POLLINATOR RESEARCH ACTION PLAN

Report of the Pollinator Health Task Force

MAY 19, 2015

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On behalf of the Pollinator Health Task Force, we are pleased to transmit the *National Strategy to Promote the Health of Honey Bees and Other Pollinators* (Strategy). Developed through a collaborative effort across the Executive Branch, this Strategy outlines a comprehensive approach to tackling and reducing the impact of multiple stressors on pollinator health, including pests and pathogens, reduced habitat, lack of nutritional resources, and exposure to pesticides. Building on the current state of the science, and with a renewed emphasis on expanding our understanding of the complex interactions among the various factors impacting pollinator health, the Strategy lays out current and planned Federal actions to achieve the following overarching goals:

- **Honey Bees:** Reduce honey bee colony losses during winter (overwintering mortality) to no more than 15% within 10 years. This goal is informed by the previously released Bee Informed Partnership surveys and the newly established quarterly and annual surveys by the USDA National Agricultural Statistics Service. Based on the robust data anticipated from the national, statistically-based NASS surveys of beekeepers, the Task Force will develop baseline data and additional goal metrics for winter, summer, and total annual colony loss.
- **Monarch Butterflies:** Increase the Eastern population of the monarch butterfly to 225 million butterflies occupying an area of approximately 15 acres (6 hectares) in the overwintering grounds in Mexico, through domestic/international actions and public-private partnerships, by 2020.
- **Pollinator Habitat Acreage:** Restore or enhance 7 million acres of land for pollinators over the next 5 years through Federal actions and public/private partnerships.

The Strategy addresses the four themes central to the June 2014 Presidential Memorandum "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators," namely: conducting research to understand, prevent, and recover from pollinator losses; expanding public education programs and outreach; increasing and improving pollinator habitat; and developing public-private partnerships across all these activities. A critical component of the Strategy is to advance the science underpinning the government's land management and regulatory decisions. To this end, the Task Force has prepared the accompanying "Pollinator Research Action Plan," which outlines gaps in current knowledge of pollinators and pollinator declines, and identifies priority research efforts needed to close these gaps.

The Strategy also advances ambitious Federal commitments to increase and improve habitat for pollinators, both directly through the large variety of facilities and acreages of land managed by the Federal government, and indirectly through the leadership role that Federal agencies can play in interactions with states, localities, the private sector, and citizens. These actions range from planting pollinator gardens and improving land management practices at Federal facilities, to advancing the availability and use of pollinator-friendly seed mixes in land management, restoration, and rehabilitation actions nationwide.

By expanding the conversation through enhanced public education and outreach, as well as strongly-built public/private partnerships, the Strategy seeks to engage all segments of our society so that, working together, we can take meaningful and important steps to reverse pollinator declines.

Pollinators are critical to our Nation's economy, food security, and environmental health. Honey bee pollination alone adds more than $15 billion in value to agricultural crops each year, and provides the backbone to ensuring our diets are plentiful with fruits, nuts, and vegetables. Through the actions discussed in this Strategy, and by working with partners across our country, we can and will help restore and sustain pollinator health nationwide.

Hon. Tom Vilsack

Secretary of Agriculture

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Administrator, U.S. Environmental Protection Agency

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Executive Summary

Pollinator health is a crucial component of managed and natural landscapes. Thriving pollinator populations promote healthy food systems and healthy ecosystems. Recently, some pollinator populations have experienced notable declines, due to changes in habitat size and structure, pests and pathogens, pesticides and toxins present in the environment, and nutritional quality of forage, among other factors. The impacts of these factors individually and the interactions among them are not well understood.

On June 20, 2014, President Obama issued the Presidential Memorandum "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators," establishing a Task Force to develop a Strategy to promote the health of honey bees and other pollinators. The Strategy has three overarching goals: to reduce honey bee losses, increase the Eastern population of the monarch butterfly, and restore or enhance 7 million acres of land for pollinator habitat. To achieve these goals through evidence-based decision-making, Federal agencies must work together and with government, university, and private sector partners, including international partners, to prioritize and address critical knowledge gaps in the influences on, and impacts of, pollinator health. The Pollinator Research Action Plan (Action Plan), a stand-alone component of the Strategy, is a roadmap for Federally-supported pollinator health research. The priorities in the Action Plan fall into five main action areas, covered in ten subject-specific chapters. These action areas are:

1. **Setting a Baseline:** Assessing the status of pollinator populations requires inventories to establish baseline conditions, with subsequent monitoring and longitudinal studies to detect deviations from the baseline, and causes of those deviations. Federal agencies will expand current surveys of beekeepers to include questions on management practices and hive losses, and will continue to support ongoing monitoring efforts of honey bee health. By developing appropriate monitoring and modeling approaches, we will increase our understanding of native managed bees that offer promising alternatives to honey bee pollination for some crops in some regions. Research will explore native managed pollinators' impact on ecosystems, how the factors driving their population trends are the same as, or different from, the factors driving population trends of honey bees, and the economic impacts on crop pollination.

   Unmanaged native pollinators, representing thousands of species in North America alone, are the least understood group of pollinators. The first step to setting a baseline for native pollinators is proper identification. Federal agencies will devote resources to developing better genetic and taxonomic tools, and to training more taxonomic professionals. Research will assess population patterns, interactions with other native and non-native pollinator species, and habitat use. Federal agencies will also seek better understanding of the environmental stressors impacting habitat functionality, both now and under future climate and land-use change scenarios.

2. **Assessing Environmental Stressors:** Many individual environmental factors have the potential to impact pollinator populations. These impacts will vary by species and can be mitigated or exacerbated by co-occurring environmental factors. Agencies will not only examine these factors individually in controlled laboratory experiments, but will also explore how these factors interact with each other in real-world situations through longitudinal studies of pollinator health.

Pollinators are exposed to a variety of pests and pathogens, some well-known and some emerging. The movement of managed bees opens avenues for pest and disease transfer into and out of those colonies. Agencies will develop monitoring protocols for new and re-emerging diseases in managed and native pollinators. Agencies will work to identify new control methods for pests and pathogens that are safe and effective for managed bees. Additionally, research will explore the role that the microbiome plays in pest and pathogen resistance, and the potential to exploit the microbiome as a natural protectant in managed colonies.

Pollinators also come into contact with a wide variety of pesticides and agrochemicals applied with different methods, at different rates, and at different times of year. Agencies will develop proper assessment tools for evaluating the lethal and sublethal effects of these substances on managed and native pollinators. Research will assess field-level exposure of pollinators to pesticides, the routes of exposure, the internal fate of agrochemicals, and the impacts of field levels of exposure on pollinator health.

Adequate nutrition has the potential to make pollinators more resilient to other stressors, including agrochemicals, pests, and pathogens. Future research will identify the key elements of proper nutrition for managed native bees and honey bees, and put them in the context of geography and time of year. Additionally, research will explore the role of the microbiome in proper nutrition.

3. **Restoring Habitat:** Pollinator populations depend directly on plant populations for nutrition, and, in turn, plants depend on pollinators for reproduction. There is much more to learn about the relationships between plants and their pollinators. Research will focus on understanding the spatial and temporal relationships between plants and their pollinators, and identifying habitat with the highest potential for pollinator benefits through restoration. Agencies will use this information to develop locally-adapted species mixes that provide adequate resources for pollinators throughout the year (both now and under future climate scenarios) and design techniques for collecting, processing, storing, and germinating these species on scales relevant to restoration. Lastly, agencies will research how to effectively establish these mixes in a way that is affordable in the short term and self-sustaining in the long term.

4. **Understanding and Supporting Stakeholders:** The choices that land managers and beekeepers make depend on a complex web of cultural and economic values. Research will explore the costs and benefits to land managers and the public of adopting pollinator-friendly practices, such as the use of buffer zones and tailored forage seed mixes. Bioeconomic models will be developed to link beekeeper survey data on colony numbers and overwintering survival to hive management practices and forage availability. Advances in our understanding of pollinator health and the social and economic factors influencing beekeepers and land managers will allow us to improve current decision-support tools and best management practices, as well as develop needed new resources and guidance.

5. **Curating and Sharing Knowledge:** Long-term monitoring and sound research require an extensive and well-curated knowledge base. This includes traditional data from individual specimens verified with their taxonomic and geographic data, as well as data from emerging

technologies such as whole-genome sequencing. Priority actions include identifying and using existing infrastructure, tools, and expertise to digitize, standardize, and share Federal pollinator and associated plant-collection data. To support quality data collection of traditional plant and pollinator specimens, as well as genetic material, best practices will be developed for specimen identification and confirmation, as well as associated electronic data. Coordinated collection efforts among Federal agencies and non-Federal partners will expedite efforts and conserve resources required to catalog pollinator species and their relationships with plant species.

Together, these five action areas represent the bodies of knowledge currently understood to be most critical to the recovery of pollinator populations in the United States and globally. The proposed research is built on a solid foundation of existing data from Federal agencies, as well as academic institutions. Task Force agencies will use emerging research findings to inform other actions in the Strategy and update goals and metrics as necessary, such as updates to best management practices for lands. Timelines for these activities are included in the Action Plan. Agencies will support Action Plan activities through prioritization and coordination of existing Federal budgetary and staff resources, and collaboration with private-sector activities.

Introduction

Pollinators are crucial members of various ecosystems, from farmland to wilderness. There are an estimated 352,000 flowering plant species, many of which depend on pollinators to reproduce (National Research Council 2007; "The Plant List" 2013). A variety of organisms serve as pollinators: bees, wasps, flies, butterflies, moths, bats, birds, and more. There are over 4,000 native bee species in the United States alone (Moisset and Buchmann 2011). The attributed value of crops in the United States that are directly dependent on insect pollination was estimated at $15.12 billion in 2009, including an estimated $11.68 billion of crop value directly attributable to honey bees (Calderone 2012). Estimates for both insect pollination, generally, and honey bee pollination, specifically, for crop values are dependent on the amount of acres cultivated and crop prices (Calderone 2012). The value of pollinators in natural systems is much more difficult to discern, given that the maintenance of natural plant communities through pollination contributes to a variety of valuable ecosystem services, including carbon sequestration, water filtration, and erosion control (National Research Council 2007). Simultaneous declines in native and managed pollinator populations globally, with highly visible decreases in honey bees, bumble bees, and monarch butterflies, have brought into focus the importance of pollinator conservation (National Research Council 2007; van Engelsdorp *et al.* 2009; Pettis and Delaplane 2010; Cameron *et al.* 2011).

In 2006, some beekeepers in the United States began to notice unusually high overwinter mortality of their honey bee colonies. In some hives, all or the majority of adult bees disappeared, leaving behind their brood and food reserves. This phenomenon is known as "colony collapse disorder" (CCD). Though the trademark symptoms of CCD have continued to account for some colony losses in the years since 2006, the proportion is shrinking, and other factors appear to be impacting bee health. In 2012–2013, 30.6% of U.S. honey bee colonies were lost during overwintering, up from 22.5% the previous year (Steinhauer *et al.* 2013; Spleen *et al.* 2013). Intensive public and private research in the United States and abroad over the past 8 years has shown that no single culprit is responsible for CCD or for the general declines in pollinator health (USDA 2012). Today, honey bees in the United States are exposed to a variety of environmental stressors, including pesticides, disease, pests (parasites), migratory stress from long-distance transport, and changes in habitat quality or outright habitat loss (USDA 2012).

Though honey bees are the most economically important—and hence the best-monitored—pollinators in the United States, there are indications that some species of native pollinators are in decline as well. Baseline information on native pollinator populations, however, is very sparse (National Research Council 2007). Some bumble bee populations are suffering from introduced pests and diseases, potentially transferred from managed bees (Colla *et al.* 2006). Native bees, butterflies, bats, and other native pollinators are all impacted by habitat loss and degradation, and there is strong evidence that for some species such factors have led to population declines (National Research Council 2007; Potts *et al.* 2010). Additionally, both honey bees and native pollinators must cope with the effects of climate change, which may have direct impacts on behavior and physiology, and indirect impacts through floral resource availability and changing dynamics of pests, pathogens, predators, and competitors (Potts *et al.* 2010; Le Conte and Navajas 2008).

The U.S. government plays a large role in the pollinator research that supports land management and regulatory decisions. On June 20, 2014, as part of a larger Federal strategy to ensure pollinator health, President Obama issued the Presidential Memorandum "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators." The memorandum called on the Federal government to draft a pollinator research action plan (hereafter referred to as "Action Plan") that includes:

1. Studies of the health of managed honey bees and native bees that assess stressors leading to species declines and Colony Collapse Disorder, as well as strategies for mitigation.
2. Plans for expanding and automating data collection and data sharing related to pollinator losses, in partnership with the private sector.
3. Assessments of native bee and monarch butterfly population patterns, and modeling of the relationship of those population patterns to habitat variables.
4. Development of affordable pollinator-friendly seed mixes and guidelines for evaluating their effectiveness in restoration and reclamation.
5. Identification of best practices for minimizing pollinator exposure to pesticides, and new cost-effective ways to manage pests and diseases.
6. Creation of strategies for targeting restoration efforts at areas that will yield the greatest expected net benefits for pollinator health.

This Action Plan addresses the six requirements specified in the Presidential Memorandum by outlining ongoing research that targets knowledge gaps and then identifying future priority actions to close those gaps. The Action Plan is structured around the major factors that have been associated with declines in pollinator health, as identified by a team of Federal experts and peer-reviewed by non-Federal subject-matter experts. The Action Plan also includes sections that identify current resources and gaps in fundamental scientific infrastructure, and decision tools related to pollinator-health research. Where appropriate, the Action Plan makes reference to relevant research activities outside of the United States and encourages international engagement. Such an approach is valuable because pollinator declines are occurring around the world, can provide transnational comparative insights into causal factors, are often driven by factors that can act transnationally and/or globally (*e.g.*, migration, transport of pesticides, invasive species, climate change), and are of sufficient urgency to compel many nations, including the United States, to cooperate in relevant global research activities. Not only does international cooperation financially and scientifically leverage U.S. investments with investments made by other nations, it also provides an opportunity for the United States, with its diversity of ecosystems and large Federal and Federally-funded research community, to contribute to solving the global challenge of pollinator declines.

The Action Plan contains elements that have received appropriations, as well as some that require additional funding to address. Completion of the latter is contingent on Federal budgeting outcomes.

Section I: Status and Trends

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Introduction/Problem Statement

While many attempts have been made to quantify the issues surrounding honey bee loss (Spivak *et al.* 2011) and CCD, few have provided longitudinal, statistically-defensible estimates that can be widely used by government and industry. Equally difficult is the task of quantifying the status and long-term trends of populations of other managed bees and wild native bees. Generally, the quantification of pollinator trends has come from comparing current population levels to historical population levels (Cameron *et al.* 2011). For honey bees, this is measured in the number of managed hives used in honey production that are registered; for native bees, assessments of their status rely on disparate historical collection data and limited contemporary surveys.

Recent work has documented the decline in the number of managed honey bee colonies in the United States (Spivak *et al.* 2011) dating back to the 1940s. Decline in some native species has been anecdotally noted (National Research Council 2007), but only collapses in bumble bee species (Cameron *et al.* 2011) have been statistically documented.

The impact of accidentally introduced bee species that are clearly spreading in range and increasing in number, *e.g.*, *Anthidium manicatum* (Strange *et al.* 2011), is unclear. Pollinator ranges and populations are changing (Winfree *et al.* 2007; Bartomeus *et al.* 2011; Cameron *et al.* 2011; Strange *et al.* 2011), but the lack of consistently collected and statistically valid information for at least invertebrate pollinators makes determining those patterns difficult. Determining the current status of pollinator communities, documenting shifts in distribution and abundance of various species, and refining methodologies for documenting changes (Lebuhn *et al.* 2013) remain important areas of research, as does the taxonomic capacity that supports such research.

Timely, accurate, and useful data are needed to address the following questions:

1. What are honey bee colony loss levels with respect to management level, region, and time of year, and what are the causes of those losses (such as queen loss, CCD, pest infestation, disease, or starvation) based on standardized surveys of beekeepers, apiary inspections, and longitudinal studies of hives?
2. What is the status of native pollinators in the United States, as a whole, in terms of distribution, abundance, and beneficial impact on the Nation's managed (*e.g.*, agricultural) ecosystems and unmanaged ecosystems?
3. What species, genera, or functional groups of pollinators are showing significant trends over space and time?

4. What proximate and ultimate biotic and abiotic factors are driving population changes, and how do these factors vary over space and time?
5. What impacts are non-native bees having on native communities?
6. How can studies of pollinators conducted in other countries inform our understanding of declines in the United States?

Key Priority Research Themes

1. **Develop the taxonomic capacity to establish a system of surveys and assessments that provide statistically-defensible estimates of change in range, distribution, abundance, and health of pollinators.** Using standardized methodologies to understand the inter- and intra-annual cycles of distribution and abundance is critical. Recent innovations in sampling methodologies (Lebuhn *et al.* 2013) (*e.g.*, use of coordinated volunteers) can facilitate the collection of data and information at scales heretofore impossible considering the limited resources for the research and professional monitoring communities. Accurate assessments of pollinator status and trends depend on gathering baseline pollinator data in habitats of interest, and correct identifications of the diverse pollinator communities. The current shortage of practitioners skilled at bee identification is limiting research and monitoring. Training and employing a new generation of invertebrate taxonomists is also key. Finally, revisionary studies of common pollinator species that are currently difficult or impossible to identify—coupled with Web-accessible identification tools (*e.g.*, Droege 2015)—are strongly needed.
2. **Quantify the status and trends of managed and non-managed pollinator species.** Identifying the historical and current distribution and abundance of species is critical to understanding current and future trends. Among managed pollinators, declines in honey bee colonies (Spivak *et al.* 2011) are generally well-documented; among non-managed pollinators, some populations are known as stable (*e.g.*, common Eastern bumble bee (Cameron *et al.* 2011)), but the status of most is unknown (*e.g.*, alfalfa leaf-cutter bee (Pitts-Singer and Cane 2011), blue orchard bee). Documented declines are only known for social species (honey bees and bumble bees (Spivak *et al.* 2011; Cameron *et al.* 2011)); little is known about trends for the solitary bees that are the majority of pollinators (Winfree *et al.* 2007; Lebuhn *et al.* 2013).
3. **Identify impacts of specific biotic and abiotic factors on pollinator populations.** A variety of biotic and abiotic factors can impact pollinator status, including climate change (Bartomeus *et al.* 2011), land-use changes (Winfree *et al.* 2007), pathogens (Cameron *et al.* 2011; Fürst *et al.* 2014), parasites, and invasive species (Strange *et al.* 2011). Understanding the effects of climate on bees (Bartomeus *et al.* 2011) is important in predicting which species will be suitably adapted to pollinate U.S. crops. Understanding the role of land management practices (Winfree *et al.* 2007) (including pesticides and crop management practices) and land-use factors on bee health and abundance can elucidate how we can modify management to benefit pollinators. Information is needed to understand how, when, and where viral, bacterial, and fungal pathogens and parasites—major causes of bee mortality (Cameron *et al.* 2011; Spivak *et al.* 2011; Fürst *et al.* 2014)—are transmitted across species or among pollinator communities (Fürst *et al.* 2014).

