Environ. Sci. Technol. **XXXX,** *xxx,* 000–000

Environmental Science & Technology
Feature

The Plight of the Bees†

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Some environmental issues polarize people, producing weary political stalemates of indecision and inaction. Others, however, grab hold of our most primeval instincts, causing us to reach deeply into our memories of childhood, and our first direct experiences with nature: the bumble bee nest we poked at with a stick; the man at the county fair with the bee beard. Those memories expand backward in time to our barefoot ancestors who climbed trees and robbed honey. They help define the human experience and provide context to our own place in the world.

And so the plight of the bees strikes a common chord. For a brief moment simple matters of politics, economics, and nationality seem irrelevant.

Colony collapse disorder, the name for the syndrome causing honey bees (*Apis mellifera*) to suddenly and mysteriously disappear from their hives—thousands of individual worker bees literally flying off to die—captured public consciousness when it was first named in 2007 (*1*). Since then, the story of vanishing honey bees has become ubiquitous in popular consciousness—driving everything from ice cream marketing campaigns to plots for *The Simpsons*. The untold story is that these hive losses are simply a capstone to more than a half-century of more prosaic day-to-day losses that beekeepers already faced from parasites, diseases, poor nutrition, and pesticide poisoning (*2*).

The larger story still is that while honey bees are charismatic and important to agriculture, other important bees are also suffering, and in some cases their fates are far worse (*3*). These other bees are a subset of the roughly 4000 species of wild bumble bees (*Bombus*), leafcutter bees (*Megachile*), and others that are native to North America. While the honey bee was originally imported from Europe by colonists in the early 17th century, it is these native bees that have evolved with our local ecosystems, and, along with honey bees, are valuable crop pollinators.

People want to know why bees are dying and how to help them. This concern provides a good opportunity to more closely examine pollinators and our dependence upon them. Bees are reaching their tipping point because they are expected to perform in an increasingly inhospitable world.

Pollination Economics. The service of animal mediated pollination is essential for the reproduction of nearly 70% of the world's flowering plants (*4*). Butterflies, some beetles, flies, hummingbirds, and even some bats provide some pollination services, inadvertently moving pollen (the plant's male gametes) from anther to stigma as they sip nectar or eat pollen from flowers.

Yet among pollinators, bees are unique. In addition to sipping nectar to fuel their own flight, they are one of the few animals to actively gather large amounts of pollen (and hence inadvertantly move some of it widely between flowers). Rich in protein, the pollen of many plant species serves as the principle food source for developing bee larvae. Wasps in contrast, while close relatives of bees, typically feed on meat, often in the form of other insects, during their larval stage.

More than one-third of the world's crop species such as alfalfa, sunflower, and numerous fruits and vegetables depend on bee pollination, an ecological service valued in North America at $20 billion a year (*5*–*7*). The cereal grains that make up the largest part of our diets, such as corn, rice, and wheat, are wind pollinated. Thus the prospect of human starvation in the absence of bees is remote, but crop declines in the most nutritious—and arguably, most interesting—parts of our diet like fruit, vegetables, and alfalfa hay for meat and dairy production, are possible.

Worldwide, over the past five decades, there has been a 45% increase in the number of managed honey bee hives. That trend, however, does not keep pace with a 300% increase in bee-pollinated crop production in the same time period (*8*). In North America the trends in honey bee numbers are decidedly downward, with the number of managed hives decreasing by 50% since the 1950s and the amount of crop acreage requiring bee pollination at an all time high (*4*). Pollination biologists doubt the prospect of a food security crisis, but suggest that in the future, as per-acre crop yields decline in the absence of enough pollinators, more acres of farmland may be needed to meet consumer demands (9).

Bees in a Mechanized World. Like people, honey bees have always suffered from disease. Records of mass bee die-offs in the U.S. extend as far back as 1869 (*10*). Those early losses were largely buffered by a prepesticide and prein-

† This manuscript is part of the Environmental Policy: Past, Present, and Future Special Issue.

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dustrial rural landscape. Our current issues affecting bees began after World War II as small farms, interspersed with woods, wetlands, and meadows were replaced with larger-scale homogeneous crops, particularly wind-pollinated cereal crops (*11*).

