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Land Use, Land Cover, and Pollinator Health: A Review and Trend Analysis

Daniel Hellerstein, Claudia Hitaj, David Smith, and Amélie Davis

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Abstract

About 35 percent of the world's food crops depend on pollinators, including managed honey bees, to reproduce. However, pollinators face a number of stressors, such as parasites, poor nutrition, pesticides, and diseases. A literature review indicates that pollinators may benefit from landscapes richer in high-quality forage (pollen and nectar sources) and highlights the different needs of managed honey bees and native (unmanaged) pollinators. This study uses 30 years of data on U.S. land uses to calculate a pollinator forage suitability index. When averaged across the Nation, the forage suitability index increased from 1982 to 2002 and declined slightly from 2002 to 2012—though in important honey bee regions (such as Central North and South Dakota), the decline from 2002 to 2012 is more pronounced. The study also analyzes the economics of providing better pollinator forage, such as assigning property rights for colony placement and voluntary government conservation programs to increase pollinator forage.

Keywords: Pollinators, honey bees, land use, land cover, forage, economics

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Land Use, Land Cover, and Pollinator Health: A Review and Trend Analysis

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What is the issue?

Crops that depend on pollinators account for up to one-third of total U.S. food consumption. However, honey bees and other pollinators face a variety of stressors, including diseases, insect pests, pesticide exposure, and changing landscapes. Over the last decade, annual losses of managed honey bee colonies have been high. Better nutrition for pollinators may help alleviate the effects of some of the stressors. Changing the Nation's land uses and land covers (LULC)—such as by planting vegetation rich in nectar and nutritious types of pollen—may improve the forage available to pollinators. This study reviews the literature on the effects of land use on pollinator health and examines trends in pollinator forage quality as LULC has changed in the United States over the last 30 years.

What did the study find?

A review of the literature reveals that both managed honey bees and native pollinators face several sources of stress that affect colony health. The main findings include:

- Honey bee mortality, as measured by the loss of a honey bee colony, is higher than in previous decades. Annual losses varied between 29 and 45 percent of colonies from 2010-11 to 2015-16.
- Assessing the status of native pollinators is difficult because long-term population data are not available. However, evidence points to population decline for several wild bee species (notably bumblebees) and some butterflies, bats, and hummingbirds.
- A variety of stressors affect the health of honey bee colonies. Beekeepers reported that in spring 2015, nearly 45 percent of colonies were affected by varroa mites, 20 percent were affected by other pests, and 17 percent were affected by pesticides.

Beekeepers in the United States have maintained and even increased the number of colonies over the last decade through intensive management of honey bee colonies:

- Adapted practices include splitting a honey bee colony and adding a new queen to one of the splits, systematic monitoring of colonies for pests and pathogens, and supplemental feeding.
- The number of honey-producing colonies has increased by 9 percent from 2.44 million in 2007 to 2.66 million in 2015. Over the same period, the value of production of the top 10 pollinator-dependent crops grew by a weighted average of around 76 percent.

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The literature review also reveals evidence of how LULCs that contain vegetation beneficial to pollinators improve both pollinator abundance and health and can lead to better agricultural outcomes. The LULC-related needs of native pollinators differ from those of managed honey bees.

- Native pollinators benefit from access to nearby high-quality forage habitat—habitat that is both rich in plants that provide pollen and nectar and that contain nesting opportunities.

- Managed honey bees are often transported from location to location by their beekeepers to provide pollination services and to increase honey production. Thus, the overall availability of forage may matter more than its exact placement. For example, the provision of high-quality forage land in the Dakotas, where many honey bee colonies spend the summer refortifying themselves, may help improve colony survival rates.

To examine how broad land-use changes have affected the ability of the land to provide forage to pollinators, ERS developed a forage suitability index (FSI) that links pollinator forage quality to LULC. Findings show that forage suitability was unchanged for most (75 percent) of the Nation between 1982 and 2012. Overall LULC changes in this timespan led to a small increase in the average FSI nationally. This is in part due to land taken out of agricultural production under USDA's Conservation Reserve Program (CRP).