The impacts of expanding ranges of recently arrived exotic solitary bees (Strange *et al.* 2011) on native plant and pollinator assemblages are not known and must be evaluated.

Existing/Current Research

1. Developing baseline data on pollinator status.

- The U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) has two programs that gather and estimate data on the honey industry. An annual bee and honey inquiry produces state-level estimates of the maximum number of colonies from which honey was taken during the year, as well as production, stocks, and values of honey. NASS also collects information on honey bee colonies (*i.e.*, number of operations with colonies on December 31st, honey collected, and honey value) every five years as part of its Census of Agriculture. Due to concerns of underreporting by beekeepers, data-collection methodology is constantly being evaluated by agricultural statisticians. Insect collections represent large datasets on historical native pollinator communities. University and government researchers have been mining these data by cataloging and georeferencing specimen information. Researchers are conducting revisionary studies of bees that will improve baseline development.
- Federally-funded research, allocated primarily through the National Science Foundation (NSF) and USDA, is supporting university researchers across the Nation and in a variety of natural and agricultural ecosystems as they establish baseline biodiversity and abundance data for native bees. One large USDA-funded program, the Integrated Crop Pollination Project (ICP) is looking at the status and diversity of native pollinators in 10 states and four major cropping systems: almonds, cucurbits, berries, and tree fruit. Models of bee abundance and distribution are being developed in this partnership. In the Northeast, the ICP is also determining which species are tree fruit pollinators, their relative significance, and economic importance. Between 40 and 50 species have been identified pollinating apple trees, and a northeastern integrated pest management (IPM) guide was developed by a Federally-funded public-private partnership (Park *et al.* 2012).
- Researchers have conducted native bee inventories in multiple National Park Service units to document the distribution of pollinator species (*e.g.*, Rykken *et al.* 2014).
- U.S. Fish and Wildlife Service (USFWS) is collaborating with the U.S. Geological Survey (USGS), the USDA Agricultural Research Service (ARS), universities, and others on native bee surveys. This collaboration has led to the development of a database representing more than a million bee specimens from across North America, and provides identification and survey design support for a broad array of private, academic, state, and Federal investigators. Projects are ongoing, with national survey programs limited in scope by the available level of funding.
- Beekeepers and researchers need the ability to monitor hives remotely and continuously for signs of distress. Federal small-business innovation grants fund entrepreneurs to develop remote-monitoring capabilities, including solar-powered colony-health monitoring systems.

2. Understanding pollinator population trends.

- University and government researchers have been actively involved in investigations of pollinator population changes (Winfree *et al.* 2007; Cameron *et al.* 2011; Strange *et al.* 2011) and theory (Lebuhn *et al.* 2013), and have launched research programs to monitor bee health, agrochemical exposure, microbiota changes, and colony growth in commercial migratory operations.
- USGS has created and vetted national programs for estimating population trends for native and invasive bee species, developed and evaluated bee survey protocols (Lebuhn *et al.* 2013) and native bee monitoring manuals, created online identification guides for the bees of North America, and held workshops on native bee identification.
- The Smithsonian Institution (SI) is conducting international studies to understand global trends. The "Arthropod Initiative" of the SI Center for Tropical Forest Science is monitoring key arthropod assemblages over the long term and studying insect-plant interactions over the network of the SI Global Earth Observatories designed to detect long-term changes in native and managed ecosystems driven by climate cycles, climate change, and habitat alteration.
- USGS and USFWS, in conjunction with the monarch Joint Venture, are developing a national monarch butterfly monitoring framework intended to track populations and assess effectiveness of conservation actions as part of the Federal monarch conservation initiative.
- Federal agencies are participating in the forthcoming assessment of pollinators associated with food production, led by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IBPES), that will assess the status of, and trends in, pollinator populations worldwide.

3. Quantifying the impacts of specific effects of drivers on pollinator populations.

- An ARS-led project to mine large datasets to evaluate the effects of land use and crop production on honey bee declines is currently underway.
- Studies funded by USDA's National Institute of Food and Agriculture (NIFA) and NSF are focused on understanding the proximal causes of bee declines (*e.g.*, pathogen prevalence, land-use factors, and climate change).
- A survey by ARS of National Parks in the Pacific Northwest is documenting distributional changes of bumble bee species and habitat connectivity across high-elevation corridors. Comparing drivers and resultant declines for the United States versus for other countries (*e.g.*, the United Kingdom and the Netherlands) could provide additional insights.
- Studies funded by USDA's Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA), and conducted by USGS and the Pollinator Partnership, are designed to better understand the uses and benefits of Conservation Reserve Program (CRP) lands to pollinator populations.

Research Gaps/Needs and Priority Actions

1. **There is a lack of consistent data on the honey bee industry in regards to colony loss and associated economic and production impacts (Spivak *et al.* 2011). Further research is needed to determine the number of colonies lost and to clarify the effects of landscape factors, including forage and commercial agriculture, on colony-level health and activity.**

- **Priority Actions:** Conduct colony loss surveys. NASS will expand its honey bee program to include two new colony loss surveys: quarterly and annual. Both surveys will collect data on colony numbers, colony loss, newly-added/replacement colonies, colony health, and instances of CCD. The quarterly survey will be used to capture data from operations with five or more colonies every three months. Operations with fewer than five colonies will receive one survey for the entire year in December. Questions are also to be added to the current bee and honey inquiry on the costs associated with loss and colony maintenance.

2. **A survey of bee communities in various ecosystems is needed to determine the status of native pollinators (Lebuhn *et al.* 2013). Further work is needed to document the current spread of non-native bees and understand the impacts these species have on native species (Strange *et al.* 2011).**

- **Priority Actions:** Develop a framework for collecting standardized status and trends information for native and introduced pollinator species. This will include evaluating the importance and possibility of including other pollinators besides bees in such a framework.

3. **For the native (non-Apis) managed bees (*i.e.*, alfalfa leaf-cutting bees, blue orchard bees, alkali bees, bumble bees) further research is needed to fully understand the factors (pathogens, parasites, abiotic) that drive population trends (Pitts-Singer and Cane 2011), as well as commercial factors that influence grower decisions on purchasing alternative pollinators.**

- **Priority Actions:** Develop methodology and models for determining the factors that drive changes in native pollinator populations, and for determining the relative value of non-Apis pollinators in various ecosystems. Engage NASS to collect data on the commercial traffic in non-Apis pollinators in order to understand the economic value of alternative pollinators.

4. **Most honey bee colonies in the United States belong to commercial operations (Spivak *et al.* 2011). More research is needed on how bee management practices affect bees on the colony level, especially for hives that are involved in migratory operations and thus exposed to a variety of agricultural systems. University-led research is being done to evaluate bee management practices at the colony level; however, this information is collected by surveying beekeepers, who may provide subjective or conflicting information[1]. These surveys are valuable in helping researchers formulate testable hypotheses on practices that potentially influence colony levels.**

1. http://beeinformed.org/programs/management-surveys/

- **Priority Action:** Further investments are needed using science-based methods (*e.g.*, replicated studies with controls and treatments) to confirm which management practices are impacting honey bee colonies.

5. **In many countries, estimates for pollinator populations and the magnitude of different possible stressors are not available for comparison to the United States. The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) assessment on pollination, pollinators, and food production, due out in 2015, may reveal other sources of information or significant international gaps.**

- **Priority Action:** Expand/explore research collaboration with countries that share pollinators, stressors, and/or complementary research strengths.

6. **Currently, staffing of insect collections is not sufficient to meet the needs of agencies and universities seeking to identify specimens obtained through pollinator surveys. The quantification of trends in populations first depends on the ability of researchers to identify correctly the target species.**

- **Priority Action:** Develop infrastructure for identification of pollinator species, including additional development of accessible taxonomic keys in print and online, taxonomic training for students, researchers, and field workers, development of genetic tools, and development of the next generation of taxonomic expertise.

Agency Roles

Priority Actions	Lead Agencies	Primary Support	Secondary Support
Quarterly and annual colony loss surveys	NASS		
Statistical framework for assessing status and trends	NASS, USGS	USGS, ARS	NIFA, SI, NSF
Develop baseline status data	USFWS, ARS, USGS	NIFA, NSF, NASS	USFS, NPS
Assess trends in pollinator populations	USFWS, ARS, USGS	NIFA, NSF, NASS	USFS, NPS
Develop bee identification capability	ARS, USGS	NIFA, NSF	
Expand/explore research collaboration	ARS, NASS, USGS, USFWS, NIFA, SI, NSF		

Section II: Habitat (Including Stressors)

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Introduction/Problem Statement

Pollinator populations and the many services they provide are threatened by the degradation, fragmentation, and loss of their habitats (National Research Council 2007). For pollinator populations to be sustained, adequate habitats for nesting, foraging, mating, dispersing, and migrating will be required. Understanding of the habitat requirements for pollinators, as well as how to identify and manage habitats effectively over time and across the variety of land uses and conditions, is limited.

Key Priority Research Themes

1. **Understanding pollinator habitat requirements.** Information on characteristics of quality habitat is necessary to define habitat requirements and to assess the pollination services provided to commercial and natural ecosystems. Understanding landscape characteristics, such as patch size and structure, corridors and connectivity, and the composition of the matrix that surrounds habitat for pollinator populations, is important.
2. **Understanding habitat loss, degradation, and fragmentation effects on pollinators, as well as stressors that interact with and exacerbate these impacts.** Predicting the impact of land-use changes on habitat suitability for pollinators is fundamentally important. Understanding habitat changes—compounded by disease, climate change, invasive species, and/or other stressors—is critically important to understanding population responses. Assessing links between changes in habitat and changes in pollinator populations is necessary to determine when habitats are sources or sinks for pollinators.
3. **Identifying viable approaches to protect, manage, and enhance pollinator habitat.** Incorporating the roles of natural disturbance in creating temporally-variable habitats and emulating habitat structure and ecosystem function while maintaining multiple uses of landscapes, including other ecosystem services, and human habitation, and livelihood, is important. Broad-scale assessments of pollinator distribution across management regimes, and ultimately research that links habitat condition to pollinator demographic processes, are also important.
4. **Identifying viable approaches to restore and create pollinator habitat.** There is a need to restore or create habitat where it has been lost or degraded. Developing viable and achievable restoration practices is needed. While some resources exist, additional needs remain.

Existing/Current Research

Research is being carried out throughout the United States and covers a wide suite of pollinators (*e.g.*, native and non-native bees, moths, butterflies, beetles, flies, bats, and birds); however, projects to date have been geographically and taxonomically limited. Current pollinator habitat research projects include partnerships with universities, the Xerces Society, state agencies, local governments, utility companies, nongovernmental organizations (NGOs), corporations, tribes, and Federal non-research agencies (such as U.S. Fish and Wildlife Service (FWS), Bureau of Land Management (BLM), National Park Service (NPS), U.S. Army Corps of Engineers (USACE), and Department of Defense (DOD)).

Scientists are currently conducting studies that examine the role of pollination in the fitness of rare plants and animals, the effects of climate change on pollinator habitats (especially with regard to shifts in phenology and range (*e.g.*, Forrest 2015)), the effects of invasive plant species on pollination networks, pollinator responses to fires and other natural disturbances, the effects of forest and grassland management and restoration activities on pollinators and host plants, the effects of invasive predators, factors associated with hive location, and the effects of road management. University researchers in the Northeast and Midwest are evaluating the impact of several habitat types and developing landscape-level models to understand better the value and range of bee habitat next to fruit tree orchards, and the cost to fruit growers of removing existing habitat.

Habitat studies of bees date to the turn of the 20th century, when natural history studies of individual taxa were common. This is a rich literature that can provide descriptive work on nest architecture and location, brood-cell provisioning, and plant-species visitation (*e.g.*, Alcock 1975; Eickwort 1975; Alcock 1979; Torchio 1984; Neff and Simpson 1997).

More recent work has largely focused on habitat associated with agricultural and urban landscapes and the benefits (*i.e.*, ecosystem services) associated with such habitat. In particular, scholars (Menz *et al.* 2011; Williams *et al.* 2012; Kennedy *et al.* 2013; Morandin and Kremen 2013) have examined agricultural-natural area interactions with respect to pollinator habitat, and others have examined pollinator habitat restoration (Nyoka 2010; Williams 2011; Cusser and Goodell 2013). Monarch butterfly habitat has received attention from university researchers (Stevens and Frey 2010; Pleasants and Oberhauser 2013).

Research on bee habitat-use characteristics in agricultural and urban settings is conducted by many non-Federal entities, including many universities, the Pollinator Partnership, Xerces Society, and the American Museum of Natural History. Urban bee populations and their habitat associations have been researched considerably over the past several decades (Hernandez *et al.* 2009; Pawelek *et al.* 2009; Tonietto *et al.* 2011; MacIvor *et al.* 2014; Potter and LeBuhn 2015). Tallamy and Shropshire (2003) compared lepidopteran and bee diversity between habitats that consisted of native versus non-native plant communities. On agricultural lands, the multi-state, collaborative Integrated Pollinator Management Project, funded by the U.S. Department of Agriculture (USDA) Specialty Crop Research Initiative (SCRI), supports scientific research on practices, outcomes, and economics of different pollinator management strategies in diverse fruit and vegetable crops, ranging from complete reliance on honey bees, to on-farm floral supplements to enhance suitability for wild pollinators, to use of managed native bees to enhance yields.

A relatively small amount of research has been devoted to pollinators in forested habitats. Logging and other forest management effects have been studied in several places (Nyoka 2010; Summerville 2013; Jackson *et al.* 2014). Other studies have focused on temporal asynchrony for forest-dependent pollinators that forage on early-spring tree blossoms and ephemeral wildflowers (Visser and Holleman 2001). One study discusses pollinator abundance and diversity in forest fragments (Williams and Winfree 2013), but it is unclear how attempts to manage for local pollinator diversity may affect native pollinators and mutualistic relationships with plants (Schemske *et al.* 1978).

Research Gaps/Needs and Priority Actions

The top priority is to better understand the basic life histories of pollinator relationships with their habitats, particularly to determine the extent to which pollinator populations are habitat-limited. Characteristics of good pollinator habitat must first be defined.

1. **Understanding pollinator habitat requirements.**

- **Natural history of habitat use.** Increase knowledge on the fundamental building blocks of pollinator habitat, such as distribution, nest-site preferences, plant preferences and degree of specialization, phenology, dispersal ability, and effective ranges over which pollinators perceive and use their environment.
- **Species' habitat requirements.** Identify the temporal and spatial requirements of stationary or migratory species (*e.g.*, monarch butterfly) at local and landscape levels, and whether species have an ability to switch to other plants or locations when preferred plants are not available.
- **Site-specific habitat assessments.** Assess assemblages of vegetation types and species, and habitat features needed by various groups and/or species of pollinators for nesting, foraging, roosting, overwintering, and dispersal. Identify pollinator species or groups in need of habitat improvements.
- **Landscape-scale assessments.** Determine landscape characteristics of quality habitat. Evaluate whether there is adequate landscape-scale habitat structure (*e.g.*, patch sizes, arrangement, connectivity) to sustain habitats for pollinator species. Determine the dispersal capacity and needs of pollinators.

2. **Understanding habitat loss, degradation, and fragmentation, and stressors that exacerbate these impacts.**

- **Status and trends.** Develop metrics that associate pollinator populations with specific habitat changes.
- **Stressors.** Assess and predict how pollinators and their host plants respond, in terms of diversity, abundance, and interactions, to stressors of climate instability, carbon dioxide increase, fire intensity and frequency increase, invasive species, control of invasive and undesirable species, and extreme weather events.
- **Habitat functionality loss.** Assess and predict how pollinators and their host plants respond to habitat loss, degradation, and fragmentation. Identify pollinator-habitat tension zones due

to land-use changes from road management, grazing, forest management, urbanization, and agricultural intensification.

- **Future projections.** Project future habitat suitability for key pollinator functional groups and/or species given projected impacts of urbanization, agricultural intensification, climate change, shifting phenologies, and other stressors.

3. Identifying approaches to protect, manage, enhance, restore, and create pollinator habitat ("stewardship activities").

- **Landscape-scale analyses.** Conduct landscape analyses to identify critical, limiting distances between suitable habitats required to meet pollinator needs (*i.e.*, distance between nesting/roosting and pollen/nectar areas), including providing migratory capacity under current and projected climate conditions.
- **Site condition analyses.** Analyze phenological data and use zone mapping to design habitat management or enhancement strategies and evaluate site-specific habitat value and condition.
- **Effectiveness of site specific techniques.** Evaluate conditions (what, where, when, how) that make site-specific management techniques supportive of pollinator habitat (*e.g.*, fire management, forest management, invasive species management, plantings). Identify assemblages of plant species to enhance the diversity of floral resources, food types, and their duration. Using heterogeneity of microclimates and landscapes, optimize the design and management for the heterogeneity of habitat within both landscapes and habitats (*e.g.*, floral variety to provide pollen and nectar in time, space, and under a myriad of conditions) to provide resilience/buffer capacity so pollinator populations can survive and persist under the uncertainty of extreme weather events and changing climates that are being projected.
- **Future projections.** Develop predictive capacity for measuring how management activities affect pollinator habitats.
- **Decision Science.** Use structured decision-making processes to identify priority habitat research projects: for example, criteria-based ratings derived via expert panels. Create decision-support tools to facilitate strategic habitat conservation choices, considering diverse protocols/procedures/sites/landscapes. Incorporate effectiveness monitoring and adaptive management into these tools. Decision-science tools will help target resources toward areas of high risk and restoration potential, and will support prioritization of plans for restoring pollinator habitat based on those areas that will yield the greatest expected net benefits.

Agency Roles

Priority Actions (Planned for 2015)	Lead Agencies	Primary Support	Secondary Support	Comments
Species Lists: Bees that use trees, and trees that need bees.	USFS	USFS, NPS		Simple, but no one has done it yet, and it will be foundational for pollinator habitat research.
"Working Trees for Pollinators": Synthesize existing research on which pollinator taxa are critical to carrying out pollinating functions. Distill into principles for enhancing and creating pollinator habitat on agricultural lands using conservation practices.	USFS/ NAC, USGS, ARS, NRCS	USFS, NRCS, ARS, NPS		Agencies have multiple studies with different questions/ approaches. Synthesizing research is a critical first step in developing a foundation for action, both to provide timely science-based guidance to meet immediate management needs, as well as identifying where the major gaps in information are to then guide future research.
Effects of environmental stressors and land management practices on pollinators.	USFS USGS	USFS USGS, NPS		Many site-level research projects are underway and include studies of effects of land management at the population (*e.g.*, honey bee productivity) and community (*e.g.*, plant-and-animal interaction networks) levels, as well as pollinator effects on fitness of imperiled plant species.
Capitalize on existing habitat reconstruction and restoration programs to improve benefits to pollinators.	USGS USFS	NPS		Currently, habitat restoration in DOI focuses on trust species. These programs should be evaluated for benefit to pollinators; the seeding/ planting data could be collated and examined for floral resources at minimal additional expense.
For host plant community restoration, identify the important plant species to support priority pollinator natural history needs across all ecosystem types across all seasons.	USGS	USFS, NPS	NRCS, NSF	What are the highly generalist plant species that will jump-start a restoration, providing habitat for the priority pollinator species?
Construct and then manage for the heterogeneity of habitat within a landscape and within a habitat.	USGS, USFS			

Priority Action (Planned for 2015)	Lead Agencies	Primary Support	Secondary Support	Comments
Compare pollinator use of high-quality managed and remnant areas across a broad variety of ecosystems to determine essential qualities of habitat that will most benefit pollinators. Develop management plans to favor this high-quality habitat in other managed areas.	USGS, USFS	NPS		For example, use of silvopasture systems in the southeastern United States as a potential means to expand flowering season for pollinators.
Design schemes for monitoring ecosystem function by establishing coordinated ecological experiments to assess relationships among primary productivity, habitat patch structure and connectivity, and pollinator efficiency.	USGS	NPS	NSF	Recognize that environmental conditions will continue to change rapidly, and utilize monitoring systems to adjust management guidance adaptively.
Use Structured Decision Making to identify the top priority natural history research gaps to fill.	USFS, USGS	ARS		

Section III: Nutrition

Leads: Gloria Hoffman (USDA-ARS), Mary Purcell-Miramontes (USDA-NIFA)

Members: Jim Cane (USDA-ARS), Frank Forcella (USDA-ARS), Jay Evans (USDA-ARS), Miguel Corona (USDA-ARS), Michelle Elekonich (NSF)

Introduction/Problem Statement

Nutrition is the foundation for health in all organisms. In honey bees and most other pollinators, all nutritional needs are met by consuming nectar and pollen. Nectar provides carbohydrates, and pollen supplies protein and all other nutrients required for growth and reproduction. Determining the nutritional components in pollen and nectar that affect the physiology of individual pollinators and—in social species—overall colony health is fundamental.