To support that increase in farm scale, new low-cost synthetic fertilizers supplanted crop rotations with nitrogen-fixing cover crops like clover and alfalfa, formerly reliable and ubiquitous sources of pollen and nectar. Along with synthetic fertilizers, newly available chemical pesticides were introduced to control the pests and diseases that spread quickly among large fields of genetically identical crops. In addition to their direct toxicity to bees, these chemicals further reduced other beneficial biodiversity from farm systems, including beneficial insects that prey upon crop pests (making insecticides even more essential) and flowering weeds on crop borders, roadsides, and other noncropped rural lands that provided supplemental sources of nectar and pollen.

Many of these changes were fostered by federal farm subsidies favoring corn, particularly as a feedstock for beef, pork, and poultry production. Where bee-pollinated crops do exist, they typically occur in larger acreages providing only a single pollen and nectar source for a few short weeks during the year. This feast or famine situation fails to support wild bees that need food throughout their adult lives. Although honey bees may store food (in the form of honey and packed pollen) for times of dearth, lack of diverse floral resources is now demonstrated to diminish their immune response (*12*).

Added Insult: New Parasites and Pathogens. In the 1980s, two obligate parasites of honey bees were introduced into the U.S., the tracheal mite (*Acarapis woodi*), first found in the UK, and the varroa mite (*Varroa destructor*). Varroa mites are native to Asia where the host bee species, *Apis cerana* [sp] has evolved a resistance to them. Over time, bees in the U.S. developed natural resistance to tracheal mites, but the effects of *Varroa destructor* have been particularly devastating and hard to overcome. This mite lives up to its name by reducing the lifespan of adult bees, suppressing their immune system, and transmitting viruses as it sucks blood from one bee and moves on to the next (*13*).

Untreated colonies infected with *V. destructor* die within 6 months to 2 years. Without treatment, 80−90% of hives in the U.S. would likely die within 2−3 years. If we did not depend on honey bees to pollinate our commercial monocultures of fruits, vegetables, nuts, and seed crops, we could possibly afford to withhold treatments and allow nature to take her course, letting only the fittest colonies survive. However, in the 10−20 years it would take for the national honey bee population to rebound, crop production would suffer.

Finding a way to control *V. destructor* has been an agonizing puzzle to beekeepers and researchers. How do you kill a bad "bug" on a beneficial "bug"? Mites (which are arachnids) have been quick to develop resistance to synthetic pesticides (*14*), making them exceedingly difficult to control. The effects of *Varroa* mites are compounded by the viruses they transmit from bee to bee (*15*) The mite can facilitate the horizontal transmission of at least five viruses between adult bees and larvae (*16*). Viruses also can be transmitted vertically through male semen and queen-laid eggs (*17*). Where the mites do not directly kill the bees, the viruses will.

Along with mites, an introduced fungal gut parasite (also from Asia), called *Nosema ceranae* could impart the final blow. It is unclear at this point if nosema kills colonies alone (*18*), or if it acts in combination with viruses, with pesticides, or with nutritional stress (*19, 20*).

Recipe for Disaster: Colony Collapse Disorder. Reports of massive bee die-offs in the winter of 2006/2007 (*10*), and every winter since, appeared against the backdrop of habitat loss and nutritional stress, escalating pesticide use, viruses, and other pathogens. The rising demand for pollination of large monoculture crops, and the necessary cross-country transportation of colonies to meet that demand, have further exacerbated all of those stress factors.

The specific symptoms of the massive die-offs seemed unusual: colonies lost their workers rapidly and unexpectedly, leaving the queen, food stores, and brood abandoned in the nest, and no dead bees were observed in the area. These specific symptoms were called colony collapse disorder (CCD) (*19*). The disappearance of so many bees from a hive caught the media's attention and the public's imagination. It is very natural for sick bees to leave the colony to die; but the scale of the die-offs is alarming.

Teasing apart the synergistic effects of multiple factors to determine the primary cause of CCD is exceedingly difficult (*21, 22*). Studies have been unable to pinpoint a single factor that distinguishes CCD from control colonies. The most likely answer is that the losses are due to multiple, interactive factors (*10, 23, 24*).