However, the overall results mask regional and temporal variation:

- From 1982 to 2002, FSI improved on about twice as many acres as it declined. But from 2002 to 2012, the index declined on more acres than it improved.

- In North and South Dakota's summer foraging grounds, FSI declined more than the national average between 2002 and 2012. This change is driven by decreases in acres with high FSI LULCs (such as CRP) and increases in acres in low FSI LULCs (such as soybeans).

These findings are limited by the study's focus on estimated changes in the FSI. Other factors that may affect pollinator health—such as changes in land management, including pesticide use, and changes in field size and associated densities of uncultivated field edges—are not considered.

The report concludes with a summary of economic insights on issues facing the development of markets for forage-rich pollinator habitat. Pollinator habitat has "public good" features, so markets to provide better pollinator habitat may not readily develop. This can lead to under-provision of forage-rich landscapes. For example, if a landowner converts land to honey bee-friendly habitat, his or her honey bees may benefit from this conversion but so, too, will honey bees managed by others. Thus, the landowner incurs the full cost of this conversion without reaping full benefits. Assigning exclusionary rights for hive placement—as is done in a few States—may encourage beekeepers and landowners to work together to install pollinator friendly habitat. In addition, the Government can support the creation of pollinator habitat, such as through pollinator-friendly covers on CRP land.

How was the study conducted?

The study reviews the economics and ecology literature on land use, land cover, and pollinators. Data from the National Resources Inventory (NRI) are used to supply land cover/use for 970,000 points in the conterminous United States from 1982 to 2012. Using an expert assessment of the average pollinator forage score for different types of land use, along with this land use/cover variable, researchers assigned each NRI point an FSI. Trends in pollinator habitat quality are computed by aggregating these index scores over regions. Lastly, economic theory informs the discussion of factors that can lead to under-provision of pollinator-friendly habitat.

Land Use, Land Cover, and Pollinator Health: A Review and Trend Analysis

Introduction

About one-third of the world's food crops depend, in varying degrees, on pollinators—including managed honey bees and more than 3,500 species of native bees (USDA-NRCS, 2016d). Some crops, such as almonds and melons, require pollination to produce nuts or fruit; other crops, such as tomatoes, apples, blueberries, cherries, and canola, receive a yield boost from pollination. The production of pollinator-dependent crops has increased over the last several decades, but the number of pollinators has declined (Aizen and Harder, 2009).[1] In addition, beekeepers report elevated honey bee colony mortality over the last decade—for example, in the United States, nearly half of managed bee colonies were lost in 2015 (BIP, 2016; USDA-NASS, 2016b).

Honey bee well-being is affected by numerous stressors, such as insect pests (e.g., varroa mites), pesticide exposure, compromised nutrition, long-distance travel, and various diseases (e.g., European foulbrood). These factors have affected colony management, with beekeepers intensifying both monitoring and treatment of their hives (Alaux et al., 2010; Grünewald, 2010). Moreover, the thousands of native bee species in the United States (Droege, 2015) are also under stress from pesticide exposure and changes in native habitat (Steffan-Dewenter, 2008; Rose et al., 2014; Potts et al., 2015).

It is generally accepted by researchers that the various stressors facing honey bees and wild pollinators have a synergistic effect (USDA, 2012, Bryden et al., 2013). The integrated nature of these interactions, where any one additional stressor amplifies the decline in bee health, may explain the broad range of actions recommended by a variety of stakeholder groups, such as limiting neonicotinoid pesticide applications or combating varroa mite infestations (EPA, 2014).

Better nutrition may alleviate some of the synergistic stress impacts. Pollinators with access to good forage—the nectar and pollen of flowering plants—better withstand other stressors (Huang, 2012; Naug, 2009). Land with good-quality forage contains vegetation that provides abundant and diverse nectar and nutritious pollen (USDA, 2014). Land meeting those criteria could be (1) wild lands, (2) restored land that is planted with appropriate vegetation, or (3) cultivated lands that contain a more pollinator-friendly set of crops or cropping patterns. In the case of wild pollinators, land must also provide quality nesting habitat.