Pollinators rely on flowering plants for food, but when flowers are unavailable, nectar and pollen substitutes can be fed to them as an alternative. This practice is especially common for commercial honey bee colonies. Such diets can prevent starvation in the short term but in their present formulations do not sustain colonies for extended periods. Though considerable research directed at bee nutrition was conducted in the past, the advent of molecular tools and sequencing of the honey bee genome have resulted in new insights into the role of nectar and pollen on gene expression, immunity, and colony health. Similarly, the role of microorganisms (hereafter referred to as "microbes") in storage and digestion of pollen and nectar has been known for decades, but, with the development of metagenomic tools, we are embarking on a new era in the study of the microbial communities in individuals and in colonies. We are finding that the beneficial microbes that bees rely on for optimum health can originate from pollen and nectar (Anderson *et al.* 2013). These microbes also affect pollination efficiency (Raguso 2004; Pozo *et al.* 2009; Herrera and Pozo 2010), thus linking pollinator health and the environment at a new and deeper level. These studies also have generated new questions on the role of beekeeping and crop management practices in microbial communities and the resulting effects on pollinator health.

Key Priority Research Themes

1. **Determining the changing nutritional needs of honey bee colonies and key managed solitary bees throughout the year.** Specifically, the roles of nutrition in physiological processes such as brood rearing, pheromone production, and immunity are key research areas, as are identifying factors that might promote or interfere with the acquisition of nutrients (*e.g.*, beneficial microbes, pathogens, parasites, and environmental toxins).
2. **Identifying combinations of plants by geographical region that will meet nutritional needs of honey bees and key managed solitary bees.** This research can be enhanced by breeding traits back into crop species that attract pollinators and provide the nutrients they need to thrive.

3. **Fully comprehending the nutritional needs of honey bee colonies and key managed solitary bees.** This requires a greater understanding of the role of microbes in food storage and digestion.

- **Methods to identify malnutrition.** Such methods, particularly in commercial honey bee colonies, are essential to prevent colony losses. Identifying key components in pollen and nectar that bees require to optimize their health is essential for improving supplemental diets to feed colonies when flowering plants are unavailable.

Existing/Current Research[2]

The nutrients available to bees in nectar and pollen have been determined for many crop species. Methods to improve nectar production have been known for decades for forage plants like alfalfa (Barnes and Furgala 1978; Teuber and Barnes 1979; Teuber *et al.* 1980; Teuber *et al.* 1983). Our understanding of the molecular genetics of nectaries in plants used as bee forage (*e.g.*, the mustards) has increased greatly (Kram and Carter 2009). This information can be used to improve the attractiveness and resource production of these plants, as well as other related crops that are attractive to bees (*e.g.*, canola and new/alternative crops like camelina, crambe, and pennycress).

In the past, the role of microorganisms in bee nutrition was limited to only those microbes that could be cultured in laboratories. Metagenomic techniques, however, have expanded the study of microorganisms to those that cannot be cultured outside the bee. Using these techniques, a core bacterial community has been determined in the digestive tract of honey bees (Martinson *et al.* 2011; Moran *et al.* 2012), suggesting that these bacteria have a positive impact on bee health, such as assisting in digestion of pollen (Engel *et al.* 2012). Further, a diverse set of bacteria and fungi have been found in nectar and can affect flower choice (Good *et al.* 2014; Schaeffer *et al.* 2014). Microorganisms also are found in stored pollen and were thought to play a role in its preservation and digestion (Gilliam 1997). Recent studies suggest, though, that microbes have limited impacts on digestion of stored pollen but may play a role in preventing spoilage (Anderson *et al.* 2014).

When flowering plants are unavailable, beekeepers feed colonies protein and carbohydrate supplements. Pollen substitutes with high protein and lipid content can improve honey bee nutrition and health when compared with carbohydrate diets alone, but are not as nutritious as the diverse pollen collected by colonies (Robinson and Nation 1966; DeGrandi-Hoffman *et al.* 2010). In addition, it has been found that bees simultaneously fed mixtures of pollen and lethal doses of pesticides lived longer than those fed artificial diets, suggesting interactions between the nutritional state of bees and pesticide sensitivity (Schmehl *et al.* 2014). Pollen substitutes lack specific nutritional components needed to sustain colony health, such as certain essential amino acids. The use of these supplements under different environmental conditions, as well as their effects on bee physiology, disease, and pesticide tolerance, is only recently being determined (Alaux *et al.* 2010; DeGrandi-Hoffman *et al.* 2010).

In addition to pollen substitutes, beekeepers often feed high fructose corn syrup (HFCS) or sucrose to colonies after harvesting honey or during periods of nectar dearth. Relative to honey, long-term feeding

2. The focus of this section is primarily on honey bees because they are the most-studied and economically-important pollinator; however, findings from studies on honey bees often can be applied to other pollinators.

of either of these alternative carbohydrate sources elicits hundreds of differences in gene expression in the fat body (a nutrient-sensing tissue analogous to our liver and adipose tissues). These expression differences include genes involved in protein and amino acid metabolism needed for pollen digestion (Wheeler and Robinson 2014). Furthermore, there is growing evidence that bees receive nutrients in honey that are not found in sucrose and HFCS, and that positively affect detoxification systems of bees (Mao *et al.* 2011).

Nutritional stress often goes unnoticed in honey bee colonies until the repercussions of malnutrition become evident (*e.g.*, poor colony growth, disease, queen loss). Recent work has shown that malnutrition causes substantial changes in gene expression during early adult development in worker honey bees (Corby-Harris *et al.* 2014). Furthermore, the aging process itself differs when bees are deprived of pollen. Though molecular markers of malnutrition are being found, these need to be translated into monitoring tools suitable for beekeepers. It is critical to identify malnutrition early in colonies because diet affects normal age-related development (Alaux *et al.* 2011; Ament *et al.* 2011) and can have long-term consequences on colony growth and winter survival.

Research Gaps/Needs and Priority Actions

1. **Determining the role of pollen and nectar in sustaining the health and reproductive capacity of pollinators, including how nutritional needs might change throughout the year and under different levels of stress.**

- **Priority Actions:** Expand on studies to define the nutritional needs of honey bees and key managed solitary bees, which should begin with analyses of healthy populations. These studies should take into consideration time of year and geographic location.

2. **Identifying combinations of plantings that meet the nutritional needs of pollinators throughout the year for major geographical regions of the United States, and developing biomarkers that can be used in the field to identify nutritional stress in order to prevent pollinator losses.**

- **Priority Actions:** The nutritional value of incoming pollen and stored food should be determined to find associations between incoming nutrients and pollinator health. Field-based markers of malnutrition need to be developed.

3. **Identifying key microbes in colonies and in individual pollinators, understanding the acquisition and transmission of these microbes, and determining their role in digestion and disease prevention. This includes understanding the role of these microbes and the effects of food sources and environmental contaminants on microbial communities.**

- **Priority Actions:** Further investigate the role of microbial organisms in nutrition of honey bees and key managed solitary bees.

4. **Understanding the complex interactions between bee diet, nutritional state, and susceptibility to pests, diseases, and pesticides. This will support improving supplemental diets in a cost-effective manner, which is essential to preventing colony losses during times when flowering plants are not available.**

- **Priority Actions:** Conduct multifactorial studies to determine these interactions. Increase understanding of the role of nutrition for other pollinators.

The priorities listed above can be accomplished by USDA-ARS researchers and through existing extramural grants to researchers funded by USDA-NIFA and/or NSF. Public-private partnerships will also be explored to leverage funding. Research findings will be published in refereed scientific journals and presented to beekeepers, pollinator groups (*e.g.*, ABF, AHPA, NAPPC), and at scientific meetings. Other products should include improved seed mixtures for pollinator plantings and development of supplemental diet formulas for pollinators. These actions can be accomplished over an estimated 3–5 year timeframe.

Agency Roles

Priority Actions	Lead Agencies	Primary Support	Secondary Support	Comments
Define nutritional needs of pollinators	ARS	NIFA	NSF	To leverage funding, public-private partnerships will also be explored. Research findings will be published in refereed scientific journals and presented to beekeepers, to pollinator research groups (*e.g.*, ABF, AHPA, NAPPC), and at scientific meetings. Other products should include improved seed mixtures for pollinator plantings and development of supplemental diets. Time frame: 3–5 years
Determine nutritional value of incoming pollen and stored food	ARS	NIFA	NSF	
Investigate role of microbial organisms in pollinator nutrition	ARS	NIFA	NSF	
Conduct multifactorial studies to determine interactions of nutritional stress with immune response, pesticides, and disease susceptibility	ARS	NIFA	NSF, APHIS	

Section IV: Pollinator Pathogens and Pests

Leads: Jeff Pettis USDA-ARS), Kevin Hackett (USDA-ARS)

Members: Theresa Pitts-Singer (USDA-ARS), James Strange (USDA-ARS), William Meikle (USDA-ARS), Gloria Hoffman (USDA-ARS), Robyn Rose (USDA-APHIS), Bob Danka (USDA-ARS), Tom Rinderer (USDA-ARS), Judy Chen (USDA-ARS), Jay Evans (USDA-ARS)

Introduction/Problem Statement

Managed honey bees, bumble bees, and solitary bees are threatened by invasive mites, small hive beetles, predators, and pathogens including viruses, bacteria, and fungi (Biesmeijer *et al.* 2006; Potts *et al.* 2010; Cameron *et al.* 2011; Vanbergen *et al.* 2013). These threats can become more severe when bees are nutritionally deficient because of lack of forage or are exposed to pesticides (Gill *et al.* 2012; Pettis *et al.* 2013). Research should be aimed at diagnosing, preventing, and controlling bee pathogens and pests, and gaining an understanding of their epidemiology and impact.

Key Priority Research Themes

1. **Reducing the impact of the parasitic mite Varroa on managed honey bees.** Varroa, a destructive parasite that attacks honey bees on all continents except Australia (and Antarctica), has the greatest impact on honey bee colony performance because it feeds off the blood of immature and adult bees and serves as a vector to transmit and activate certain viral diseases (Mondet *et al.* 2014). Best management practices (BMPs), breeding for resistance, and new and improved controls (including RNAi targeted at Varroa and associated viruses) are needed to reduce the impact of this mite. Substantial research investments by other countries in these areas may provide opportunities for leverage and more rapid progress.
2. **Understanding factors that increase the impacts of viral and fungal infections in honey bees and bumble bees.** Some pathogens, such as the bacterial disease American foulbrood, independently cause bee mortality. Other pathogens, including important fungi and viruses, are especially damaging in conjunction with environmental, nutritional, and pesticide stresses. Understanding under what conditions these pathogens become problematic is vital for maintaining healthy honey bees and bumble bees.
3. **Determining the extent of pathogen movement from managed bees to native bees.** There is evidence of pathogen movement from managed to non-managed species (Colla *et al.* 2006; Fürst *et al.* 2014). A better understanding is needed of how pathogens move among species and the resulting impact.
4. **Improving pathogen identification and control in managed bees other than honey bees.** Populations of managed solitary bees can be affected by chalkbrood, parasitic wasps, predatory beetles, and pollen-feeding mites. Relatively little is known about the diversity and distributions of bumble bee pathogens and parasites. A U.S. baseline of these parasites and pathogens is needed. Efforts are also needed to develop realistic disease and parasite thresholds by examining current bumble bee production practices.

5. **Identification of exotic threats and border vigilance to prevent unwanted introductions.** Honey bee pests and pathogens are a major factor in the regulation of movement of honey bees and hive products across borders. Any country wanting to send bees to the United States is required to conduct a rigorous risk assessment. Surveys of bees shipped into the United States should continue to verify the absence of exotic pests (*e.g.*, *Apis cerana, Tropilaelaps* spp. mites).

Existing/Current Research

1. **Reducing the impact of the parasitic mite Varroa on managed honey bees.** Studies to determine mite migration rates and Varroa population growth are being conducted as part of a USDA-ARS Areawide Project. New methods to control Varroa are being developed and tested, including biological agents, plant-based oils and acids, RNAi, and compounds to disrupt Varroa host-finding behaviors. Monitoring for acaricide resistance is ongoing in an effort to support strategies to reduce resistance buildup.
2. **Understanding factors that increase the impacts of virus and fungal infections in honey bees and bumble bees.** Research is underway to investigate the role of viral and fungal infections on managed bee health (Cornman *et al.* 2012), including interactions with stress factors such as poor nutrition, pesticide exposure, and Varroa. Methods are being developed to detect and quantify infection levels of diseases and pests in bumble bees. Determination of the timing of detection and the level of infection will be critical in the development of a reliable tool for use in commercial systems that provide bumble bee colonies for pollination.
3. **Determine the extent of pathogen spillover from managed bees to native bees.** The potential for pathogen movement from honey bees to other species, and between wild and managed bumble bee populations, has been documented in Canada and Europe, and is being assessed in the United States (Colla *et al.* 2006; Fürst *et al.* 2014). Pathogen outbreaks may be mitigated by using improved BMPs and pathogen detection.
4. **Improving pathogen identification and control in alfalfa leaf-cutter bees and blue orchard bees.** For alfalfa leaf-cutter bees, researchers are examining environmental impacts on the occurrence of disease and parasites in commercial production, the dynamics of infections composed of more than one fungal pathogen, and the ability of fungal pathogens to cross-infect with honey bees. Plans are to determine effective attractants for pests of blue orchard bees and to use the attractants to create "attract and kill" traps for pests.
5. **Identification of exotic threats and border vigilance to prevent unwanted introductions.** The development of rapid techniques for diagnostic tools and new pest response guidelines for exotic pests such as *Tropilaelaps* spp. mites and *Apis cerana* (Asian honey bee) are underway in the United States and in other countries (Pettis *et al.* 2012).

Research Gaps/Needs and Priority Actions

1. Longitudinal studies with honey bees.[3]

- **Priority Actions:** Evaluate the roles of nutrition, enhanced forage, and pesticide exposure on pathogen buildup and honey bee colony growth and activity using longitudinal studies. The health of honey bee colonies placed on CRP and non-CRP lands would be monitored over time as colonies are moved between pollination (*e.g.*, of almonds) and honey production. Nutritional value, diversity of pollen, pesticide load, pathogen levels, queen loss, colony growth, survival, pollination availability, and honey production would be monitored. This builds on existing collaborations within ARS, NRCS, FSA, Animal and Plant Health Inspection Service (APHIS), USGS, and others.

2. Varroa control.

- **Priority Actions:** There is a need for better methods to control Varroa, including (1) identification of Varroa-resistant or -tolerant genes in A. *mellifera*, (2) identification of genes associated with avirulent mites and mites with low fecundity, (3) development of new Varroa biopesticides such as RNAi and novel chemical miticides to disrupt mite reproduction, (4) identification of resistance mechanisms to Varroa in the original host bee, A. *cerana*, and molecular mechanisms to better understand the mite's vulnerabilities, (5) clarification of developmental metabolic pathways in mites using genomic (Honey bee Genome Sequencing Consortium 2006) and transcriptomic approaches, and (6) improvement of BMPs.

3. Using microbes as natural protectants against disease.

- **Priority Actions:** Bees carry known pathogens and parasites as well as a community of gut symbionts whose impacts on bee health are poorly known. Laboratory and field experiments are needed to identify and exploit beneficial associations that may fend off disease in managed bees.

4. Identifying and controlling new and emerging pathogens.

- **Priority Actions:** New or emerging diseases caused by previously unidentified pathogens or the reemergence of known pathogens with new properties is inevitable but unpredictable. There is a need to develop, in concert with international partners, integrated approaches that make it possible to address the emergence of new diseases or the reemergence of disease threats, especially in the context of moving managed bees among crops and regions. These approaches include such specific research as clarification of strain variation, and virulence in deformed wing virus.

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3. A longitudinal study is defined as "an observational research method in which data is gathered for the same subjects repeatedly over a period of time". In this context, we are using the basic longitudinal study framework to layer on treatments that might affect honey bee health. It is not a "true" longitudinal study as honey bee hives do not survive long (1–3 years at best).

Agency Roles

Priority Actions	Lead Agencies	Primary Support	Secondary Support	Comments
Longitudinal studies	ARS	NIFA	APHIS	
Varroa controls	ARS	NIFA	APHIS	
Beneficial microbes	ARS	NIFA	APHIS, NSF	
Emerging pathogens	ARS	APHIS	NIFA, NSF	

Section V: Pesticides and Toxins

Leads: David Epstein (USDA-OPMP), Anita Pease (EPA-OPP), Tom Steeger (EPA-OPP)

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Introduction/Problem Statement

Pesticide use has become an integral part of the Nation's agricultural economy. Many growers in the United States depend on pesticides, as a whole and as a core component of integrated pest management (IPM) programs. A more thorough understanding of current pesticides and the development of new products are needed to balance crop production requirements with sustaining pollinator health in agricultural settings and adjacent landscapes.

Pesticides and herbicides, used individually or in combination, can have direct and/or indirect effects on non-target organisms and have been identified as one of the factors contributing to declines in pollinator health. Such effects may be worsened if they occur with other stressors associated with pollinator declines (*e.g.*, diseases, habitat modification, improper nutrition, arthropod pests, and overwintering).

Beyond the direct lethal effects of pesticides on individual pollinators, an increasing number of sublethal effects continue to be identified. There is uncertainty regarding whether sublethal effects measured at the level of the individual bee impact whole colonies/populations to cause pollinator declines.

To assess pesticide products for managed bee-safe use, domestic and international labs in academia, industry, and government are developing laboratory- and field-based methods to assess potential exposure to, and effects from, pesticides on both honey bees and native bees.