The Other Bees. Before the honey bee was introduced from Europe in 1622, over 4000 species of bees were native to North America (*25*). These include a vast and colorful diversity of bumble bees, mason and leafcutter bees, mining bees, sweat bees, and others.

Many of these bees are more efficient crop pollinators than the non-native honey bee, especially for New World fruits and vegetables such as pumpkin, tomato, cranberry, and blueberry (e.g., refs *26 and 27)*. This specialization results in more efficient pollination and higher yields for certain crops valued at at least $3 billion USD annually (*6, 28, 29*). Recent research has demonstrated that native bees in some cases provide all necessary pollination when adequate foraging and nesting habitat is available, making them crucially important as honey bees continue to decline (*30, 31*).

Unfortunately while honey bees have been the focus of most media on disappearing bees, scientists are also documenting declining native bee numbers across the country (*3*), including the possible extinction of some species (*32*). Native bees are facing unprecedented habitat loss, pesticide threats, and introduced diseases.

Most of our native bees eke out a solitary existence, going about their business of pollinating flowers hidden from our daily view. Native bees in the temperate zone begin to emerge from winter hibernation in spring and early summer to feed, mate, and raise a new generation. Solitary female bees raise a new generation of bees in the soil, hollow twigs, rock crevices, and dead trees. Alone, she provisions each egg with a small mass of pollen and nectar that will provide all the protein required for the immature larval bee to develop into an adult. The entire process can take up to a full year for some species and will occur only if the nesting site is not tilled, poisoned, or otherwise disturbed. Such nesting sites are sparse in urban and agricultural landscapes.

In contrast to the majority solitary native bees, a few native bees, like bumble bees (*Bombus* spp.), are social, living in small annual colonies founded in the spring by an individual queen after she wakes from winter hibernation. Bumble bee nests are typically located within a dry cavity, such as an abandoned mouse nest, a cavity in a tree, or under a tussock of grass, and at their peak may contain more than a hundred workers.

Bumble bees are often the first bees active in spring and the last bees active in the fall. Thus, early blooming and late-blooming plants like wildflowers are especially important to their survival. A second feature that makes bumble bees important pollinators is their unique ability to buzz-pollinate flowers by disengaging their wings from their flight muscles, and using those muscles to shake their entire body at a frequency close to a middle C musical note (∼262 Hz) (*33*).

This vibration significantly increases the release of pollen from some flowers, including tomatoes, peppers, blueberries, and cranberries. Few other bees have the ability to perform buzz-pollination.

These combined factors make bumble bees significantly more efficient pollinators of many crops than honey bees on a bee-for-bee basis. Ironically, this same efficiency may have become instrumental in the downfall of several bumble bee species. According to a leading theory, efforts by several multinational companies to rear and distribute bumble bees for managed pollination are thought to have introduced or amplified one or more bumble bee diseases (*4*). According to this hypothesis, the pathogens then spread to wild bumble bees in the late 1990s as bumble bees were transported throughout the U.S. for pollination of tomatoes and other crops (*34, 35*).

It now appears that several formerly very widespread species of bumble bees have declined across most of their ranges (*3*). In mid-1990s surveys, the yellow-banded bumble bee (*Bombus terricola*) was the most abundant bumble bee in Wisconsin. Ten years later it made up less than 1% of the state's bumble bees. Across the continent, a similar fate has befallen the western bumble bee (*B. occidentalis*). Once the most abundant bumble bee on the West Coast, its' numbers have also crashed and it is now rarely seen. Another species, Franklin's bumble bee (*B. franklini*), once native to Oregon−California, is now believed extinct (*3*).

Roughly 45 bumble bee species are native to North America, and while many species seem to be resistant to diseases, others are clearly not. Bumble bees frequently seen on crop flowers and in gardens give the appearance of stable populations, but the diversity of species is in rapid decline.

Turning it Around. Bee declines can be attributed to three factors:

1. Bees have their own diseases and parasites that weaken and kill them (*10, 19, 23*). Sick bees are more susceptible to the effects of poor nutrition and pesticide poisoning, and vice versa.
2. Many flowers, nest sites, and nesting materials are contaminated with pesticides (*24*). Bees pick up the insecticides, herbicides, and fungicides applied to home gardens and lawns, golf courses, roadsides, and crops. These pesticides, alone and in combination, can be toxic.
3. There are not enough blooming flowers over the length of the growing season in our agricultural and urban landscapes to support bees (*36, 37*).