This study seeks to address the following questions. What is known about the impacts of LULC on pollinator health? How have nationwide changes in LULC affected honey bee forage availability? What economic issues may limit the capability of markets to provide pollinator-friendly LULC? And what issues bear consideration when evaluating how voluntary Government conservation programs, such as USDA's Conservation Reserve Program and Environmental Quality Incentives Program, can provide pollinator-friendly habitat?

[1]The number of honey-producing colonies declined from 5.9 million in 1947 to 2.3 million in 2008, before recovering to 2.78 million in 2016 (Hoff, 1995; USDA-NASS, 2017).

Pollinators in Agriculture: Native Bees, Pollination Services, Honey Production, and Population Trends

While most agricultural commodities are wind pollinated, about 35 percent of the world's food crops, primarily fruit, nuts, and vegetables, either require or benefit from insect pollination (USDA-NRCS, 2016d). Estimates of the annual value of pollinators in the United States range from $150 million to $19 billion (National Research Council, 2007), depending mainly on whether those values account for willingness to pay and indirect benefits of crops that require pollinators to produce seeds. [2] A frequently used estimate of the value of insect pollination services to crops is $15 billion, of which $12 billion is attributable to honey bees and $3 billion is attributable to other pollinators (Johnson 2010, Calderone 2012, Pollinator Health Task Force 2016).

Pollinators can be broadly classified in two categories: native pollinators and honey bees (*Apis melilifera)*. The broad variety of native pollinators includes over 3,500 species of bees (most of which are solitary), moths and beetles, and other animals (such as bats and birds). With a few exceptions, native pollinators are not domesticated—they live, forage, and breed in the wild.[3]

Native bees in North America that pollinate crops include bumblebees (tomatoes and other greenhouse crops), the alkali bee (alfalfa hay, clover, and mint), the blue orchard bee (almonds, apples, and sweet cherries), and the aptly named squash and gourd bee, sunflower bee, and blueberry bee (National Research Council, 2007). Assessing the status of wild pollinators is difficult because data on long-term population are not available. However, there has been demonstrable evidence of population decline for several wild bee species (notably bumblebees) and some butterflies, bats, and hummingbirds (National Research Council, 2007).

Native pollinators are particularly efficient pollinators for a variety of crops, including pumpkin, tomato, cranberry, and blueberry—crops valued at $3 billion annually in the United States (Losey and Vaughan, 2006). With sufficient habitat, native pollinators could provide all of the necessary pollination for these specific crops (Barfield et al., 2015). In contrast, honey bees are generalist pollinators and can pollinate a wider variety of crops, though not as efficiently as some native pollinators (National Research Council, 2007). However, honey bees can be managed by beekeepers and placed around crops during pollination time.

Honey bees are social insects that live together as a colony in a hive, usually a special box provided by a beekeeper. A colony consists of a single queen bee along with tens of thousands of female worker bees and hundreds of male drones. Honey bees collect pollen and nectar from flowering plants. During the winter, honey bees survive on the honey they have produced, though beekeepers can supplement their feed with sugar water and plant-based protein powders. Beekeepers can

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[2]The higher values are derived by calculating the loss of agricultural production due to a hypothetical removal of all commercial honey bees with no substitute pollination method employed, and all other economic variables held constant (e.g., output prices, input costs). They do not include other values, such as impacts on the reproduction and diversity of noncultivated flora.

[3]Other than honey bees, a few insects are commercially available for pollination services. These include bumblebees—a colony insect that is often used in greenhouses to pollinate tomatoes and other high-value crops (http://extension.psu.edu/pests/ipm/pestproblemsolver/greenhouse/bugvsbug/bumble). The solitary alfalfa leaf cutter bee—a European bee introduced into the United States sometime after 1930—is used in the production of alfalfa seed (http://agr.mt.gov/agr/Programs/Bees/LeafcutterBees.html), and the solitary blue orchard bee is used as an orchard pollinator (www.ars.usda.gov/pacific-west-area/logan-ut/pollinating-insect-biology-management-systematics-research/docs/blue-orchard-bee/).

manage their colonies to produce honey, pollination services, and even other products, such as beeswax, throughout the year.