Key Priority Research Themes

1. **Determining whether current methods/tools used to assess pesticide exposure and effects are sufficient to support regulatory decision-making for all pollinators.** As many as 121 different pesticides have been identified in honey bee colonies and within pollen, honey, and wax (Mullin *et al.* 2010). While test methods exist to evaluate acute effects on individual honey bee adults (OECD 1998a, 1998b; EPA 2012a, 2012b) and larvae (OECD 2013), and some progress has been made in evaluating acute exposure effects on native (non-Apis) bees, there is a limited understanding of chronic exposure effects on insect pollinators in general. Continued review of draft protocols and development of formal test guidelines and guidance documents for pesticide exposure and effect studies at environmentally-relevant concentrations is needed to inform regulatory decisions.
2. **Understanding the relation between sublethal effects (e.g., subcellular, organ-level, behavioral) reported for individual bees and the effects (i.e., impaired survival, growth, and reproduction) typically used by regulators to support quantitative risk assessments.** Qualitative and quantitative links between effects reported at various levels of biological organization need to be developed to enable extrapolation from lower to higher levels of biological

organization in what has been characterized as an "adverse outcome pathway" (Ankley *et al.* 2009).

3. **Determining how pesticides interact with each other and other stressors (e.g., poor nutrition/food quality, pest infestation, environmental conditions, etc.) to impact pollinator health.** A wide range of pesticides has been detected in bee-related matrices (*e.g.*, bees, pollen, honey, beeswax). Available research has demonstrated potential interactive effects (*e.g.*, antagonism, synergism) on bees from some pesticide combinations, and in some cases the inerts/adjuvants that may be formulated with the pesticides.

4. **Assessing effectiveness of mitigation measures (*e.g.*, BMPs).** Efforts are underway to develop measures to mitigate exposure to, or effects from, pesticides, and to provide a means of monitoring/evaluating the efficacy of such mitigation measures. These include the development of effective means of disseminating information to growers/applicators and beekeepers for reducing the effects of pesticides on bees.

5. **Identifying effective chemical, mechanical, and managerial tools that can be developed for combatting arthropod pests of managed bees.** The development of effective tools (discovery/testing/registration) in support of the chemical control of Varroa mites and small hive beetles includes research examining potential adverse effects of these control measures on bees, either directly or indirectly, through interactive effects with other compounds.

Existing/Current Research

1. **Determining whether current methods/tools used to assess pesticide exposure and effects are sufficient to support regulatory decision-making for all pollinators.**

- Evaluating factors associated with exposure to pesticide-abraded dust during planting of pesticide-treated seed (DeGrandi-Hoffman *et al.* 2014), including honey bee colony development, health, and overwintering ability relative to pesticide exposure (Hoffman *et al.* 2013; Anderson 2014; Purucker *et al.* 2014).
- Studies specifically to evaluate direct exposure to, and effects of, pesticides (*e.g.*, neonicotinoid insecticide seed and foliar applications) on honey bee colonies. Studies are also underway to evaluate the effects of neonicotinoid insecticide exposure on honey bee colony growth and activity using continuous monitoring, colony measurements, and laboratory cage studies (Carrol 2014).
- Research on environmental fate and effects of pesticides on pollinating insects, including effects of herbicide applications for habitat restoration, pesticide exposure to native bees found in CRP landscapes (Hladik *et al.* 2014), and effects of pesticides on butterflies from exposure related to mosquito control.

2. **Understanding the relation between sublethal effects (*e.g.*, subcellular, organ-level, behavioral) reported for individual bees and the effects (*i.e.*, impaired survival, growth, and reproduction) typically used by regulators to support quantitative risk assessments.**

- Evaluation of the ability to detect nervous system impairment due to exposure to neonicotinoids, and examination of the effects of overwintering stress on colony susceptibility to pesticides (Rinderer and Danka 2013). Research on how pesticides adversely affect bee physiological mechanisms and how expression of genes controlling pesticide detoxification provides insights into maintaining the health of migratory bee colonies.

- Evaluation of the effects of winter dormancy on detoxification enzymes (Johnson 2012), honey bee susceptibility to sub-lethal doses of pesticides and other chemicals (Stoner and Eitzer 2013), and the effects of pesticides on mating biology of queen honey bees and the benefits of within-hive genetic diversity (Rangel *et al.* 2012).
- Investigation of the effects of organic contaminants on reproductive and endocrine systems (Jenkins *et al.* 2014), and evaluation of systemic pesticides (*i.e.*, fipronil, thiamethoxam, and clothianidin) on behavior as well as blood, neuron, and sperm cell quality and function in honeybees.

3. Determining how pesticides interact with each other and other stressors (*e.g.*, poor nutrition/food quality, pest infestation, environmental conditions, etc.) to impact pollinator health.

- Research on the effects of pesticide mixtures and inert ingredients on bees, and evaluation of differential sensitivity of larval and adult worker bees to pesticides.
- Monitoring of health and performance of commercial bee colonies as they move through their pollination service cycles and are exposed to multiple pesticides/inerts. Residues measured in pollen will be compared to reported pesticide usage in areas where bees are used.
- Assessment of pesticide interaction with pollinators' pests/pathogens and nutrition stress.
- Evaluation of the effects of fungicides on honey bee metabolism and immunity. Evaluation of the exposure levels and effects of fungicides, insecticides, and adjuvants used for tree fruit and blueberry production on managed native (non-Apis) bees (bumble bees and blue orchard bees), including sublethal effects such as changes in nesting and foraging behavior and disease susceptibility (Pitts-Singer and Strange 2013).

4. Assessing effectiveness of mitigation measures (*e.g.*, BMPs).

- Identification of current actions and activities involving pesticide application intended to protect pollinators in three representative commercially-pollinated specialty crops (almonds, apples, and melons) and in one commodity crop (corn) (Wojcik *et al.* 2014).
- Monitoring of residues to evaluate how land management practices (*e.g.*, buffer strips, hedge rows) influence pesticide exposure, and developing guidelines for management of vector-borne diseases to minimize negative effects on pollinators (Ginsberg 2014).
- Collaboration with European counterparts to understand whether the temporary suspensions of some neonicotinoid uses by the European Commission are having an effect on pollinator populations within the European Union (EU). Several countries within the EU have had monitoring studies in place for multiple years and have sufficient baseline information with which to compare more recent data collected subsequent to the suspensions.

5. **Identifying effective chemical, mechanical, and managerial tools that can be developed for combatting arthropod pests of managed bees.**

- Monitoring and identification of factors affecting Varroa population growth in commercial and noncommercial colonies to determine the effects of miticides and/or agricultural chemicals on queen health and sperm viability, and to define sublethal pesticide effects against all castes and life stages of bees.
- Research examining the efficacy of insect growth regulators (IGRs) in the control of small hive beetles through inclusion in supplemental bee protein diets (Rennich *et al.* 2012), and developing genomic tools for examining the susceptibilities of non-target species to pesticides, with case studies for neonicotinoids and IGRs. This technology may prove to be an effective means of screening pesticides for control of Varroa mites.

Research Gaps/Needs and Priority Actions

Research is necessary to address uncertainties regarding the extent to which pollinators may be exposed to pesticides (both singularly and in combination), the effects of such exposures, whether suitable measures can be developed to reduce exposure, and characterization of the relationship between sublethal effects reported at the individual level to impacts at the colony or population level.

Priority Actions:

- Develop appropriate assessment tools for sublethal effects of pesticides, adjuvants, and combinations of pesticides with other products on the fitness, development, and survival of managed and wild pollinators (EPA OPP).
- Add features to existing population models to improve in-field predictive power, including incorporating sensitivity to pesticides. Models should predict colony (social bees) and/or offspring survival (solitary bees) to support the further development of *a priori* hypothesis testing in advance of the deployment of extensive, and expensive, empirical investigations (EPA OPP/ORD; USDA ARS).
- Determine field-level exposure rates to managed pollinators in commercial operations, and perform field and laboratory evaluations of the effects of such exposures on managed and wild pollinators (EPA OPP).
- Determine routes of field exposure of bees to pesticides from seed treatments by evaluating pollen, nectar, nesting materials (leaf pieces and soil), and plant fluids containing pesticide residues that are transported by adult bees and that contaminate larval provisions and nest cells (USDA ARS).
- Determine the absorption, distribution, metabolism, and excretion (ADME) of agriculturally-relevant chemicals and xenobiotics in Apis and non-Apis pollinators (USDA; USGS).

Agency Roles

Priority Actions	Lead Agencies	Primary Support	Secondary Support	Comments
Develop appropriate assessment tools for sublethal effects.	EPA OPP			
Add features to existing population models.	EPA OPP/ORD and USDA ARS			
Determine field-level exposure rates to managed pollinators.	EPA OPP			
Determine routes of field exposure of bees to pesticides.	USDA ARS			
Determine the absorption, distribution, metabolism, and excretion (ADME) of agriculturally-relevant chemicals and xenobiotics.	USDA; USGS			

Section VI: Genetics, Breeding, and Biology

Leads: Tom Rinderer (USDA-ARS), Bob Danka (USDA-ARS), Michelle Elekonich (NSF)

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Introduction/Problem Statement

Developing hazard-resistant stocks of pollinators can help alleviate their reduced availability. USDA research has produced two stocks that are resistant to Varroa: Russian honey bees and those exhibiting Varroa-Sensitive Hygiene (VSH) (Rinderer *et al.* 2010). Current efforts use prior knowledge of stock-specific resistance to improve selection methods and develop novel resistance traits. Additionally, molecular markers are being developed for marker-assisted selection of bees with VSH and other resistance traits. Combining selection for resistance with selection for honey production and general vigor will improve bee health, particularly in environments with multiple stressors.

Development of selected honey bee stocks leads to a need for germplasm conservation. Unlike the vast majority of other domesticated species, there is no organized germplasm repository for the honey bee (Hopkins *et al.* 2012). Hence, the development of protocols that support the creation of a National Honey Bee Germplasm Repository is critical.

Key Priority Research Themes

1. **Genetics and breeding of honey bees resistant to Varroa destructor.** The USDA held a "Varroa Summit" in February 2014 and identified the following research priorities: develop simplified resistance measurement tools, select and identify key mechanisms of resistance (VSH, grooming, and non-reproduction are high priority), characterize genetic architecture and heritability, and test for variation in mite virulence. Overcoming the challenges of transferring the products of breeding was also highlighted. Meeting these research and technology transfer needs will enable beekeepers to manage Varroa effectively, while reducing reliance on miticides and the attendant problems of acaricide-resistant mites, high costs of treatment, and the threat of chemical contamination of hive products.

2. **Genetics, breeding, and biology of honey bees to mitigate hazards other than Varroa.** Numerous parasites, pests, and pathogens negatively affect the strength and survival of honey bee colonies. Significant effort is needed to develop new resistance traits, with priorities for *Nosema ceranae*, deformed wing virus, and combined resistance to multiple pests and pathogens. Improved molecular technologies and information, including the genome sequences of the honey bee (Honeybee Genome Sequencing Consortium 2006) and Varroa, open new avenues for marker-assisted selection.

3. **Establishment of a National Honey Bee Germplasm Repository.** Three issues must be addressed to establish a repository: (1) develop an improved sperm cryopreservation proto-

col, (2) develop a protocol for the cryopreservation of honey bee embryos, and (3) develop a cryogenically-based system for the safe importation of honey bee germplasm.

4. **Genetics and breeding of native (non-Apis) bees to enhance health and pollination ability.** To understand the causes of declines in both wild and managed bee species, it is imperative to understand first the relation of population genetic structure and species vulnerabilities to environmental disturbances. Identifying evolutionarily significant units of species and differential susceptibility to stresses is necessary for initiating breeding regimes in captivity. Selection and breeding in managed species for disease resistance and other management traits, such as physiological adaptations to diverse climates, are needed. There is a need for molecular systematic studies of native bees to support the taxonomic needs of the broader research community.

Existing/Current Research

1. **Genetics and breeding of honey bees resistant to *Varroa destructor*.**

- USDA has developed basic and applied information about breeding Varroa-resistant bees and has developed and released two resistant types of bees to industry: Russian honey bees and honey bees with the Varroa Sensitive Hygiene (VSH) trait.
- USDA has ongoing collaboration with an industry group to select Russian honey bees to maintain the stock and to improve Varroa resistance and honey production. In addition, USDA is breeding and selecting for VSH-based resistance in commercial populations, and plans to continue refining the population.
- USDA is conducting further selection of VSH bees in large-scale, migratory beekeeping operations to enhance general fitness and beekeeping functionality of the population.
- USDA is seeking simpler selection tools for VSH because the trait is technically challenging to measure. Potential tools include the stimuli that elicit the behavior and molecular markers to support marker-assisted selection.
- USDA also is evaluating new potential Varroa-resistance traits.

2. **Genetics, breeding and biology of honey bees to mitigate hazards other than Varroa.**

- USDA is capitalizing on known patriline-based variation to produce lines with differential susceptibility to Nosema to develop a resistant line of honey bees.
- USDA is selecting for bees with resistance to deformed wing virus through stock screening and line-based selection. USDA is also determining the genetic basis of resistance or tolerance through genomic marker identification, and differential expression analysis at both transcriptomic and proteomic levels.
- USDA will collect genomic information from honey bee stocks used in research and breeding programs. The new set of genomic sequences will lead to customized in-house markers for mapping, analysis of differential allele frequencies or identification of rare alleles present among stocks, and comparison of genomic structure (gene order and gene copy number) among stocks.

3. Establishment of a National Honey Bee Germplasm Repository.

- USDA is developing protocols for improved spermatozoa and embryonic cryopreservation to overcome limits of current technology (Harbo 1977; Hopkins *et al.* 2012).

4. Genetics and breeding of native (non-Apis) bees to enhance health and pollination ability.

- USDA is developing molecular tools for studies of managed and wild bee species (the alfalfa leaf-cutter bee, the alkali bee, the blue orchard bee, and several bumble bee species).
- USDA is investigating the genetics of immune response in bees. USGS and NSF-supported researchers are investigating the structure of immune response pathways to understand commonalities in how bees respond to pathogens.
- USDA is studying the population genetic structure of bumble bee species, blue orchard bees, and alfalfa leaf-cutter bees to understand the effects of mass rearing and movement of bees on wild bee populations. Special focus is placed on understanding the degree of gene flow from domesticated stocks into wild bees, and its impact on the health of wild populations.
- Few native bee genomes have been sequenced. The genome of the halictid bee *Lasioglossum albipes* recently has been sequenced with support from NSF.

Research Gaps/Needs and Priority Actions

1. Develop simplified tools to enhance selection of Varroa-resistant bees.

- **Priority Actions:** Tools should include methods to measure resistance based on phenotypes and molecular-marker-assisted selection to enable selection based on genotypes, proteomes, etc. Characterize Varroa resistance mechanisms in honey bees and ways to measure them. Research on mechanisms would benefit from research on Varroa-resistance in *Apis cerana*.

2. Improve acceptability and adoption of Varroa-resistant bees.

- **Priority Actions:** Researchers should engage in breeding in close partnership with commercial beekeepers and bee breeders, whose participation provides guidance for commercial acceptability, serves as the foundation for education among beekeepers, and will increase buy-in to new technology. A future opportunity could employ USDA-funded "Tech Transfer Teams" to help bee breeders select for Varroa resistance.

3. Genomic sequencing of multiple honey bee stocks.

- **Priority Actions:** The single honey bee that was initially sequenced and made publically available was derived from a colony that exhibited VSH. However, many other economically important stocks of honey bees are used as research sources due to their specific economically valuable traits, and researchers would benefit from their genomic information to allow more effective marker-assisted selection.

4. **Develop technologies and allocate existing infrastructure for a National Honey Bee Germplasm Repository.**

- **Priority Actions:** Supporting technologies can be developed by USDA, beginning with genetically diverse strains identified by collaborators at Washington State University and elite breeding strains selected by the USDA. The resulting collection can be housed and curated by the USDA ARS-managed National Animal Germplasm Program, which curates similar collections in accord with an FAO global plan (FAO 2007). The cryopreservation of honey bee sperm requires refinement to increase the quality after storage, and protocols to assess sperm quality. An embryonic honey bee cryopreservation protocol is needed.

5. **Develop molecular markers for native (non-Apis) managed species.** Currently, research in multiple areas, including studies of disease, decline, phylogenies, and management is hindered by the lack of molecular tools. Reference genetic data are not available for most species of native bees that are of interest for domestication. Thus, little is known about the variability that exists in nature and our ability to select from various traits during the development of native bee pollinators.

Agency Roles

Priority Actions	Lead Agencies	Primary Support	Secondary Support	Comments
Varroa	ARS	NIFA	NSF, APHIS	
Other	ARS	NIFA	NSF	
Germplasm	ARS	USGS	NIFA	
Non-Apis bees	ARS	NIFA	NSF	

Section VII: Native Plant Development and Deployment

Leads: Jessica Wright (USDA-FS), Kas Dumroese (USDA-FS)

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Introduction/Problem Statement

Native plant materials are needed to create, enhance, or restore pollinator habitat. They provide critical foraging and breeding areas for wild and managed pollinator species, including transnational migratory species such as hummingbirds and monarch butterflies. Although many pollinators and plants are generalists, some have limited, obligate relationships (*i.e.*, one requires the other for survival) (Proctor 1996). While reproduction and propagation information is available for many commercially important plant species, this information is lacking for most native species. Commercially available native plant seed has typically gone through a selection process for particular genetic traits (USDA-NRCS 2014a), often for agricultural and production purposes. Sometimes these selections have been sold and planted across the country without regard to their origin. Today, Federal land-managing agencies are the largest purchasers of native plant seeds (US Government 2014), chiefly for native plant community restoration. Because Federal mandates require consideration of the conservation of native plant communities commensurate with multiuse management (Richards *et al.* 1998), plant community integrity, function, genetic diversity, and stability are paramount considerations when selecting plant materials for restoration purposes (Johnson *et al.* 2010). Native plants are adapted to their local conditions, but they can be moved by using seed transfer guidelines with good promise of establishment and persistence (Bower *et al.* 2014). For most native plant species, however, because we know neither the limits to genetic adaptability nor their specific seed transfer guidelines, provisional zones can be applied until better data are available (Bower *et al.* 2014).

Key Priority Research Themes

Although developing and deploying native plant materials specifically to sustain pollinators are emerging needs, many Federal programs and projects already include these topics as parts of an overarching, general strategy for habitat creation, enhancement, and restoration. Native plant communities provide critical ecosystem services (*e.g.*, clean water and economic activities such as ranching and recreation) and other benefits (*e.g.*, supporting sage-grouse and other wildlife).

Thus, existing knowledge and current projects should be leveraged to address these four priority research themes:

1. **Reproductive biology.** Identifying pollinator-plant associations and plant reproductive biology issues that should be considered when assembling native plant materials for habitat restoration.

2. **Native plant species mixtures.** Identifying local and regional native plant species mixtures that provide the best temporal support for the most pollinators now and under future climate scenarios.

3. **Propagation.** Identifying the most efficient propagation methods for native plants required by pollinators to ensure plant establishment, resilience, persistence, and genetic diversity within restored habitats.

4. **Establishment.** Identifying the most efficient, economic, and effective methods for the establishment and persistence of these plant mixtures in wildland, agricultural, and urban landscapes.