Responses to the first factor are limited primarily to policy makers, the research community, and beekeepers themselves. The second two of these factors are scalable and can be addressed at the individual and national level. We now address responses to these factors beginning with measures to curb the effects of bee parasites and disease.

Emerging Responses to Declines in Bee Health. To study CCD and other pollinator health issues, the 2008 Farm Bill approved more than $17 million in funding annually for five years for the U.S. Department of Agriculture (USDA) and for university research grants. The Farm Bill also approved another annual $2.75 million for five years to increase honey bee health inspections. Since the Farm Bill became law this funding has never been fully appropriated.

The 2008 Farm Bill also dictated that current USDA competitive grant programs should include pollinators—honey bees and native bees—as research priorities. As a result, research programs funded by the USDA under the National Institute of Food and Agriculture (NIFA), such as the Specialty Crops Research Initiative (SCRI) and the Agriculture and Food Research Initiative (AFRI), made pollinators a research priority in 2010 (*38*).

Along with research funding, statutory measures have been proposed to address pollinator health under the authority of the Plant Protection Act, the Honey Bee Act, and the Animal Health Act, all of which designate regulatory authority to the USDA Animal and Plant Health Inspection Service (APHIS). To address declining bumble bees specifically, in 2010 a group of more than 60 scientists working in collaboration with the Xerces Society for Invertebrate Conservation submitted a petition to the agency to implement rules prohibiting the movement of bumble bees outside of their native range and to require disease-free certification of commercially produced bumble bees prior to shipment within their range. That petition is still under administrative review.

Protection from Pesticides. A factor that can be addressed at multiple levels is the use of pesticides. In particular, while extensive literature exists on the sublethal effects of insecticides on bees in the laboratory, little exists on sublethal effects to colonies under natural conditions (*24, 39*). Common insecticides such as neonicotinoids and pyrethroids have been shown to affect learning, foraging activities, and nest site orientation by honey bees at sublethal doses (*40, 41*).

To assess the effects of pesticides on bees, the U.S. Environmental Protection Agency (EPA) uses a multistep process. The first of these steps is an acute contact toxicity test on honey bees that provides a median lethal dose (LD_{50}) based upon a single exposure; i.e., a dose that causes death to 50% of the exposed subjects (*42*).

If sublethal effects are observed, the EPA can, on a case-by-case basis, require additional studies, such as assessment under field conditions. No formal agency guidelines exist however on when such additional tests must be conducted (*42*). Risk assessment data collected through this multistep process are used to determine suitability of the product for legal registration (use), and to provide label information to end users (e.g., potential harm to honey bees).

One major uncertainty behind this assessment approach is the extent to which honey bees can be considered an appropriate surrogate for other pollinators. Larval honey bees are fed glandular secretion from adult bees that contains a very small proportion of pollen and nectar, whereas larvae of native bees feed directly on pollen and nectar and thus potentially have more direct exposure to pesticides. In addition many native bees are significantly smaller than honey bees, and are likely impacted by correspondingly smaller doses. Current EPA assessment protocols do not address this issue.

Individual farmers and homeowners have the ability to mitigate harm to pollinators through simple changes in application methods such as avoiding treatments around blooming plants or to areas where bees are nesting. Evening spraying when bees are less active is another simple, underutilized way to reduce harm. The best course of action, and the one most accessible to gardeners, for whom insect damage is cosmetic rather than economic, is to eliminate the use of pesticides entirely.

An important but under-recognized consideration is that the same landscape features that support healthy pollinator numbers also support other beneficial insects, especially those that prey upon crop pests, further reducing the need for pesticides.

The Need for Habitat. The third major challenge facing bees is a lack of season-long food sources, especially in agricultural landscapes where, if bee-pollinated plants even exist, they typically consist of large monocultures like cranberries, canola, or almonds, which provide only a few weeks of abundant food followed by a season-long dearth. Roughly 360 million ha or more than one-third, of the lower 48 states are managed as private cropland, pasture, or rangeland (*43*). This makes agriculture the largest land use activity in the country and thus one with the most potential impact on bees.

