects that are incorporated into the classroom's science curriculum. These activities also involve collaborations with groups, like the Xerxes Society, that bring citizens into the project. The Xerxes Society collaborated on Dr. Kremen's pollinator project in California's central valley.

The themes *student education* and *dissertation research* represent the large role that NSF plays in training the next generation of basic research scientists from undergraduate research experiences to post-graduate programs and graduate training while working toward masters and doctoral degrees. A substantial portion of NSF's graduate student support is through individual investigator grants like those in the pollinator portfolio where a student is supported on a larger grant to a research laboratory. Among the 543 projects in the portfolio, there are 117 Doctoral Dissertation Research Grants. These small grants resulting from student-submitted proposals are often the first grants a future independent scientist receives. They allow a student to extend the impact of their dissertation work, and provide support to present that work at national and international scientific conferences. Among these projects is a dissertation project by Sandra Gillespie and her mentor, Dr. Lynn Adler, at the University of Massachusetts Amherst (Award # 0808292) to understand the effects of parasitic flies and protozoan infection of bumble bees on bumble bee pollination behavior. They also investigate the impacts of bumble bee behavioral shifts on the ecosystem of agriculturally associated plants found along fields--important sources of food for both managed and native pollinators.

The results of NSF-funded basic science research projects are now being used by our sister agencies like the USDA. For example, Dr. Nancy Moran, from the University of Texas, Austin (Award # 1415604), is examining the genome sequences and metabolism of beneficial microbes found in honey bee guts. Dr. Moran is investigating how different microbes' abundance and gene expression changes when bees experience nutrient stress and disease. She is documenting which species of microbes are found in the guts of bumble bees and honey bees collected around the world. This research is important to understanding bee health. This project informs other projects at our sister agencies such as a USDA/ARS project investigating the role of beneficial microbes in the pollen stored in the hive as "beebread," and the role of microbes in forager bees' crops where they store collected nectar during flights back to the hive.

Conclusions: This analysis suggest that pollinator research at NSF has been and continues to be robust and well-funded across the directorates within NSF. Moving forward, NSF will continue to welcome research proposals on a variety of insect and animal pollinators and plant-pollinator interactions in its ongoing core programs solicitations where the majority of this award portfolio was funded. NSF looks forward to continuing to support pollinator health and pollination services for the nation.

References:

1. Keywords used in award search: honeybee* honey colony collapse* bee bees apis* bombus* bumblebee* bumble beekeep* hive* beetle* coleoptera* hopliini* butterfly butterflies danaus* agraulis* pyrgus* urbanus* battus* lepidoptera* hummingbird* anthophora* anthophora abruptba* eulaema* eulaema meriana* pollen* pollinat* wasp* hymenoptera* sphecidae* vespidae* pompilidae* masarinae*

2. Calderone, Nicholas W. "Insect Pollinated Crops, Insect Pollinators, and U.S. Agriculture: Trend Analysis of Aggregate Data for the Period 1992–2009." *PLoS ONE* 7.5 (2012): e37235. Web. doi:10.1371/journal.pone.0037235