Existing/Current Research

1. **Reproductive biology.** Reports are available on general pollination requirements for some native plants, particularly those that are endangered (Tepedino *et al.* 1999) or have interesting specialized mechanisms (Lipow *et al.* 2002). Specific information about ecological and reproductive needs, community and pollination ecologies, and responses to wildfire and competition from exotic plants is available for fewer native species, and their responses to restoration and management techniques remain poorly understood. Current efforts are underway to complete or provide the information missing for prevalent native species, or for the ecotypes needed by diverse, valuable, native pollinators, in order to rehabilitate habitat in certain United States regions, such as the Great Basin (Cane 2008). Other regions have received less attention (Reed 1995).

2. **Native plant species mixtures.** Some research has been completed correlating pollinator populations with plant communities, as well as on the pollination needs of focal plants (Cane *et al.* 2013) and whether those needs are (or can) be met by pollinator populations in agricultural landscapes (*e.g.*, Cane 2011). While some excellent resources exist for promoting pollinator habitat on a small scale (such as Mader *et al.* 2011), completed and current research on practical plant species mixtures for native plant community restoration at larger scales is lacking. For instance, the two native species seeded most commonly because of their low cost and successful establishment in the Great Basin are proving unattractive to native bees (Cane and Love, unpublished data).

3. **Propagation.** Much research exists for general seed collection, increase, storage, and certification (*e.g.*, USDA-NRCS 2014b). General plant propagation techniques (Dumroese *et al.* 2008), and specific information on native plants, albeit limited, continue to be developed (*e.g.*, Borders and Lee-Mäder 2014). Although the appropriate seed-transfer guidelines are known for most commercial tree species (see Wright 2014), this information is lacking for all but a few other native plants. Provisional seed-transfer zones for all native plants, based on ecoregions and current climates, have been proposed (Bower *et al.* 2014). Putting seed into suitable habitats/climates enhances chances for success.

4. **Establishment.** Much research has been completed for seeding and planting restoration sites, but these generally involve limited species compositions and can be prone to failures, especially on harsh or competitive sites (Knutson *et al.* 2014). Some work evaluates optimal seeding depths for a few native forbs (Rawlins *et al.* 2009). More recent work has begun to evaluate novel

techniques (*e.g.* Herron *et al.* 2013) and combinations of techniques, which are particularly needed for reliable establishment and persistence of native plants on restored sites (Steinfeld *et al.* 2007). Researchers are determining proper plant material transfer guidelines (Bower *et al.* 2014) and discussing how these may be adjusted to meet future climatic conditions (Williams and Dumroese 2013). Research continues on pollinator community response to restoration (Cane and Neff 2011).

Research Gaps/Needs

1. **Reproductive biology.** A better understanding is required of the spatial and temporal relationships of native plants and their pollinators, especially in areas identified as critical for pollinators. Investigating large-scale (transnational and nationwide) and small-scale (landscape-level) relations between plant and pollinator distributions will help determine where specific plant species are appropriate, and elucidate which species are "broad-spectrum" (appropriate in many locations and contexts and for many pollinators) and "specialist" (appropriate to support one or a few obligate pollinators). Documenting the phenology of plant-pollinator interactions in high-priority settings, and how those may be influenced by, for example, invasive species and changes in climate, will help ensure that resilient plant species mixtures provide resources critical to pollinators throughout all life stages of species in the pollinator community.

2. **Native plant species mixtures.** Information is needed to assemble sustainable, context-appropriate plant mixtures that ensure the availability of seasonal, essential needs of all life stages of targeted pollinators locally and regionally, including species that migrate transnationally. Most native bees are highly seasonal and feed their larvae specific ratios of nectar and particular kinds of pollen. Research is needed to identify (a) plant species that are compatible with each other and complementary in the resources they provide for pollinators, (b) critical site conditions (*e.g.*, soil type, aspect, elevation, level of degradation) in which different mixtures are needed to assure success within wildland, agricultural, and urban landscapes, (c) individual and population genetic characteristics critical for perpetuating resilient pollinator support, and (d) spatial distribution of plant species' genetic variants for delineating seed-transfer guidelines under current and future climate scenarios.

3. **Propagation.** There is an essential need for information about the propagation of native plants. Research is needed to identify cost-effective means for properly collecting, processing, storing, and germinating seeds of high-priority plants, and for growing these plants for large-scale seed or seedling production. Different and/or multiple techniques will likely be needed and practical to conserve genetic diversity within species, establish an array of important pollinator plants, and provide efficient and economically-feasible strategies to address appropriate restoration of pollinator habitat in wildland, agricultural, and urban landscapes.

4. **Establishment.** Site properties, plant propagation quality, and the scale of the habitat to be created, enhanced, or restored should influence the type and mix of plant materials used. We require new concepts and techniques—which may include novel combinations of existing techniques—for establishing the broad palette of plants required for pollinator habitat

restoration at different spatial scales across diverse regions to address variable levels of site degradation. Understanding how best to deploy those materials spatially and temporally is imperative, especially for recovery of habitats within wildlands and at the wildland/agriculture interface, reflecting Federal mandates to ensure species and genetic diversity. Research is needed to compare the cost and effectiveness of establishment techniques for high-priority species mixtures to identify optimal establishment techniques for different species, mixtures, and settings. Projects should span several years to monitor the full impact of different seed mixes on pollinator species as the restored communities mature.

Priority Actions

Priority Actions 1 and 2 summarize the existing state of knowledge of the relationship between native plants and pollinators, and catalog the current status of available native plant materials that benefit pollinators. This foundation allows Action 3 to assess gaps to determine priorities for future research in pollinator plant development. Based on the gaps and priorities, Action 4 begins the process of enhancing the available inventory of native plant species for wildland, agricultural, and urban use. Finally, Action 5 establishes a mechanism to assess long-term success of native plant development and deployment. The scope, timeframes, and outcomes of all priority actions are contingent on available resources and staffing.

1. **Synthesize existing science** to identify geographic, taxonomic, ecological, and temporal gaps in knowledge of which plant species provide broad-spectrum pollinator support. This action will help ensure land-managers can make sound science-based decisions now, and help enable scientists to focus new research most effectively.

- **Strategy:** Identify existing science capacity to develop an inter-agency synthesis document. Subdivide pertinent areas among agencies based on specialties/expertise (*e.g.*, ARS: pollinators; NRCS: seed increase; USFS: genetic conservation).
- **Timeframe:** 2 years.
- **Metric:** Document(s) summarizing best available science for land managers to implement and critical knowledge gaps to be addressed.
- **Future opportunities:** Develop and maintain a national, on-line clearinghouse for "best restoration science and practice" with emphasis on pollinators.

2. **Develop a science-based plant selection decision support tool** to assist land managers in appropriate deployment of the most effective and affordable plant materials currently commercially available for pollinator habitat in wildland, agricultural, or urban areas. These materials may be named cultivars or germplasm or local selections, and their appropriate use determined by management objectives.

- **Strategy:** Identify existing science capacity to produce a decision-support tool.
- **Timeframe:** 2–3 years.

- **Metric:** A decision-support tool that land managers can use to select appropriate available plant materials for improving pollinator habitat in their restoration projects.

3. **Systematically address important science and resource gaps,** using knowledge from Actions 1 and 2, concerning the Priority Research Themes to inform future priorities for development and deployment of locally-adapted, pollinator-friendly, native plant materials suitable for wildland, agricultural, and urban landscapes.

- **Strategy:** Identify existing science capacity to combine the results of the science synthesis with the plant section decision-support tool to determine where geographical and/or ecological gaps exist in either knowledge or seed resources available for restoring particular habitat.
- **Timeframe:** 3 years.
- **Metric:** Knowledge and resource gaps identified to inform future research and seed mix development priorities.

4. **Initiate work on additional, critical native plant species needed specifically to restore and enhance pollinator habitat,** leveraging Action 3. This four-step process follows the Priority Research Themes and adds native plant species to those currently available as described in Action 2. Progress on this action item will be commensurate with the amount of available funding.

   I. Develop comprehensive knowledge of specific native plant-pollinator species' reproductive biology (*e.g.*, "broad-spectrum" and/or threatened and endangered species) for wildland, agricultural, and urban settings.

   II. Identify resilient, self-sustaining native plant species mixtures for public lands and plant species mixtures appropriate for private lands of important pollinator-appropriate native plants, and determine appropriate seed transfer guidelines.

   III. Discover information about the propagation of these plant species, especially annual plants, as it pertains to seed collection, processing, storage, germination, and increase. Many native plants are difficult to propagate. Thus it is likely that research is required to increase their availability for use.

   IV. Identify and develop novel outplanting techniques to increase the efficient, economic, and efficacious establishment of selected native plant materials, particularly as site degradation increases. Native plants have an immense variety of establishment requirements. Thus, ensuring that all species within desired mixtures are present after restoration likely will require novel and integrated methods.

- **Strategy:** Leverage existing Federal and NGO/private industry knowledge to expand the currently-available native plant palette through the four steps outlined above.
- **Timeframe:** 10 years.
- **Metric:** For key habitat restoration priorities: expanded knowledge of the reproductive biology of key plant-pollinator species associations, quantified seed mixtures, with sound transfer guidelines and reliable techniques for seed propagation and establishment for those mixes.

5. **Develop a system for monitoring deployment of native plant materials.** We currently lack a mechanism for tracking deployment of native plants, the long-term success of those deployments, and their benefit(s) to pollinators on Federally-managed (*e.g.*, BLM, USFS, USFWS) and Federally-subsidized (*e.g.*, CRP, EQIP) restoration projects. This missed opportunity to assess success and failure condemns land managers to repeat the same mistakes.

- **Strategy:** Develop an interagency, online, searchable database based on the USGS Land Treatment Digital Library to collect and analyze relevant data efficiently (species, plant material type, location, acreage, year, establishment, impacts on pollinators, etc.) to evaluate the developed and deployed native plant materials.
- **Timeframe:** 2 years.
- **Metric:** An online database available to land managers and researchers.

Agency Roles

The USDA and DOI are members of the Plant Conservation Alliance (PCA), a collaborative partnership among 12 Federal agencies and almost 300 non-Federal cooperators. PCA, through its proposed Interagency Seed Strategy, proposes similar research work. Research coordinated through the PCA framework could ensure focus, optimization of resources, and enhance dissemination of results. The following USDA/DOI agencies could provide collaborative leadership within PCA to address the five priority actions described above:

Priority Action 1: ARS, USFS, USGS

Priority Action 2: ARS, USGS, NRCS

Priority Action 3: BLM, ARS, USGS, USFS, NRCS

Priority Action 4: USFS, NRCS, BLM, USGS, NSF

Priority Action 5: USFS, NRCS, USGS, BLM, ARS

Section VIII: Economics

Leads: Mark Jekanowski (USDA-ERS), Jennifer Bond (USDA-ERS), Carl Shapiro (DOI-USGS)

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Introduction/Problem Statement

Until recently, there was relatively little economics research focusing on pollinator health issues. Growing awareness of the complex interactions underlying increased hive mortality, coupled with concern about dietary consequences and environmental implications, underscores the need to improve understanding of the economic and social costs and benefits of pollinator health challenges and proposed solutions.

Key Priority Research Themes

The major economics themes and research questions currently being addressed by the Federal government and through public-private partnerships include the following:

1. **Economic value: Estimating the direct and indirect economic values and impacts of pollinators to the United States.** What direct and indirect economic and social values do wild and managed pollinators contribute to the U.S. economy? What are the associated local, regional, and national economic impacts, including job creation, income, and sales that stem from various segments of the pollination service, bee supply, and honey, pollen, and wax production markets? Who has an economic incentive to promote pollinator health and what are the magnitudes of those incentives?
2. **Social welfare: Determination of the social values and costs of changes in the availability of pollinators.** How do changes in the health and availability of honey bees affect food prices and food availability? What kinds of ecosystem services do pollinators provide and what is their social value? What social costs are associated with pollinator protection?
3. **Adaptive management: Application of adaptive management techniques to conservation program management.** How can pollinator health outcomes and the state of the science be improved through the application of adaptive management tools to beekeeping, land management, and conservation program practices?
4. **Habitat enhancement: Assessment of availability of forage resources, habitat requirements, and pollinator support.** What is the current availability and quality of pollinator forage resources and other habitat requirements, such as nesting sites? Are current forage programs effective in supporting pollinator health and increasing related ecosystem services? What are the economic trades offs associated with customizing seed mixes?
5. **Pesticides: Determining a method of valuing pollinator health in the context of pesticide regulation.** How should changes in pollinator health be accounted for within the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) risk-benefit framework that is used in

pesticide registration and registration review programs? What are the economic impacts of changes in pesticide use on land managers and consumers, and what mechanisms exist to mitigate increased costs?

Existing/Current Research

1. **Economic value.** A recently-submitted Report to Congress on the economic value of honey bees in the United States and supporting articles focused on the pollination services and honey sectors have addressed research questions under this theme. Complementary work related to the economic impact of the pollination services sector, for select geographic locations and for the United States as a whole, is being developed.

2. **Social welfare.** A 3-year project analyzing the impacts of variations in honey bee health and availability on social welfare has recently begun and involves collaborations with Montana State University and North Carolina State University. This project assesses how honey bee dynamics impact food prices, taking into account changing production patterns for almonds, other tree nuts, and vegetables that have augmented demand for pollination services.

   Research on the yield and economic impacts associated with the use of alternatives to honey bees as managed pollinators is also underway. Pollinator foraging and hive survivability data are being gathered from the North Dakota Prairie Pothole Region and will be used to infer the magnitude of pollination services that support ecosystem services and their value (largely nonmarket benefits) to society.

3. **Adaptive management.** Adaptive management strategies are being applied to identify affordable and appropriate pollinator-friendly seed mixes for use on lands enrolled in the Environmental Quality Incentives Program and grassland enrolled in the Conservation Reserve Program (CRP).

4. **Habitat enhancement.** A multiagency research team is addressing research questions included in this theme by conducting analyses of linkages between targeted land management practices, CRP forage habitat and honey bee use of this habitat, productivity, and health. Partnerships with several land-grant universities have been funded with the goal of comparing the health of honey bees and native pollinators that forage on cropland, lands participating in the CRP CP-42 Pollinator Habitat Initiative, and CRP lands without CP-42.

5. **Pesticides.** This theme addresses how Federal agencies can best account for the impacts of changes in pollinator health within the FIFRA risk-benefit framework that is used in pesticide registration and registration review programs. Agencies are developing methodologies that can be used to estimate the benefits and costs associated with changes in pesticide use aimed at enhancing pollinator health in agricultural settings. These methodologies will be used in economic analyses conducted as part of pesticide regulatory activities.

   Further, social scientists at many Federal agencies, including the USDA-ERS, USDA-FSA, USGS, USACE, and EPA, have economics research underway or planned that is focused on a wide range of pollinator-related issues, including improving the understanding of trade-offs in management practices, and evaluating relations among various environmental and management variables.

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) assessment on pollination, pollinators, and food production, due out in 2015, will also address monetary and nonmonetary ecosystem services provided by pollinators across the world.

Research Gaps/Needs and Priority Actions

Regarding research needs, data limitations are noted, and priority actions are predicated on having access to data gathered from two proposed NASS Colony Loss Surveys and an ARS-led longitudinal study of honey bee colony health, among other data sources.

1. **Determination of environmental impacts on pollinator health.** Economists regularly use dynamic, spatial, and bioeconomic statistical models to investigate complex systems and relationships over time and space. Applications of these tools to knowledge gaps for pollinator disease, pest loads, and environmental considerations such as pollinator migration, agricultural chemical exposure, and other stressors have been limited and are required in order to synthesize data collected from multiple disciplines and prepare holistic analyses.

- **Priority Actions:** The roles of access to enhanced forage (on CRP and non-CRP land), provision of pollination services, and treatment for pests and diseases will be evaluated relative to colony numbers and overwinter survivability via application of spatial bioeconomic modeling techniques.

2. **Evaluation of agricultural practices on pollinator health.** Current work that links land management practices and pollinator health is limited in geographic scope and largely focused on honey bees. This work needs to be expanded to include wider geographic coverage and other pollinators, including native species. Information on the costs and benefits to crop producers of adopting pollinator-friendly practices is critical but also lacking. An expansion of efforts to assess the availability and feasibility of substitutes for commercial pollination, such as development of self-pollinating cultivars, application of nanotechnology, and hand pollination is also needed.

- **Priority Actions:** Using costs of pollination services data and data gathered from a longitudinal study of pollinator health and migration, this research will build on an existing, though limited, land management project to examine relationships between pollinator health outcomes and the use of buffer zones and tailored forage seed mixes, both on contract and non-contract lands. Efforts should be made to quantify both private and social benefits and costs that are likely to stem from increased utilization of conservation practices.

3. **Economic assessment of beekeeper management practices.** While the biological sciences have advanced studies linking beekeeper management practices such as miticide and fungicide application, supplement feeding, and other practices to pollinator health, there is little information on the economic costs and benefits of such actions. Further, unlike crop and other livestock producers, beekeepers often lack access to applicable enterprise budgets, feasibility studies, and industry-specific financial benchmarks. It is also not clear whether current financial risk management tools, such as insurance products, are widely available and well-suited to modern apiary needs.

- **Priority Actions:** With input from beekeepers and USDA-RMA, the current suit of risk management tools available to beekeepers will be summarized. The limitations of current products will be identified and beekeeper input sought on improvements to available insurance products.

Agency Roles

Identified lead and support agencies are largely assigned on the basis of previous experience and potential capacity. Ability to conduct research will depend on resource availability, mission, and research priorities of individual Federal agencies.

Priority Actions	Lead Agencies	Primary Support	Secondary Support
Environmental impacts	ERS	FSA, ARS	EPA, USDA-NASS, USGS
Agricultural practices	FSA	ARS, USGS, ERS,	NRCS, EPA
Beekeeper management	ERS	USDA-RMA	FSA

Section IX: Collections and Informatics

Lead: Gary Krupnick (SI)

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Introduction/Problem Statement

Object-based scientific collections and their associated digital data are invaluable components of the Federal government's and the Nation's research infrastructure. Systematics collections are created and maintained because they provide permanent vouchers for past and ongoing research, are usually the basis for the only data available on the past status of pollinators and their associated plants, are always the final check for the difficult process of identifying species (insects in particular) and/or detecting the diseases, pathogens, and parasites they carried at the time of collection, and are often a storehouse of molecular, genetic, and isotopic information. In some instances, literature related to historical collections is the only evidence of species occurrence data remaining after specimens have deteriorated or been destroyed. Biological collections can also have unanticipated relevance to research being conducted in fields other than the one for which they were collected, and are often reanalyzed by using new instruments and techniques, providing new data from old specimens. Collections provide irreplaceable evidence of long-term historical trends, which also forms the basis for predictive research.

The data associated with specimens in a collection must be made more readily available through specimen digitization (both photographs and metadata), adoption of data standards, and the creation and indexing of metadata about each collection. High-quality, high-resolution or highly granular, georeferenced pollinator and plant species-occurrence data derived largely from specimen collections form the basis for species distribution modeling and for determining current or predicting future species occurrence and habitat requirements: especially in response to environmental disturbances such as invasive species, fire, habitat loss, climate change, and conservation and management treatments applied by resource and land managers.