The USDA agencies responsible for administering and providing technical oversight on private lands are the Farm Service Agency (FSA) and the Natural Resources Conservation Service (NRCS). These agencies have achieved monumental conservation gains by coupling direct farm management advice to farmers with cash incentives to establish permanent, noncrop vegetation on highly erodible lands (*44*). As of 2004, more than 13 million ha were enrolled in various USDA conservation programs providing varying levels of benefits to wildlife (*44*). Both FSA and NRCS implement conservation policy through the Farm Bill (an omnibus statute passed roughly every 5 years). Of special significance is the 1985 Farm Bill establishing the Conservation Reserve Program (CRP) which offered landowners incentive payments to establish permanent, noncrop vegetation on highly erodible lands. Subsequent Farm Bills added additional conservation programs, include the Wildlife Habitat Incentives Program (WHIP) and the Environmental Quality Incentives Program (EQIP) (*44*). In the 2008 Farm Bill, all conservation programs, especially EQIP, were designated as funding mechanisms for the enhancement of bee habitat on private farms and ranches (*45*).

The 2008 Farm Bill was the first one to directly prioritize pollinators in USDA administered programs. This development occurred in direct response to CCD and the less publicized declines of native bees. Implementation of this prioritization has largely been left to individual states. For example, the Michigan NRCS and FSA developed a pollinator initiative through the CRP program that authorizes funding for the creation of up to 1101 ha of wildflower plantings on fruit farms to support resident native bees. As of this writing, nearly 405 ha of bee habitat have been enrolled. In California the NRCS supported the establishment of more than 445 ha of new bee habitat through the EQIP and WHIP programs in 2009. In addition, over the past several years, California NRCS has supported the creation of approximately 80 km of hedgerows that consist of pollen- and nectar-producing native plants. Similar efforts are underway in states as diverse as Maine, Florida, Pennsylvania, Wisconsin, and Oregon.

While the bee health research provisions of the Farm Bill have been difficult to implement due to nonappropriation of funds, the conservation provisions addressing the deficiency of habitat through USDA programs is proving to be very successful. Ongoing research supported by NRCS Conservation Innovation Grants, the NRCS Agricultural Wildlife Conservation Center, and others is documenting changes in pollinator and beneficial insect communities around NRCS conservation plantings that target pollinators.

In nonfarm settings, educational efforts reaching homeowners and greenspace managers can encourage the greater incorporation of floral diversity in parks and urban landscapes. One particular opportunity is the potential for incorporating bee-friendly native wildflowers in roadside vegetation programs. Initial investigation indicates that roadside plantings may provide corridors for pollinator movement, refuge from pesticides in adjacent farm fields, erosion control, and lower vegetation management costs for transportation agencies (*46*). Initial research also indicates that pollinator mortality from traffic may actually be lower when native wildflowers are abundant, as it reduces the need for foraging over greater distances (*47*).

Specific habitat guidelines for all of these landscapes (rural, urban, roadside) vary across regions. Baseline habitat guidelines encourage the inclusion of at least 3 different plant species that bloom at any given time during the growing season (spring, summer, fall), with more being even better (*45*). Recommendations often include clumping single species in groups to increase foraging efficiency by bees, and placement of foraging habitat adjacent to nest sites. The majority of native bees nest in the ground, with a few species using woody snags, brush piles, and clump-forming grasses. Another important consideration is the protection of potential nest sites from disruptive management practices like widespread burning or tillage (*48*).

Concluding Remarks

Pollinators are receiving more conservation attention today than at any other time in history. Scientists, conservationists, and farmers are working harder than ever—in partnership—to understand how pesticides, diseases, and habitat loss impact pollinator populations. They are also working to understand the most successful strategies for creating landscapes that support the greatest abundance of these important insects.

At the same time, the public and policy-makers are increasingly aware of the problems afflicting bees and the critical role they play in food production and natural systems. This awareness by such diverse audiences has led to significant positive policy changes (e.g., the 2008 Farm Bill) due in large part to the bipartisan appeal of policies and habitat conservation efforts that support crop production, honey bee colony health, and wild native bees and wildlife. Pollinator conservation provides a venue for diverse audiences to collaborate to solve common problems.