Farmers who grow crops that depend on pollination can choose to rely on wild pollinators in the area or pay beekeepers to place honey bees or other managed bees, such as the blue orchard bee, around their crops. In 2016, commercial honey bee keepers in the United States produced honey valued at $336 million and other products, including queens and beeswax, valued at $149 million (USDA-NASS, 2017) and earned $354 million from pollination services (USDA-NASS, 2016c).[4] Almost four-fifths of pollination service fees in 2016 were collected from producers of almonds, followed by producers of apples, blueberries, and cherries (table 1). Production of the top four crops grown by farmers requiring pollination services increased from 2007 to 2015. For the top 10 crops as a whole, growth averaged around 76 percent (in value of production terms, weighted by the proportion of collected pollination fees for each crop). Over the same period, the number of honey-producing colonies grew by 9 percent (USDA-NASS, 2017).

Table 1

Top 10 crops by pollination value in 2016 and change in the value of their production from 2007 to 2015

Crop (region)	Colonies used in 2016	Total value of pollination, 2016	Price per colony in 2016	Value of production in 2015	Change in value of production, 2007-15 (inflation adjusted)
	Number	*1,000 dollars*	*Dollars*	*1,000 dollars*	*Percent*
Almond (6&7)	1,680,000	280,560	167.0	5,325,000	93.9
Apple (1,2,4,5,6&7)	183,400	10,167	52.6	3,394,185	13.8
Blueberry (1,2,3,5,6&7)	147,000	10,166	66.5	584,150	59.6
Cherry (1,4,5,6&7)	134,100	7,711	51.8	703,228	19.9
Melon: watermelon, cantaloupe, honeydew (1,2,3,5,6&7)	133,500	7,156	53.6	825,072	-9.6
Cranberry (1,5,6&7)	88,000	6,740	74.6	27,455	-1.3
Alfalfa (6&7)	92,000	5,851	63.6	8,729,134	-13.8
Plum (6&7)	46,000	2,962	64.4	104,760	-9.4
Avocado (6&7)	69,000	2,815	40.8	295,797	-24.2
Cucumber (1,2,3,6&7)	42,500	2,112	48.6	176,983	-35.2
Other	362,300	17,977	49.6		
All crops	**2,977,800**	**354,217**	**119.0**		

Note: NASS Cost of Pollination Survey provides the cost of pollination by crop for specific regions (1 through 7, available at http://usda.mannlib.cornell.edu/usda/current/CostPoll/CostPoll-12-22-2016.pdf) but not for the United States as a whole to avoid disclosing data of individual producers in particular regions. Thus, the category “other” in the table above may include the cost of pollination of some of the already listed crop categories for excluded regions. The total of colonies used is not a measure of total colonies because a colony can be used to pollinate multiple crops throughout the year. These numbers do not necessarily account for the value of all pollination services provided by honey bees. The price per colony is an unweighted average price across all regions for which an estimate is available.

Source: USDA, Economic Research Service analysis of USDA, National Agricultural Statistics Service (NASS) Cost of Pollination Survey (USDA-NASS, 2016c) and USDA, NASS QuickStats data portal (USDA-NASS, 2016a).

[4] Beekeepers can engage in one or more of these activities throughout the year.

Honey-producing colonies in the United States declined from 5.9 million in 1947 to a low of 2.3 million in 2008, before recovering to 2.8 million in 2016 (Hoff, 1995; USDA-NASS, 2017; vanEngelsdorp and Meixner, 2010). The recent increase in honey-producing colonies has not kept pace with the growth in the value of production of pollinator-dependent crops.