Key Priority Research Themes

1. **Characterizing the extent of specimen collections and collections data of North American pollinators, associated plants (or relevant plant derivatives such as pollen, germplasm, etc.), and plant-pollinator associations.** Collections could be utilized to help understand the current decline of pollinating taxa and potential associated impacts on pollination-dependent species, if these collections were more available as datasets.
2. **Developing precise vouchering standards for studies that create genetic and genomic analyses of pollinators and their biotic threats.** Scientists make mistakes in species identifications. Taxonomy can change as groups are revised and new subspecies or unique populations are identified after genomic analysis is done. Thus, voucher specimens are needed to maintain the proper identification of the source of genetic material. Vouchering will also allow for long-

term sample preservation of nucleic acids for barcoding and sequencing projects, and isotopic and chemical analyses of migratory pollinators.

3. **Developing national genetic preservation resources for honey bees and other managed bees.** Though individual research groups are making progress on genome mapping, no national genetic preservation resource exists for honey bees or other bees. Genetic diversity is needed to maintain breeding programs that can help honey beekeepers deal with future invasive pests and climate changes. Similarly, a DNA and RNA sequence database is needed to enhance our scientific ability to identify gene function and the potential for breeding bees resistant to different environmental stresses.

Current Status

Federally-owned collections and collections datasets relevant to pollinators are currently housed at DOI, USDA, and Smithsonian Institution (SI) facilities and university partners' facilities throughout the United States; however, the degree to which these collections and associated historical collections literature have been digitized and standardized for integration with other datasets varies widely. The U.S. government's Federal Open Data Initiative, launched in 2013, offers an avenue through which Federal agencies are coordinating the cataloging and digitization of Federal collections data. Collaborative initiatives such as the Consortium of the Barcode of Life (CBOL), TraitBank (EOL), the Global Biodiversity Information Facility (GBIF), the EcoInformatics-based Open Resources and Machine Accessibility (EcoINFORMA) initiative, and other open-access data aggregators are encouraging the use of internationally-accepted data standards and procedures, and providing gateways for interactive data access. Similarly, complementary digitization efforts are being coordinated through national nongovernment networks, such as the U.S. Virtual Herbarium Network and regional Herbarium Consortia, the Southeast Regional Network of Expertise and Collections, and the National Science Foundation (NSF)-funded Advancing Digitization of Biodiversity Collections (ADBC) project.

Gaps/Needs and Priority Actions

1. **Digitize existing collections/mobilize data.** A better understanding is needed of pollinator and plant representation/gaps in Federal, state, university and private collections, their digital status in terms of photographs and metadata, and limited access to high quality/resolution specimen and literature-based collections/species occurrence data—especially those from longer-term, historical, continuous sampling efforts.

- **Priority Actions:** Identify and use existing cyber-infrastructure, tools, and expertise to support taxonomic identification and mobilization of Federal pollinator and associated plant collections and collections-related literature by continuing to digitize, standardize, and share high-quality, high-resolution, georeferenced data, including via the Internet. Focus digitization efforts on specimens from longer-term, continuous monitoring efforts and locations that have been intensively sampled. Establish interagency species-occurrence data sharing and use agreements. Encourage and enable agencies to publish pollinator and plant species occurrence data in a format appropriate for use by other agencies, non-Federal researchers, and the public through existing mechanisms such as the USGS Biodiversity Information Serving Our Nation (BISON), which provides a gateway for Federal collections data, GBIF, EOL TraitBank, or other open-access data aggregators. Enhance access to large non-Federal pollinator data, including host plant-pollinator association information collected and held by non-Federal organizations.

2. **Coordinate collecting.** Initiate new and coordinate existing Federal pollinator and plant specimen and observation-based species-occurrence data collection and curation efforts by identifying existing or developing new agency-approved standard protocols and tools for pollinator and plant specimen (including vouchers) and observation data collection, inventory, monitoring, digitization, and curation. Encourage partnerships with non-Federal entities, such as states, universities, and programs like Master Naturalists. Adopt policies that encourage research on Federal lands, such as making it easier to transfer ownership of specimens to non-Federal entities.

- **Priority Actions:** Develop guidance/best management practices for pollinator and plant specimen collection.

3. **Facilitate taxonomy/species identification.** Identify tools, expertise, and resources for facilitating the accurate identification and taxonomy of pollinators (especially insects, including immature life stages), for example, by producing taxonomic revisions of key pollinators, creating online identification tools/software, conducting training workshops, funding additional identification service positions (taxonomists) in agencies, and building voucher-based species DNA barcode libraries for target taxa (pollinators, major pests and predators (pathogens, parasites, viruses, etc.), and pollen). Develop a national genetic preservation resource for honey bees and other managed pollinating species and a centralized national long-term repository for field samples.

- **Priority Actions:** Ensure that pollinator DNA and RNA sequence datasets are preserved (with appropriate voucher systems), and create voucher-based DNA barcode libraries for taxonomic identification. Develop standard methods for creating vouchers for specimens used in nucleic acid sequencing and genomics studies.

Agency Roles

Priority Actions	Lead Agencies	Primary Support	Secondary Support	Comments
Digitize collections.	SI, Biodiversity Heritage Library			
Coordinate collecting.	USDA, USGS			
Facilitate taxonomy/ species identification.	USGS, Consortium for the Barcode of Life			

Section X: From Research to Application: Models, Tools and Best Practices

Leads: Mary Purcell-Miramontes (USDA-NIFA), Tom Moriarty (EPA-OPP)

Members: Gloria Hoffman (USDA-ARS), Kathryn Thomas (DOI-USGS), Steve McNulty (USDA-FS), Matt Thompson (USDA-FS), Eunice Padley (USDA-NRCS), Rosalind James (USDA-ARS), Jeff Pettis (USDA-ARS)

Introduction

Translating basic research into decision tools—and vetting those tools in real-world situations—is a critical component of improving pollinator health. Coordination among domestic research entities with a broad array of expertise, as well as participation in international activities such as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) inaugural assessment on "Pollinators, Pollination and Food Production", is necessary to synthesize data relevant to pollinator health into management tools applicable to the diverse needs and constraints of stakeholders.

Decision tools inform decision-making processes, and provide informational and analytical content upon which decisions will be based (Thompson *et al.* 2013). Formulating a common understanding of the problem to be addressed, identifying decision-makers and stakeholders, and establishing clear and measurable management objectives are first steps in applying decision tools. Decision-support tools are not decision-making tools, but ideally provide an improved informational basis upon which to base decisions. Uncertainties may remain, and decision-makers will also have to balance considerations like available resources, timelines, and competing objectives.

Examples of information needs by stakeholder group are outlined below:

Communities of Decision Makers with Concern for Pollination Services	Examples of Information Needs and Decisions
Agriculturalists: crop farmers	What government programs are available to develop bee habitat and forage? Where can I get seeds or plants for bee habitat? What plants should I grow? What plants should I use for bee forage? What pest control methods are safe for pollinators? Will planting pollinator habitat benefit me financially?
Beekeepers	Where can I get the best information on keeping bees? How do I identify diseases in my colonies? What plants provide nectar for honey? What plants are good pollen resources? How do I become a pollination service provider?
Citizen scientists, general public	What are pollination services and why do we need them? Are there ways I can help support pollination services?
Gardeners: urban and small vegetable gardening	What plants attract pollinators? What are the pollinators in my area? What plants are suitable to my area that attract pollinators?
Habitat managers: Federal, state, tribal, NGO managers of natural areas	How do I create high-quality pollinator habitats? How do I best plan restoration activities to protect and support pollinators? Do I manage areas that are important migration corridors for pollinators? What are my responsibilities to educate the public about pollinators and how do I fulfill those?
Horticultural consultants, landscape architects, extension specialists, Master Gardeners	Where do I get the most current information on pollinator needs and best practices to manage pollinators for my consultations? What plants should I use to create visually appealing pollinator habitat? What integrated pest management strategies work best for the recommended plants?

Communities of Decision Makers with Concern for Pollination Services	Examples of Information Needs and Decisions
Policy makers	What are the costs of providing pollination services? How do I get the best information on the adequacy of pollination services? What policies support pollination services?
Researchers	What pollinators occur in wild lands, managed lands, or on weeds? How do managed and unmanaged pollinators respond to biotic and environmental stressors such as fire, invasive species, disease, climate change, pesticides, and habitat fragmentation?
Teachers and other education providers	Where can I get curriculum materials on pollinators?
Utility and road managers	What are the best practices for supporting pollinators on my right-of-ways (RoW) and other managed areas? What plants are suitable for both pollination and our management constraints? How do pesticide applications affect surrounding crops, habitats, or gardens?

Current Decision Tools and Areas for Development

Various decision tools exist or are in development to address the wide variety of stakeholder needs. These tools perform several functions, from illuminating basic biological processes to helping land managers evaluate and mitigate risks from multiple stressors to pollinator health. Decision tools may be derived from various databases, information-sharing platforms, and research models, which may ultimately be formulated into a compendium of best management practices. Importantly, how this information is most effectively disseminated is critical to wide-scale adoption of practices to support pollinator health. Current and existing literature, as well as knowledge gaps for these kinds of decision tools, are covered in more detail below.

Databases and Information-Sharing Platforms

There are many Federally-supported databases that serve pollinator research objectives. These vary widely in the quantity of data they host. For example, the University of Maryland-led Bee Informed Partnership has been developing a honey bee health database that stores information collected by surveying beekeepers about the management practices they use and what practices are most effective. From those data, epidemiological methods are used to find trends towards better beekeeping practices that result in healthier honey bees. Other examples include the Consortium for the Barcode of Life, which houses genetic data for classifying organisms; Biodiversity Information Serving our Nation (BISON), which stores data on species occurrence/location; and Discover Life, which houses species lists, maps, and ID guides for a wide variety of organisms, including pollinators. The USA National Phenology Network (USA-NPN) is a platform for sharing data on phenological events for pollinators and plants such as leafing, flowering, reproduction of plants, and pollinator migration. In addition to supporting research directly, USA-NPN also assists resource-management decision-making through development of decision tools (*e.g.*, phenology "calendars" that assist planning of management activities).

For the monarch butterfly, USGS is working with Federal, academic, and NGO partners on a series of monarch-related (Eastern population) science activities in order to develop a geospatial decision support tool for monarch habitat restoration. Researchers are currently assembling various data layers into an ArcGIS online data server (https://usgs.maps.arcgis.com/home). This tool is being designed to guide the prioritization of restoration activities (*i.e.*, which lands and actions have the most potential benefit to monarch butterflies?). This approach will characterize the value of habitats for Eastern monarch populations based on demographic models and habitat value information. Data gaps exist for this tool, and the team is working to fill those gaps.

Information platforms are needed for the human dimension of putting the results from pollinator research into practice as well. An information-sharing platform for social scientists, researchers, and extension specialists has the potential to guide the refinement and future improvements on decision tools and best management practices. Sharing case studies that document the results of pollinator-related policy interventions, such as those drawn from around the world in a recent FAO Policy Analysis Paper, can also provide valuable insights.

Access to the scientific literature on pollination biology and pollinators is also an important resource for primary researchers, policy makers, and anyone interested in the ecosystem service of pollination. In partnership with a pollinator researcher, USGS has assisted in making a large (>11,700 citations) bibliographic database available on Mendeley, a free reference management software platform available online.

Models

Models are critical tools for synthesizing complex information and exploring novel combinations of stressors on pollinator health. Models have been useful in exploring the relationship between native bees and their habitats, including mapping shifts in historic ranges (*e.g.*, Cameron *et al.* 2011), and predicting how native bee abundance and biodiversity interacts with habitat to affect pollination services (Kremen *et al.* 2004; Lonsdorf *et al.* 2009; Jha and Kremen 2013; Kennedy et. al. 2013; Morales *et al.* 2013). Several models are available that predict climate-driven effects on pollinator abundance, species richness, and distribution and interactions with plants (Corbet *et al.* 1993; Kaiser-Bunbury *et al.* 2010; Vanbergen *et al.* 2013; Faagen *et al.* 2014). Conceptual models have been developed to explore the effects of land-use change on pollinators (Kremen *et al.* 2007), while other models have dug deeper into the impacts of specific land-use changes on pollinator communities in a given region (Priess *et al.* 2007, Ricketts *et al.* 2008).

Models can also help explore the dynamics within a honey bee hive. By inputting hive weight data into a model, researchers can model colony growth and survival (Meikle *et al.* 2006, 2008). Researchers have investigated the impacts of parasites (*e.g.*, Fries *et al.* 1994; Boot *et al.* 1995; Martin 1998; Calais et. Al.1999; Wilkinson and Smith 2002; DeGrandi-Hoffman and Curry 2004) and pesticides (Thompson *et al.* 2005; Thompson and Maus 2007; Henry *et al.* 2012; Cresswell and Thompson 2012) on colony size and behavior by using models. Using models of parasite populations, researchers can determine thresholds for effective treatment and control of those parasites (Strange and Sheppard 2001; DeGrandi-Hoffman *et al.* 2014). Combining hive and habitat models, the honey bee model BEEHAVE integrates colony dynamics, mite population dynamics, epidemiology of mite-transmitted viruses, and habitat structure to explore interacting impacts on honey bee health (Becher *et al.* 2014).

Better knowledge of the factors affecting pollinator health and improved methodologies open opportunities to improve models and increase understanding of the system. Four areas that would benefit from expanded investment in modeling are: (1) integrated models that address multifactorial impacts on pollinators, (2) spatial models of plant and pollinator habitat applicable to restoration activities and for protection of pollinator migration corridors, (3) agent-based approaches that elucidate how pollinators interact with the landscape and how they respond to complex environmental drivers, and (4) predictive models of how the changing climate may affect pollinators and their forage/nutritional resources.

Best Management Practices

Land managers and beekeepers need actionable recommendations that are specific to their management goals, geographic locations, and capabilities. Integrating natural and social science research can produce best management practices for a variety of user needs. In response to the Presidential Memorandum on pollinator health, Federal agencies are developing a set of best management practices for promoting pollinators on Federal lands. Additional efforts are targeting the needs of private land owners. For example, two USDA-funded Coordinated Agricultural Projects (CAPs) provide resources to beekeepers and land managers who are concerned about sustaining pollinator health. The first was the University of Georgia-led Managed Bee CAP, which, among several research objectives, established a virtual Community of Practice on bee health (CoP). This CoP is a group of university experts in apiculture and pollinator conservation, which arose out of the National eXtension initiative (http://about.extension.org/foundation/). In collaboration with the nonprofit organization Project Apis m., the CoP populated a Web site with the most current literature on best management practices for managed bees.

The second example is the Integrated Crop Pollination Project (ICP). The ICP is developing decision frameworks and models to design forage habitats for managed and unmanaged pollinators in specialty crops. The team is conducting research to develop BMPs to manage forage habitat that incorporates plant species choices, consideration of plant and pollinator phenology, and cost-benefit scenarios of different strategies. Future work can expand the ICP model to a more diverse array of land uses and target specific pollinator species.

Information Dissemination

Practical and efficient mechanisms are required for disseminating information to stakeholders. Multiple forms of information delivery may be needed to assist different user communities in making better decisions. The Land-Grant University Cooperative Extension System provides science-based decision tools for improving pollinator health via educational workshops, websites, and technical guidance and training for farmers, beekeepers, and the general public. Similarly, the USDA's Natural Resources Conservation Service and Farm Service Agency offer technical guidance and financial support to private landowners and tribes to improve habitat for pollinators.

The Managed Bee CAP's Web site provides information on various topics relevant to managing honey bees, such as "Genetic Tool Kits" to diagnose diseases of honey bees. Similarly, the ICP project provides a list of tools and resources for managers and is conducting research on optimal delivery of information and measuring the level of adoption of decision tools by users.

The private sector also plays an important role in transmitting information to help protect pollinators from stressors and recommended measures to support pollinator populations. For example, labels on pesticide products communicate both mandatory and precautionary measures established by EPA to guide pesticide users on ways to minimize potential adverse effects to pollinators. Drawing on recommendations from pollinator-promoting non-governmental organizations, various horticultural nurseries have marketed particular plant species as attractive to pollinator species or recommend combinations of plants to create habitats that support a diverse array of pollinators.

Equally important information resources for improving pollinator health are distributed across government, university, non-profit organizations, and private sources (Appendix A). While many tools are available for assessing, maintaining, or improving pollinator health, gaps still exist in transferring this information in a user-friendly way to a wide audience of users. Public and private partners should be engaged on needed background research to determine the feasibility of creating a centralized Web-based location to ensure delivery and long-term maintenance of well-vetted decision tools and best management practices for pollinators. Existing resources, like the Web-based eXtension Communities of Practice, the USDA's Integrated Pest Management Centers, and USDA Climate Hubs, could help fill this role.

Partnerships

The research needs outlined in this plan are broad, encompassing a range of complex biological factors, taxonomic groups, and societal implications. Clearly, no single entity is capable of executing the entirety of this plan. A collective effort among organizations and sectors is needed to make significant gains in pollinator health. The current science described in this plan benefits from numerous partnerships already in place, and future work will increasingly rely on intellectual, financial, and related partnerships.

Researchers from Federal, university, and private institutions have a long history of jointly conducting studies and authoring reports, contributing different aspects of knowledge and capabilities. The examples in this section provide an idea of the types of relationships that exist and can be built upon as Federal agencies work to implement this plan.

Research Coordination

Federal researchers are collaborating intellectually with multiple partners on a variety of practical and theoretical research activities, including programs to monitor bee health, agrochemical exposures, changes in pests and pathogens, and impacts of commercial migratory operations on pollinators, habitats, and ecosystem services. Activities include development of integrated pest management guidelines and best management practices, as well as outreach and education for beekeepers, agriculturalists requiring pollination services, and the public.

For example, the Integrated Crop Pollination Project, a pollinator enhancement project funded by the USDA Specialty Crop Research Initiative, brings together university and Federal researchers and NGO partners to work on habitat enhancement and monitoring of pollinators in agricultural landscapes to benefit America's farmers.

The Great Basin Native Plant Project and the Colorado Plateau Native Plant Program are two USFS and BLM efforts that coordinate research partnerships among more than 30 organizations within the Federal (*e.g.*, NRCS, ARS, USGS), state (*e.g.*, Utah Division of Wildlife Resources), university (*e.g.*, Brigham Young University, Texas Tech), and private (*e.g.*, Utah Crop Improvement Association) sectors to improve both the availability of native plant materials and the knowledge and technology required for their use in restoring diverse native plant communities.

The EPA and USDA-ERS are collaborating to develop methodologies to estimate the benefits and costs of potential pesticide regulatory decisions in an agricultural setting. Current approaches estimate the impacts of regulatory decisions on changes in agricultural yields and production costs, but do not incorporate potential effects on pollinator health and beekeeper income. To address these limitations, the USDA-ERS and EPA research partnership aims to identify appropriate valuation methods that will account for the spectrum of direct and indirect economic effects of potential regulatory changes. The identified methodology will assist EPA in determining how pollinator health should be accounted for within the FIFRA risk-benefit framework that is used in pesticide registration and registration review programs.

Partnerships ensure that Federal research activities are responsive to beekeepers' needs, and that the best available science is made available to beekeepers. By partnering with commercial beekeepers, USDA-ARS scientists are able to test ideas for mite controls, improved genetic stock, nutrition, and supplemental feeding on a larger scale and under more realistic conditions than would otherwise be possible. Much of this research depends on beekeeper input into the design and/or practicality of the research, and on beekeepers providing access to the large numbers of colonies necessary for research purposes. Testing improved management schemes within functioning beekeeping operations provides a rapid two-way flow of information: beekeepers can see for themselves if something works, or if it is not practical or does not appear to be making a difference, and in turn give important feedback to the researcher. Over the past few years, USDA-ARS scientists have worked with thousands of commercial hives from across the United States to field-test improved management schemes.