But there is no reason to wait for research and policy to mitigate the plight of the bees. Individuals can modify their immediate landscapes to make them healthier for bees, whether that landscape is a public rangeland in Wyoming or a flower box in Brooklyn. It is also possible to reduce agricultural and urban pesticide use to mitigate bee poisonings. We can engage in the sustainable management of honey bees and native bees (*49*). Promoting the health of bee pollinators can begin as an individual or local endeavor, but collectively has the far-reaching potential to beautify and benefit our environment in vital and tangible ways.

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Acknowledgments

Funding support to M.S. was provided by the USDA National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative (AFRI) Managed Pollinator Coordinated Agricultural Project 2009-85118-05718, and to M.S. and N.H.E., Jr. by a USDA NIFA AFRI Competitive Grant 2010-65615-20631. We also thank Scott Hoffman Black and Sarina Jepsen of the Xerces Society for their feedback.

Literature Cited

(1) Skokstad, E. The case of the missing hives. *Science* **2007**, *316*, 970–972.
(2) vanEngelsdorp, D.; Meixner, M. D. A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *J. Invertebr. Pathol.* **2010**, *103*, S80–S95.
(3) Evans, E.; Thorp. R.; Jepsen, S.; Hoffman Black, S. Status review of three formerly common species of bumble bee in the subgenus Bombus: *Bombus affinis* (the rusty patched bumble