USDA-NIFA also supports the Bee Informed Partnership, a collaboration among researchers from a wide variety of disciplines and beekeepers across the United States. The Partnership takes an epidemiological approach to studying honey bee losses, surveying thousands of beekeepers about their colony losses and management practices. USDA-APHIS also partners with Bee Informed to collect more detailed data from beekeepers on diseases, pests, and pathogens. Bee Informed keeps beekeepers up-to-date on results, and also offers diagnostic services and technology transfer support.

Research Funding

Financial arrangements are obviously important partnerships for science, as research needs typically outnumber funding resources. USDA-ARS has been conducting mite and disease control products research with contributions from private industry. With funding from USDA, USGS is collaborating with the University of California at Davis to analyze linkages between land management practices and pollinator health (including honey bees and native bees). The National Science Foundation currently funds many university-based studies addressing basic science questions (Appendix B). USDA-ARS partners with, and receives research funding from, non-governmental organizations (Pollinator Partnership and Project Apis m.) and commodity boards (National Honey Board and the Almond Board of California) for a range of investigations.

Data and Information Sharing

The Smithsonian Institution, USDA, USGS, and other Federal agencies are involved in a variety of partnerships with non-profits, museums, and universities to achieve the goals of expanding access to data and collections. These partnerships include Biodiversity Information Serving Our Nation (BISON), Integrated Taxonomic Information System (ITIS), Global Biodiversity Information Facility (GBIF), Consortium for the Barcode of Life (CBOL), Encyclopedia of Life (EOL), and the Biodiversity Heritage Library (BHL), among others.

Citizen Engagement

Federal and non-governmental organizations are also collaborating on the creation and maintenance of tools and outreach materials in support of pollinators and their habitats. These include online resources and publications that inform the general public about pollinator health, such as the U.S. Forest Service and Pollinator Partnership's *Bee Basics: An Introduction to Native Bees*, the Butterflies and Moths of North America Project, NatureServe Explorer, and iNaturalist.

Citizen-science programs are increasing the prevalence of useful and popular partnerships that help to assess the status and trends of native pollinators across the country. These partner-based programs connect volunteers with researchers to provide volumes of observations on targeted topics. Federal agencies benefit greatly through data collected by programs such as Great Sunflower Project, Nature's Notebook—A Project of the USA National Phenology Network, Journey North, eBird, Hummingbirds at Home, and others, which provide data at spatial and temporal scales previously impossible with limited Federal resources.

Conclusion

Pollinators are facing a wide variety of stressors, including habitat loss, shifts in forage quality, pests and pathogens, pesticides and toxins, changing farm and hive management practices, and introduced (non-native) species. In addition to the impacts of each individual stressor, stressors are interacting, and in some cases acting synergistically, to cause pollinator declines. The approach proposed in the Pollinator Research Action Plan supports better understanding of individual stressors as well as the cumulative influence of these stressors on overall pollinator health. The plan identifies a full suite of activities that considers both economically-important drivers as well as the biodiversity of ecosystems. It includes project areas that are readily practicable, as well as more ambitious goals.

Research to address the objectives of the Presidential Memorandum fall into five main areas that overlap and interact to determine pollinator health:

1. **Population trends and basic biology.** Assessing the status of pollinator populations requires inventories to establish baseline conditions, and subsequent monitoring and longitudinal studies to detect deviations—and causes for these deviations—from the baselines. For managed bees, expanded quarterly and annual surveys of beekeepers, including questions on management practices and hive losses, and development of technologies to monitor hive health continuously, are a top priority. For native pollinators, research must address species distributions, population patterns and habitat use, which are poorly understood for many species. These fundamental data can feed into models of the larger system of interacting factors affecting pollinators.

2. **Environmental stressors.** Many environmental factors have the potential to impact pollinator populations. Information is needed on these stressors individually, particularly the sublethal impacts of pesticides and mite parasites. Research must focus on developing miticides for honey bees that safely and effectively manage colony infestations. Just as importantly, information is needed on how these stressors interact in real-world situations to cause declines in both honey bees and native pollinators. Best management practices on public and private lands, and actions by Federal, state, and local governments, require synthetic studies of multiple stressors. Collaboration with scientists internationally will add to the information base from which stressors can be assessed under diverse conditions and habitat.

3. **Land managers.** Human behavior influences environmental stressors on pollinator health. The choices that land managers make depend on a complex web of cultural and economic values. Best management practices have to balance what is best for the pollinator and best for the land manager. Information on how decisions are made, and how tools can support those decisions, is crucial to positively changing the environment for pollinators.

4. **Restoration.** Pollinator populations depend directly on plant populations. Effective habitat restoration must be appropriate for the desired pollinator species, affordable to establish in the short term, and self-sustaining in the long term. Research that helps identify habitat with the highest potential for pollinator benefits, restore that habitat with appropriate seed mixtures,

and monitor that habitat for adaptive management, is essential to creating more and better pollinator habitat.

5. **Knowledge curation.** Long-term monitoring and sound research require an extensive and well-curated body of data. This includes traditional data from individual specimens validated with their identification and geographic data, as well as data from techniques as cutting-edge as whole-genome sequencing. Capacity to store information has expanded exponentially in recent years, and maintaining and sharing specimen and genomic collections, as well as population data, will aid in understanding patterns in decline and survival.

Together, these main areas represent the bodies of knowledge currently understood to be most critical to the recovery of pollinator populations in the United States. The proposed actions are built upon a solid foundation of existing research from the Federal agencies as well as academic institutions. Activities outlined in the Pollinator Research Action Plan use existing research and development to apply new technologies and approaches to make immediate progress in protecting beekeeper and grower livelihood, and in sustaining agricultural crops and native plant habitats dependent on pollination services, while undertaking longitudinal studies to uncover the underlying causes of major bee health problems. Finally, the plan uses the interagency process to inform other relevant activities (*e.g.,* BMP's for habitat) of emerging research findings.

Appendices

Appendix A—Web Sites with Resources and Tools for Pollinator Health

Pollinator Health Organizations

- Bee Informed Partnership: http://beeinformed.org/
- eXtension Bee Health Community of Practice: http://www.extension.org/bee_health
- Integrated Crop Pollination Project: http://icpbees.org/
- Managed Pollinator Coordinated Agricultural Project: http://www.beeccdcap.uga.edu/
- Pollinator Partnership (P2): http://www.pollinator.org/
- Sustainable Agriculture Research and Education's (SARE's) Managing Alternative Pollinators: http://www.sare.org/Learning-Center/Books/Managing-Alternative-Pollinators
- Xerces Society: http://www.xerces.org/

Risk Management for Pesticides

- Organisation for Economic Co-operation and Development (OECD)—Pesticide Exposure of Insect Pollinators: http://www.oecd.org/chemicalsafety/risk-mitigation-pollinators/pesticide-exposure-insect-pollinators.htm
- Pesticide Risk Assessment for Pollinators—Summary of a SETAC Pellston Workshop (Society of Environmental Toxicology and Chemistry 2011): http://c.ymcdn.com/sites/www.setac.org/resource/resmgr/publications_and_resources/executivesummarypollinators_.pdf
- Purdue University—Protecting Honey Bees from Pesticides: http://extension.entm.purdue.edu/publications/E-53.pdf
- The Guide to Seed Treatment Stewardship: http://seed-treatment-guide.com/
- U.S. Environmental Protection Agency--Reducing Pesticide Drift: http://www2.epa.gov/reducing-pesticide-drift
- University of Florida—Minimizing Honey Bee Exposure to Pesticides: http://edis.ifas.ufl.edu/in1027http://edis.ifas.ufl.edu/in1027

Best Management Practices for Beekeepers and Growers

- Managed Pollinator Coordinated Agricultural Project—Best Management Practices (BMPs) For Beekeepers: http://www.beeccdcap.uga.edu/documents/bmpcalagr.html
- Pollinator Partnership—Securing Pollinator Health and Crop Protection: http://pollinator.org/PDFs/SecuringPollinatorHealthCropProtection.pdf
- 2015 Crop Protection Guide for Tree Fruits in Washington—Bee Protection: http://www.tfrec.wsu.edu/pages/cpg/Bee_Protection

- Farm Services Agency—FSA Pollinator Information: http://www.apfo.usda.gov/FSA/webapp?area=home&subject=ecpa&topic=nra-pl
- Natural Resources Conservation Service—Conservation Stewardship Program: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/
- Natural Resources Conservation Service—How NRCS is Helping Pollinators: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/plantsanimals/pollinate/help/
- Natural Resources Conservation Service—Environmental Quality Incentives Program: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/
- New York Integrated Fruit Production Protocol for Apples: http://hdl.handle.net/1813/5219
- Pollination Overview—Honey Bees are Essential for a Successful Crop: http://www.almonds.com/growers/pollination

Appendix B—Matrix of Current Federal Pollinator Research

			Geographic Region									Pollinator						Research Plan Section									
Department	Agency	Study Title	Pacific Northwest	Southwest	Northern Plains	Southern Plains	Midwest	Southeast	Northeast	Hawaii	International	Honeybee	Native Bee	Wasps	Moth/Butterfly	Fly	Vertebrate	Status & Trends	Habitats	Nutrition	Pesticides	Nativve Plants	Collections	Genetics	Pathogens	DecisionTools	Economics
DOI	USGS	Modeling/monitoring land-change effects on honey bee landscape suitability in the Northern Plains			x		x					x						x	x								
DOI	USGS	Evaluating how invasive wasp management restores plant-pollinator mutualisms in Hawaii								x		x	x					x	x								
DOI	USGS	Effects of Herbicide Applications for Shrubland Habitat Restoration on Ground-Dwelling and Pollinator Insect Communities on the Morley Nelson Snake River Birds of Prey National Conservation Area	x										x	x	x	x			x		x						
DOI	USGS	Pollinators of highbush blueberry in southern New England							x				x						x								
DOI	USGS	Male Gamete Quality for Reproductive Assessment and Genetic Improvement	x					x				x	x											x			
DOI	USGS	Systemic Fipronil, Thiamethoxam, and Clothianidin Effects on Cell Quality and Function in Amphibians, Crayfish, and Honeybees						x				x					x				x						
DOI	USGS	Baseline monitoring of indicator species (butterflies) at tallgrass prairie restorations						x							x			x	x								
DOI	USGS	Assessing the utility of CRP grasslands and rowcrops for native bees; in collaboration with USDA				x							x						x								
DOI	USGS	Assessment of pesticide exposure to native bees found in USDA Conservation Reserve Program fields, rowcrop agriculture and rangeland				x							x						x		x						
DOI	USGS	Effects of climate change on the Karner blue butterfly					x								x			x	x								
DOI	USGS	Distribution of native bees in climate sensitive habitats of the national parks	x	x	x	x	x	x	x			x	x					x	x								
DOI	USGS	Assessment of Population Genetic Structure and Management Considerations for Threatened and Endangered Butterflies	x												x									x			
DOI	USGS	Modeling pollinator communities for huckleberries in response to climate change near Glacier National Park, MT; in collaboration with Montana State University.	x									x	x	x					x								
DOI	USGS	Estimating mosquito control pesticide risk to butterflies in the Florida Keys.						x							x						x						
DOI	USGS	Pollination interaction webs to understand effects of invasive plant species on native plants and pollinator communities			x		x						x	x	x	x			x								
DOI	USGS	Evaluation of pollen limitation and pollinator efficacy for the rare endemic plant, Eriogonum visheri, at Badlands National Park			x								x	x		x			x								

Appendix B—Matrix of Current Federal Pollinator Research (Cont.)

Department	Agency	Study Title	Geographic Region									Pollinator						Research Plan Section									
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DOI	USGS	Importance of Canadian Thistle (Cirsium arvense) to pollinators: a removal experiment			x								x	x	x	x			x								
DOI	USGS	Effects of fire versus conservation grazing for management of tallgrass prairie remnants and their pollinator and butterfly communities (planned 2015)					x						x	x	x	x			x								
DOI	USGS	Biodiversity Information Serving Our Nation (BISON) Prioritizing Access to High Quality Pollinator and Plant Species Occurrence and Association Data for the United States and U.S. Territories with Emphasis on (but not limited to) Invertebrate Pollinators including Native Bees and Monarch Butterflies.	x	x	x	x	x	x	x		x	x	x	x	x	x	x						x				
DOI	USGS	Integrated Taxonomic Information System (ITIS) Global Update of World Bee Taxonomy and the World Bee Checklist of Over Twenty Thousand Valid Scientific Names for Bees.	x	x	x	x	x	x	x		x	x	x	x	x	x	x						x				
DOI	USGS	Modeling honey bee habitat suitability in the Northern Great Plains			x							x							x								
DOI	USGS	Monarch Conservation Science Partnership		x	x	x	x	x	x		x				x				x		x					x	
DOI	USGS	Online Identification guide to the 162 Genera of Bees of the Caribbean, Mexico, United States, and Canada	x	x	x	x	x	x	x	x	x	x	x					x					x				
DOI	USGS	Species level identification guides to 1200 North American bee species	x	x	x	x	x	x	x		x	x	x					x					x				
DOI	USGS	Creation and Maintenance of the Handy Bee Manual	x	x	x	x	x	x	x	x	x	x	x					x					x				
DOI	USGS	Creation of the USFWS manual on Native Bee Monitoring	x	x	x	x	x	x	x	x		x	x					x									
DOI	USGS	Creation of North American Native Bee Monitoring Program	x	x	x	x	x	x	x	x	x	x	x					x									
DOI	USGS	Creation of 300,000 specimen National bee specimen database	x	x	x	x	x	x	x	x	x	x	x					x					x				
DOI	USGS	Pilot Program to Survey Native Bees in Woodlands	x	x	x	x	x	x	x			x	x					x									
DOI	USGS	Creation of Hi-Resolution Public Domain Photographs of Native and Introduced Bees	x	x	x	x	x	x	x	x	x	x	x					x					x				
DOI	USGS	Pesticide National Synthesis Project a national-scale assessment of the occurrence and behavior of pesticides in the United States. http://water.usgs.gov/nawqa/pnsp/	x	x	x	x	x	x	x												x						
DOI	USGS / USA NPN	Vetted and published standardized phenology monitoring protocols for 41 pollinators, including 7 hummingbird species, 7 bee species, and 27 butterfly and moth species; protocols capture presence, absence, abundance, flower visitation, migration and other defined life cycle stages	x	x	x	x	x	x	x	x		x	x		x		x	x									

Appendix B—Matrix of Current Federal Pollinator Research (Cont.)

Department	Agency	Study Title	Geographic Region									Pollinator						Research Plan Section									
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DOI	USGS / USA NPN	Vetted and published standardized monitoring protocols for 18 pollinator-dependent, economically important crop species	x	x	x	x	x	x	x	x		x	x		x		x	x									
DOI	USGS / USA NPN	Standardized output of phenology information on pollinators and pollinator plants including: data visualizations and maps, freely available customized data downloads, synthetic data products (e.g., onset, duration and peak of activity; site-based species richness and abundance for animals), and modeled data products (e.g., gridded indices, regional and national indicators linked to climatology)	x	x	x	x	x	x	x	x		x	x		x		x	x									
EPA	OPP	Broad Spectrum Pesticide Residue Analysis of Bee Pollen in the Pacific Northwest Crops. Project Number B14-47	x									x									x						
EPA	OPP	Development of a Honey Bee Colony Simulation Model for use in Ecological Risk Assessment of Pesticides	x	x	x	x	x	x	x	x	x	x									x						
EPA	OPP	Imidacloprid Residue Analysis of Bee Matrices in Support of Science to Achieve Results (EPA STAR Grant) to Judy Wu (University of Minnesota)			x							x									x						
EPA	ORD	Regionally Applied Research Effort Grant to Perform Data Analysis and Create an Experimental Design Concerning Bee Kill Incidents in the Upper Midwest Associated with Neonicotinoid Pesticides Treated Seed Plantings					x					x									x						
EPA	ORD	Molecular target sequence similarity as a basis for species extrapolation to assess the ecological risk of chemicals with known modes of action.										x									x			x			
EPA	USGS	Broad Spectrum Pesticide Residue Analysis of Bee Pollen from Honey Bees foraging on USDA Conservation Lands			x							x									x						
NSF	NSF	Antibiotic Resistance in Honey bee Microbiota				x						x								x							
NSF	NSF	Genomics, functional roles, and diversity of the symbiotic gut microbiotae of honey bees and bumble bees				x						x	x							x							
NSF	NSF	Access, visualization, and statistical tools for the analysis of butterfly monitoring data							x						x			x								x	
NSF	NSF	A specimen-level database of the world's bees (Apoidea) at the University of Kansas				x						x											x				
NSF	NSF	New Software Tools for Genome Comparisons of Non-Model Organisms					x																	x			

Appendix B—Matrix of Current Federal Pollinator Research (Cont.)