bee), *B. terricola* (the yellowbanded bumble bee), and *B. occidentalis* (the western bumble bee). The Xerces Society, 2008. http://www.xerces.org/wp-content/uploads/2009/03/xerces_2008_bombus_status_review.pdf.
(4) National Research Council. *Status of Pollinators in North America*; National Academies Press: Washington, DC, 2007.
(5) Gallai, N.; Salles, J.-M.; Settele, J.; Vaissiere, B. E. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ.* **2009**, *68*, 819–821.
(6) Klein, A.; Vaissière, B.; Cane, J.; Steffan-Dewenter, I.; Cunnigham, S.; Kremen, C.; Tscharntke, T. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc.* **2007**, *274*, 303–313.
(7) Morse, R.; Calderone, N. The value of honey bees as pollinators of U.S. crops in 2000. In *Bee Culture*, Medina, OH, 2000.
(8) Aizen, M. A.; Harder, L. The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. *Curr. Biol.* **2009**, *19*, 915–918.
(9) Aizen, M. A.; Garibaldi, L. A.; Cunningham, S. A.; Klein, A. M. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals Bot.* **2009**, *103*, 1579–1588.
(10) vanEngelsdorp, D.; Evans, J. D.; Saegerman, C.; Mullin, C.; Haubruge, E. Colony collapse disorder: A descriptive study. *PLoS ONE* **2009**, *4* (8), e6481.
(11) Dimitri, C.; Effland, A.; Conklin, N. *The 20th Century Transformation of U.S. Agriculture and Farm Policy*; Electronic Information Bulletin Number 3; USDA: Washington, DC, 2005. http://www.ers.usda.gov/publications/eib3/eib3.htm.
(12) Alaux, C.; Ducloz, F.; Crauser, D.; Le Conte, Y. Diet effects on honeybee immunocompetence. *Biol. Letters* **2010**; 10.1098/rsbl.2009.0986.
(13) Le Conte, Y.; Ellis, M.; Ritter, W. Varroa mites and honey bee health: Can varroa explain part of the colony losses? *Apidologie* **2010**; 10.1051/apido/2010017.
(14) Milani, N. The resistance of *Varroa jacobsoni* Oud. to acaricides. *Apidologie* **1999**, *30*, 229–234.
(15) Ball, B. V.; Bailey, L.; Viruses. In *Honey Bee Pest, Predators, & Diseases*; Morse, R. A., Flottum, K., Eds.; The A. I. Root Co.: Medina, OH, 1997; pp 11−31.
(16) Chen, Y. P.; Siede, R. Honey Bee Viruses. *Adv. Virus Res.* **2007**, *70*, 33–80.
(17) Chen, Y. P.; Evans, J.; Feldlaufer, M. Horizontal and vertical transmission of viruses in the honeybee *Apis mellifera*. *J. Invertebr. Pathol.* **2006**, *92*, 152–159.
(18) Higes, M.; Martín-Hernández, R.; Botías, C.; Garrido Bailón, E.; González-Porto, A. V.; Barrios, L.; Jesús del Nozal, M.; Bernal, J. L.; Jiménez, J. J.; García Palencia, P.; Meana, A. How natural infection by *Nosema ceranae* causes honeybee colony collapse. *Environ. Microbiol.* **2008**, *10* (10), 2659–2669.
(19) Cox-Foster, D.; Conlan, S.; Holmes, E. C.; Palacios, G.; Evans, J. D.; et al. A metagenomic survey of microbes in honey bee colony collapse disorder. *Science* **2007**, *318*, 283–286.
(20) Alaux, C.; Brunet, J.-L.; Dussaubat, C.; Mondet, F.; Tchamitchan, S.; Cousin, M.; Brillard, J.; Baldy, A.; Belzunces, L. P.; Le Conte, Y. Interactions between *Nosema* microspores and a neonicotinoid weaken honeybees (*Apis mellifera*). *Environ. Microbiol.* **2010**, *12* (3), 774–782.
(21) Cox-Foster, D.; vanEngelsdorp, D. Saving the honey bee. *Sci. Am.* **2009**, *300*, 40–47.
(22) Johnson, R. M.; Pollock, H. S.; Berenbaum, M. R. Synergistic interactions between in-hive miticides in *Apis mellifera*. *J. Econ. Entomol.* **2009**, *102*, 474–479.
(23) Johnson, R. M.; Evans, J. D.; Robinson, G. E.; Berenbaum, M. R. Changes in transcript abundance relating to colony collapse disorder in honey bees (*Apis mellifera*). *Proc. Natl. Acad. Sci., U.S.A.* **2009**, *106*, 14790–14795.
(24) Mullin, C. A.; Frazier, M.; Frazier, J. L.; Ashcraft, S.; Simonds, R.; et al. High levels of miticides and agrochemicals in North American apiaries: Implications for honey bee health. *PLoS ONE* **2010**, *5* (3), e9754.
(25) Winfree, R.; Griswold, T.; Kremen, C. Effect of human disturbance on bee communities in a forested ecosystem. *Cons. Biol.* **2007**, *21*, 213–223.
(26) Tepedino, V. The pollination efficiency of the squash bee (*Peponapis pruinosa*) and the honey bee (*Apis mellifera*) on summer squash (*Cucurbita pepo*). *J. Kansas Entomol. Soc.* **1981**, *54*, 359–377.
(27) Javorek, S.; Mackenzie, K.; Vander Kloet, S. Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (Ericaceae: *Vaccinium angustifolium*). *Ann. Entomol. Soc. Am.* **2002**, *95*, 345–351.