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NSF	NSF	Community assembly of nectar-inhabiting microbes		x																x					x		
NSF	NSF	Organization of Social Structure and its Influence on Transmission Dynamics in a Honeybee Colony			x							x													x		
NSF	NSF	Phenology, ontogeny and the consequences of shifts in the relative timing of milkweed-monarch interactions		x											x			x	x								
NSF	NSF	Probabilistic Frameworks for Studying Gene Regulatory Sequences and their Evolution					x																	x			
NSF	NSF	Genomic Analysis of Pheromone-Mediated Behavior							x			x												x			
NSF	NSF	CC-NIE Network Infrastructure: Enabling data-driven research																									
NSF	NSF	Genomics across the speciation continuum in Heliconius butterflies						x	x						x												
NSF	NSF	Geographic Variation in Plant-Herbivore-Parasite Interactions: Self-Medication in Monarch Butterflies					x	x							x					x		x			x		
NSF	NSF	Collaborative Databasing of North American Bee Collections within a Global Informatics Network		x					x		x	x	x										x				
NSF	NSF	Context-Dependency in the Exploitation of Pollination Mutualisms		x					x				x						x				x				
NSF	NSF	Epigenetic Gene Regulation in the Social Bee (Apis Mellifera)						x	x			x												x			
NSF	NSF	Alternative strategies and evolutionary routes in the escalation of the bat-moth arms race: Ultrasonic stridulation in hawkmoths			x			x							x		x	x	x								
NSF	NSF	The role of floral secondary compounds in bee performance and disease transmission in a natural ecosystem							x			x	x									x			x		
NSF	NSF	RCN:UrBioNet: A global network of urban biodiversity research and practice					x		x		x	x	x	x	x			x	x								
NSF	NSF	DISSERTATION RESEARCH: Bats, Bugs and Pecans: Using Next-Generation Pyrosequencing to Evaluate Ecosystem Services of Insectivorous Bats							x								x										x
NSF	NSF	DISSERTATION RESEARCH: Evolution of diet breadth of Melissodes (Hymenoptera: Apidae)		x									x					x	x	x							
NSF	NSF	DISSERTATION RESEARCH: Microbial mediation of pollinator performance							x				x							x					x		
NSF	NSF	DISSERTATION RESEARCH: Modeling Bird and Bat Mediated Pest Control Services Across Costa Rican Countryside		x							x						x										x

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NSF	NSF	DISSERTATION RESEARCH: The impact of ecological traits on the immunogenetic evolution of bats		x													x								x		
NSF	NSF	DISSERTATION RESEARCH: The role of phenology in plant-pollinator interactions and plant reproduction							x				x				x	x	x			x					
NSF	NSF	DISSERTATION RESEARCH: Understanding how shifts from migratory to sedentary behavior influence host-pathogen dynamics						x							x										x		
NSF	NSF	DISSERTATION RESEARCH: Social Capital and Policy Networks: Exploring the Factors that Influence Adoption of Pollinator Conservation							x			x	x													x	
NSF	NSF	EAGER: Climate change and phenological mismatch - an experimental test with cavity nesting bees, cleptoparasites, and floral resources							x				x					x							x		
NSF	NSF	EAGER: Re-thinking crop pollination by bees: How the interplay of agricultural and natural landscapes influences pollination by native bees in Southern California		x									x					x								x	
NSF	NSF	Epigenetic Influences on the Honey Bee Transcriptome and Behavior					x					x												x			
NSF	NSF	ICOB: miRNAs and the social regulation of behavioral plasticity					x					x												x			
NSF	NSF	Independent effects of tropical forest fragmentation and habitat loss on hummingbird movement and pollination dynamics	x														x	x	x								
NSF	NSF	LiT: Phenotype-based models for ecological and evolutionary responses to climate change						x										x	x								
NSF	NSF	MPS-BIO: Dynamics and stability of plant-pollinator mutualistic networks in response to ecological perturbations							x			x	x		x	x		x	x								
NSF	NSF	Develop a statistical framework to integrate high-resolution spatially replicated field data, detailed case reports and molecular sequence data into mechanistic mathematical models of disease transmission.									x						x								x		
NSF	NSF	OPUS: A synthesis of 55 years of research on the monarch butterfly						x							x			x	x								
NSF	NSF	Pollinator Diversity and Foraging Specialization						x					x					x	x								
NSF	NSF	Resin to Propolis: Biological origins and role in honey bee social immunity and health					x					x													x		

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NSF	NSF	Scholar's Award: A Social Scientific Study of how Stakeholders Produce Knowledge about the Cause and Treatment of Colony Collapse Disorder							x			x														x	
NSF	NSF	The effect of sociality on transmission and spread of a multi-host pathogen (Geomyces destructans)		x													x								x		
NSF	NSF	The Human Impact Pollen Database: Development of searchable internet image database of pollen taxa							x			x	x	x	x	x	x					x	x				
NSF	NSF	The Hymenoptera Ontology: Part of a Transformation in Systematic and Genome Science							x			x	x											x			
NSF	NSF	The interplay of genes and ecology in the social behavior of a halictid bee							x				x											x			
NSF	NSF	Understanding the Geographical and Community Context of Mutualism Dynamics: Fig-Pollinator-Parasite Interactions in the Sonoran Desert					x							x					x						x		
NSF	NSF	Olfactory processing and learning of complex scents in insects	x												x				x			x					
NSF	NSF	Effects of pulsed floral resources on pollinator population dynamics		x					x				x					x	x								
NSF	NSF	EAGER: An Interoperable Information Infrastructure for Biodiversity Research (I3BR)		x								x	x	x	x	x	x						x	x			
NSF	NSF	CSBR: Natural History Collections: Building a central database and curation improvements for The McGuire Center for Lepidoptera at the Florida Museum of Natural History							x						x								x				
NSF	NSF	SusChEM: Atmospheric Fates of Neonicotinoids and Their Role in Food Security and Agricultural Sustainability		x								x									x						
NSF	NSF	LTREB Renewal: Drivers and consequences of phenological change at high altitudes			x								x					x	x								
SI	CTFS	CTFS-ForestGEO Arthropod Initiative is monitoring key arthropod assemblages at selected ForestGEO sites in tropical rain forests									x		x		x			x					x				
SI	NMNH	Digitize the full 46,000 specimen bumble bee collection from the entomological collections	x	x	x	x	x	x	x	x	x		x					x					x				
SI	NMNH	Digitize the full 5,000 specimen honeybee collection from the entomological collections	x	x	x	x	x	x	x	x	x	x						x					x				
SI	NMNH	Reconstruction and analysis of plant-pollinator networks from Plummers Island using next generation sequencing and DNA barcoding						x	x			x	x					x					x				

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SI	NMNH	Pollinator competition and plant competition as mechanisms for evolutionary diversification, in collaboration with Amherst College									x						x	x					x				
SI	SCBI	Assessing pollinator diversity and abundance on private lands with differing agricultural practices, in collaboration with UVA Blandy Farm						x				x	x		x			x	x	x							
SI	SCBI	Impact of native grass restoration activities on pollinator diversity and adundance, in collaboration with UVA Blandy Farm						x				x	x		x			x	x	x							
SI / USBG	NMNH	Compilation and detailed accounts of pollinators of every native North American orchid species	x	x	x	x	x	x	x	x	x	x	x		x	x		x									
USDA	APHIS	Determining the role of Varroa mites and other arthropod pests in vectoring disease pathogens.										x															
USDA	APHIS	Developing control strategies for Varroa										x															
USDA	APHIS	Addressing acaricide resistance and develop strategies to control Varroa including genetic breeding for resistance in queens and colonies								x		x															
USDA	APHIS	Rapid identification and response of exotic pests and diseases.										x															
USDA	APHIS	Small hive beetle- IGR to prevent reproduction during protein feeding.										x															
USDA	APHIS/ ARS	Nosema sampling and effects of nutrition on Nosema incidence.										x								x							
USDA	APHIS	Understanding forage opportunities for honey bees					x					x								x		x					
USDA	APHIS	National survey of honey bee pests and diseases.	x	x	x	x	x	x	x	x		x															
USDA	APHIS	National survey of pesticides sampled from pollen in hives.	x	x	x	x	x	x	x	x		x									x						
USDA	APHIS/ ARS	National survey of bumblebee diseases.	x	x	x	x	x	x	x	x			x														
USDA	APHIS	Develop an online Bee Mite ID guide.	x	x	x	x	x	x	x	x			x														
USDA	ARS	Area-Wide Management of Agricultural Pests	x	x	x		x	x	x			x						x	x	x	x	x	x	x	x	x	x
USDA	ARS	Advancing Sustainable and Resilient Cropping Systems for the Short Growing Seasons and Cold, Wet Soils of the Upper Midwest					x					x						x	x	x	x	x		x		x	x
USDA	ARS	Mite Systematics and Arthropod Diagnostics with Emphasis on Invasive Species										x									x		x		x		
USDA	ARS	Chemical Biology of Insect and Plant Signaling Systems										x									x		x		x		

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USDA	ARS	Managing Honey Bees Against Disease and Colony Stress										x						x	x	x	x			x	x	x	x
USDA	ARS	Managing and Conserving Diverse Bee Pollinators for Sustainable Crop Production and Wildland Preservation	x	x	x							x	x					x	x	x		x	x	x	x		x
USDA	ARS	Production and Disease and Pest Management of Horticultural Crops						x				x	x						x	x							
USDA	ARS	Understanding Honey Bee Microbiota to Improve Bee Nutrition and Colony Health										x							x	x	x					x	x
USDA	ARS	Determining the Impacts of Pesticide and Nutrition-Induced Stress on Honey Bee Colony Growth and Survival										x						x		x	x					x	
USDA	ARS	Genetics and Breeding in Support of Honey Bee Health										x												x	x	x	
USDA	ARS / NIFA	Genomic approaches to characterize & mitigate impact of Nosema disease in honey bees																x			x			x	x	x	
USDA	ERS	An Economic Evaluation of Honeybees in the United States	x	x	x	x	x	x	x	x		x															x
USDA	ERS	Land Management and Pollinator Health			x		x					x	x														x
USDA	ERS	Impact of Pollinator Health Challenges on Consumer Welfare	x	x	x	x	x	x	x	x		x															x
USDA	ERS	Risk Management Tools for Beekeepers	x	x	x	x	x	x	x			x															x
USDA	FS	Creating monarch habitat at the USFS-PSW Institute of Forest Genetics		x											x												
USDA	FSA	Effect of CRP covers on honey bee and native pollinator populations, honey bee productivity	x		x		x					x	x						x	x		x	x				
USDA	FSA	Monitoring CRP effects on pollinator presence in Playa Lakes				x							x						x			x	x				
USDA	FSA	Monitoring CRP effects on pollinator presence in short grass and mixed grass prairie ecosystems in agriculturally dominated landscapes			x							x	x						x	x		x	x				
USDA	FSA	Monitoring and comparing the effect of ISU STRIPs and CRP contour strips on pollinator presence in agriculturally dominated landscapes					x					x	x						x	x		x	x				
USDA	NASS	Quarterly Loss Survey	x	x	x	x	x	x	x	x		x						x									
USDA	NASS	Annual Loss Survey	x	x	x	x	x	x	x	x		x						x									
USDA	NASS	Cost of Pollination Survey	x	x	x	x	x	x	x	x		x															
USDA	NIFA	Sustainable Solutions to Problems Affecting Bee Health (20 universities)	x	x	x	x	x	x	x	x		x							x	x	x		x	x	x	x	

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USDA	NIFA	Consequences of floral chemistry and bee pathogens for bee performance and crop pollination							x			x	x							x					x		
USDA	NIFA	Co-formulants and pollinators										x									x						
USDA	NIFA	Farming for native bees in California	x										x					x	x				x				
USDA	NIFA	Queen Supersedure in Honey bees: How do Agricultural Pesticides Impair Fertility in Queens and Drones?		x								x									x						
USDA	NIFA	Pollination Security For Fruit And Vegetable Crops In The Northeast							x				x					x			x				x		
USDA	NIFA	Determining the Roles and Limiting Factors Facing Native Pollinators in Assuring Quality Apple Production in Pennsylvania; a Model for the Mid-Atlantic Tree Fruit Industry																					x				x
USDA	NIFA	Developing Sustainable Pollination Strategies for U.S. Specialty Crops	x	x			x	x	x				x						x							x	x
USDA	NIFA	Breeding Honey bees: From Evolutionary Biology & Functional Genomics to Sociology							x			x												x			
USDA	NIFA	Interactions Between Honey Bee Nutrition and Viral Infection: An Integrative Approach to CCD					x					x								x					x		
USDA	NRCS	Evaluation of pollinator plant mixes for EQIP						x				x	x						x							x	
USDA	NRCS	Production and increase of five native wildflowers for range diversity		x									x	x	x							x					
USDA	NRCS	Evaluation of commercially available wildflower mixes for NRCS conservation programs		x								x	x	x	x	x	x		x			x				x	
USDA	NRCS	Establishing and managing pollinator meadows		x								x	x	x	x	x	x		x							x	
USDA	NRCS	Evaluating native wildflowers for pollinator meadows		x								x	x	x	x	x	x		x			x				x	
USDA	NRCS	Establishing and managing pollinator hedgerows in crop production systems		x								x	x	x	x	x	x		x							x	
USDA	NRCS	Native plants for pollinator pastures		x								x	x	x	x	x	x		x			x				x	
USDA	NRCS	Propagation and production of milkweeds for Monarch habitat				x									x							x					
USDA	NRCS	Propagation and demonstration of pollinator friendly tree species						x				x	x	x	x	x	x		x			x					
USDA	NRCS	Stabilizing irrigation reservoir shorelines with plant species beneficial to pollinators						x				x	x	x	x	x	x		x								
USDA	NRCS	Establishing Montana native plants to enhance pollinator habitat			x							x	x	x	x	x	x		x							x	

Appendix B—Matrix of Current Federal Pollinator Research (Cont.)

Department	Agency	Study Title	Geographic Region									Pollinator						Research Plan Section									
			Pacific Northwest	Southwest	Northern Plains	Southern Plains	Midwest	Southeast	Northeast	Hawaii	International	Honeybee	Native Bee	Wasps	Moth/Butterfly	Fly	Vertebrate	Status & Trends	Habitats	Nutrition	Pesticides	Nativve Plants	Collections	Genetics	Pathogens	DecisionTools	Economics
USDA	NRCS	Testing seed mix proportions and a seed carrier for establishing pollinator habitat			x							x	x	x	x	x	x		x			x					
USDA	NRCS	Pollinator plant evaluations		x								x	x	x	x	x	x					x					
USDA	NRCS	Propagation and production of milkweeds for Monarch habitat		x											x							x					
USDA	NRCS	Pollinator plant seeding and establishment		x								x	x	x	x	x	x		x								
USDA	NRCS	Seed collection and evaluation of milkweeds for Monarch habitat		x											x							x					
USDA	NRCS	Establishment of plant species beneficial to pollinators	x									x	x	x	x	x	x		x							x	
USDA	NRCS	Formulating pollinator seed mixes based on seeding dates and rates	x									x	x	x	x	x	x		x			x					
USDA	NRCS	Comparison and evaluation of commercially available pollinator mixes for NRCS conservation programs	x									x	x	x	x	x	x		x			x					
USDA	NRCS	Organic site preparation for pollinator habitat	x									x	x	x	x	x	x		x							x	
USDA	NRCS	Evaluating plant and seed mixes for effective pollinator habitat				x						x	x	x	x	x	x		x			x					
USDA	NRCS	Determining optimum planting dates of native legumes and wildflowers for maximum establishment				x						x	x	x	x	x	x		x								
USDA	NRCS	Evaluating wildflower establishment for wildlife and pollinator habitat	x									x	x	x	x	x	x		x							x	
USDA	USFS R&D	Creating monarch habitat at the USFS-PSW Institute of Forest Genetics		x											x				x	x		x					
USDA	USFS R&D	Research study on relationships between butterflies and restoration management actions.					x								x				x								
USDA	USFS R&D	Effects of non-native predators on pollinators and native plant reproduction								x		x	x	x	x	x		x	x			x			x	x	
USDA	USFS R&D	Examining the effects of temperature, drought, CO2 concentration, on floral volatiles and pollinator attraction.			x							x	x	x	x	x			x								
USDA	USFS R&D	Understanding conditions for successful tree pollination by bees.							x				x						x								
USDA	USFS R&D	Propagating milkweeds to restore habitat and provide waystations for monarch butterflies	x	x	x	x	x	x	x						x			x	x			x					
USDA	USFS R&D	Insect pollinator response to removal of invasive shrubs						x					x		x				x								

Appendix B—Matrix of Current Federal Pollinator Research (Cont.)

Department	Agency	Study Title	Geographic Region									Pollinator						Research Plan Section									
			Pacific Northwest	Southwest	Northern Plains	Southern Plains	Midwest	Southeast	Northeast	Hawaii	International	Honeybee	Native Bee	Wasps	Moth/Butterfly	Fly	Vertebrate	Status & Trends	Habitats	Nutrition	Pesticides	Nativve Plants	Collections	Genetics	Pathogens	DecisionTools	Economics
USDA	USFS R&D	How insect pollinators are affected by forest management.						x					x		x				x								
USDA	USFS R&D	Vertical distribution of pollinators in forests						x					x		x				x								
USDA	USFS R&D	"Working Trees for Pollinators" Develop scientific basis and science delivery for integrating pollinator concerns into planning/design of agroforestry systems.	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x							x	
USDA	USFS R&D	Climate Smart Agriculture: Agroforestry as means to provide adaptive services in support of biodiversity, including pollinators.	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x							x	
USDA	USFS R&D	Compilation of science resources to develop guidelines for supporting pollinators through agroforestry.	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x							x	
USDA	USFS R&D	Interaction of fire regimes and lepidopteran communities in fire-maintained pine forests				x	x	x							x				x								
USDA	USFS R&D	Research study on effects of riparian restoration and wild and domestic ungulate herbivory on abundance, diversity, and composition of native pollinators, esp. bees	x										x		x			x	x			x					
USDA	USFS R&D	Development of pollinated forbs to restore sites damaged by fire and to re-establish lost pollinator relationships.		x									x		x			x	x			x					
USDA	USFS R&D	Bee Monitoring across Experimental Forests and Ranges	x	x	x	x	x	x	x				x					x									
USDA/ DOI	USGS/ FSA	USGS Pollinator Library: Developing an online repository of pollinator forage information.			x	x	x						x	x	x	x	x						x				
USDA/ DOI	USGS/ FSA/ NRCS	Improving forage conditions for honey bees and native pollinators on US Department of Agriculture Conservation Lands			x		x					x	x	x	x	x	x		x								

Appendix C—Abbreviations Used in the Report

Agencies/Organizations

ABF	American Beekeeping Federation
AHPA	American Honey Producers Association
APHIS	Animal and Plant Health Inspection Service
ARS	Agricultural Research Service
BLM	Bureau of Land Management
DOI	Department of the Interior
EPA	Environmental Protection Agency
ERS	Economic Research Service
FSA	Farm Service Agency
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
NAC	National Agroforestry Center
NAPPC	North American Pollinator Protection Campaign
NASS	National Agricultural Statistics Service
NGO	Non-governmental organization
NIFA	National Institute of Food and Agriculture
NPS	National Park Service
NRCS	National Resources Conservation Service
NSF	National Science Foundation
OPP	Office of Pesticide Programs
ORD	Organic Transitions Program
PCA	Plant Conservation Alliance
RMA	Risk Management Agency
SI	Smithsonian Institution
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Other

BISON	Biodiversity Information Serving Our Nation
BMP	Best management practice
CCD	Colony Collapse Disorder
CP42	Pollinator Habitat under the Conservation Reserve Program
CRP	Conservation Reserve Program
EOL	Encyclopedia of Life
EQIP	Environmental Quality Incentives Program
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GBIF	Global Biodiversity Information Facility
ICP	Integrated Crop Pollination Project
IPM	Integrated Pest Management
RNAi	RNA interference
VSH	Varroa-sensitive hygiene

Appendix D—Common and Scientific Names Used in Report

[NA, not applicable; spp., unspecified species of the preceding genus]

Common name	Scientific name
Kingdom Animalia	
NA	*Nosema* spp.
NA	*Nosema bombi*
NA	*Nosema ceranae*
alfalfa leaf-cutter bee	*Megachile rotundata*
alkali bee	*Nomia melanderi*
arthropods	*Arthropodaria* spp.
Asian honey bee	*Apis cerana*
bats	Order: Chiroptera
bees	Order: Hymenoptera
beetles	*Apis* spp.
blue orchard bee	*Osmia lignaria*
bumble bees	*Bombus* spp.
butterflies	Order: Lepidoptera
common Eastern bumble bee	*Bombus impatiens*
crayfishes	Family: Cambaridae
halictid bee	*Lasioglossum albipes*
honey bees	Family Apidae; *Apis mellifera*
hummingbirds	Family: Trochilidae
monarch butterfly	*Danaus plexippus*
Tropilaelaps mite	*Tropilaelaps*
Varroa mite	*Varroa destructor*
Kingdom Plantae	
almond	*Prunus dulcis*
apples	*Malus* spp.
blueberry	*Vaccinium* spp.
canola	*Sinapis* arvensis
corn	*Zea mays*
crambe	*Crambe abyssinica*
false flax	*Camelina* spp.
melons	*Cucumis* spp.
pennycress	*Thlaspi* spp.
Kingdom Fungi	
NA	*Ascosphaera* spp.

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