(28) Greenleaf, S.; Kremen, C. Wild bee species increase tomato production and respond differently to surrounding land use in Northern California. *Biol. Conserv.* **2006**, *133*, 81–87.
(29) Losey, J. E.; Vaughan, M. The economic value of ecological services provided by insects. *Bioscience* **2006**, *56*, 311–323.
(30) Kremen, C.; Williams, N.; Bugg, R.; Fay, J.; Thorp, R. The area requirements of an ecosystem service: crop pollination by native bee communities in California. *Ecol. Lett.* **2004**, *7*, 1109–1119.
(31) Winfree, R.; Williams, N. W.; Gaines, H.; Ascher, J. S.; Kremen, C. Wild bee pollinators provide the majority of crop visitation across land-use gradients in New Jersey and Pennsylvania, USA. *J. Appl. Ecol.* **2008**, *45*, 793–802.
(32) Foltz, S.; Black, S.; Jepsen, S.; Evans, E.; Thorp, R. Species fact sheet: *Bombus franklini*. The Xerces Society, 2009. http://www.xerces.org/wp-content/uploads/2009/09/sfs-iihy-bombus-franklini.pdf.
(33) Buchmann, S.; Nabhan, G. *The Forgotten Pollinators*; Island Press: Washington, DC, 1996.
(34) Colla, S.; Otterstatter, M.; Gegear, R.; Thomson, J. Plight of the bumblebee: Pathogen spillover from commercial to wild populations. *Biol. Conserv.* **2006**, *129*, 461–467.
(35) Grixti, J.; Wong, L.; Cameron, S.; Favert, C. Decline of Bumble Bees (*Bombus*) in the North American Midwest. *Biol. Conserv.* **2008**, *142*, 75–84.
(36) Biesmeijer, J. C.; Roberts, S. P. M.; Reemer, M.; Ohlemuller, R.; et al. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* **2006**, *313*, 351–354.
(37) Winfree, R.; Aguilar, R.; Vazquez, D. P.; LeBuhn, G.; Aizen, M A. A meta-analysis of bees' response to anthropogenic disturbance. *Ecology* **2009**, *90* (8), 2068–2076.
(38) Managed Pollinator Coordinated Agricultural Project. Web site: http://www.extension.org/beehealth.
(39) Thompson, H.; Maus, C. The relevance of sublethal effects in honey bee testing for pesticide risk assessment. *Pest Manage. Sci.* **2007**, *63* (11), 1058–1061.
(40) Desneux, N.; Decourtye, A.; Delpuech, J. M. The sublethal effects of pesticides on beneficial arthropods. *Annu. Rev. Entomol.* **2007**, *52*, 81–106.
(41) Aliouane, Y.; El Hassani, A.; Gary, V.; Armengaud, C.; Lambin, M.; Gauthier, M. Subchronic exposure of honey bees to sublethal doses of pesticides: effects on behavior. *Environ. Toxicol. Chem.* **2009**, *28* (1), 113–122.
(42) OPPTS. *Ecological Effects Test Guidelines OPPTS 850-3020 Honey Bee Acute Contact Toxicity*; EPA 712-C-96-147; U. S. Environmental Protection Agency: Washington, DC, 1996. http://www.epa.gov/opptsfrs/publications/OPPTS_Harmonized/850_Ecological_Effects_Test_Guidelines/Drafts/850-3020.pdf.
(43) Heard, L. P.; Allen, A.; Best, L.; Brady, S.; Burger, W.; Esser, A.; Hackett, E,.; Johnson, D.; Pederson. R.; Reynolds, R.; Rewa, C.; Ryan, M.; Molleur, R.; Buck, P. *A comprehensive review of Farm Bill contributions to wildlife conservation, 1985−2000*; Technical Report WHMI-200; U.S. Department of Agriculture, Natural Resources Conservation Service, 2000.
(44) Gray, R.; Teels, B. Wildlife and fish conservation through the farm bill. *Wildlife Soc. Bull.* **2006**, *34*, 906–912.
(45) Vaughan, M.; Skinner, M. Using Farm Bill Programs for Pollinator Conservation; USDA Natural Resources Conservation Service National Plant Data Center, 2008. http://www.xerces.org/wp-content/uploads/2008/11/using_farm_bill_programs_xerces_society.pdf.
(46) Hopwood, J. L. The contribution of roadside grassland restorations to native bee conservation. *Biol. Conserv.* **2008**, *141*, 2632–2640.
(47) Ries, L.; Debinski, D. M.; Wieland, M. L. Conservation value of roadside prairie restoration to butterfly communities. *Conserv. Biol.* **2001**, *15*, 401–411.
(48) Vaughan, M.; Mader, E.; Norment, J.; Keirstead, D.; Alexander, T.; Barrett, N.; Schreier, B.; Lipsky, A.; Giorgi, K.; Henry, H.; Stubbs, C. *New England Pollinator Conservation Handbook*; USDA Natural Resources Conservation Service, 2009. ftp://ftp-fc.sc.egov.usda.gov/NH/WWW/Technical/New_England_NRCS_Pollinator_Tech_Note_FINAL.pdf.
(49) Mader, E., Spivak, M., Evans, E. *Managing Alternative Pollinators: A Handbook for Beekeepers, Growers and Conservationists*; NRAES-186; Natural Resource, Agriculture, and Engineering Service: Ithaca, NY, 2010; 162 pp.

ES101468W