In addition, honey bee mortality, as measured by the loss of a honey bee colony, has remained high for the past decade (fig. 1). Nationwide data on winter loss rates are not available prior to 2006, but several studies indicate winter loss rates in previous decades were 17-20 percent (John, 2010) or around 15 percent (Burgett et al., 2010; Pernal, 2008; Rucker et al., 2016; vanEngelsdorp et al., 2007). In 2006-07, approximately 30 percent of honey bee colonies were lost during the October 1 through April 1 over-winter period. While the over-winter loss rate has since diminished (22 percent in 2014-15), over-summer losses have grown. Colony loss is expected predominantly during the colder winter, but in 2014-15, summer losses (27 percent) exceeded winter losses (23 percent) for the first time (Kaplan, 2015). The net result is that in 2015-16, about 44 percent of colonies perished, compared with 36 percent in 2010-11 (BIP, 2016). The 2015-16 loss estimate of 44 percent is similar to the 43.4 percent annual loss estimate that ERS calculated based on quarterly numbers from the USDA, National Agricultural Statistics Service Colony Loss Report (USDA-NASS, 2016b). The Colony Loss Report provides quarterly loss estimates beginning only in 2015, but the survey is representative nationally, while the Bee Informed Partnership (BIP) survey is based on validated responses from 5,756 beekeepers that collectively managed about 15 percent of the country's 2.66 million managed honey-producing colonies.[5]

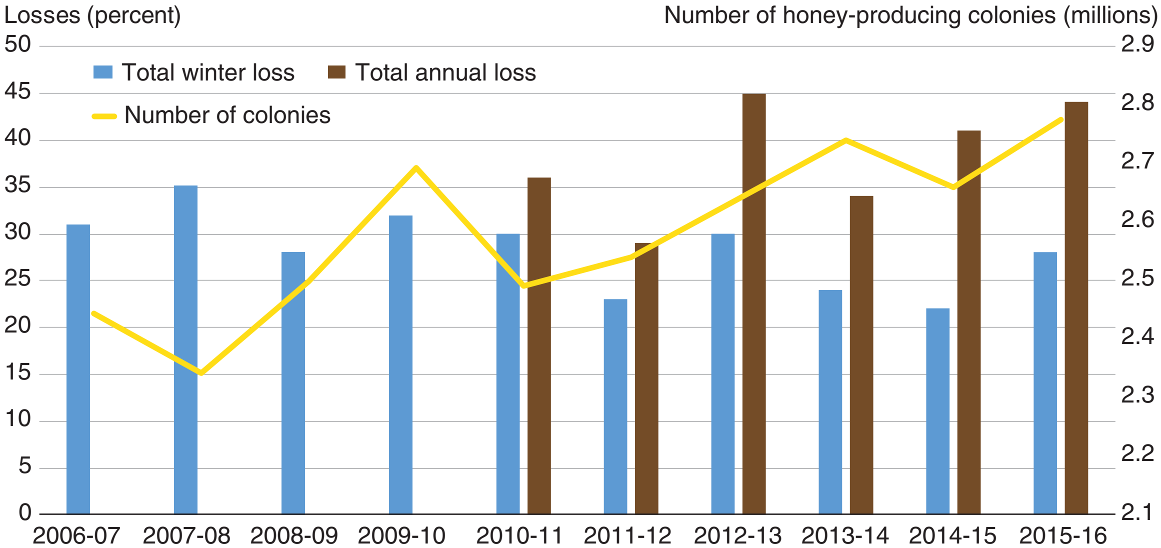
The increase in honey-producing colony numbers since 2008, even with high colony mortality, is driven by intensified beekeeper management—splitting hives, purchasing new queens, and adopting preventative measures to maintain colony health. This includes systematic monitoring for pests and pathogens to inform the application of miticides, antibiotics, and other chemicals; and the use of supplemental feeds, such as during the early spring before almond bloom (USDA, 2012; Bee Culture, 2016), a time when honey bees are naturally in a dormancy period.

Honey bee colonies are lost for a variety of reasons, as many stressors affect honey bee health simultaneously. The recently released Colony Loss Survey (USDA-NASS, 2016b) asked beekeepers to identify the stressors affecting their colonies. Responses showed that in spring 2015, nearly 45 percent and 20 percent of colonies were affected by varroa mites or other pests, respectively, and 17 percent were affected by pesticides (fig. 2).

Given the importance of pollinators to the Nation's food supply, farmers, researchers, and Government agencies are considering various pathways to improve pollinator health. One such pathway is improved pollinator habitat—a landscape that provides nutritious forage, nesting opportunities for native pollinators, and reduced risk from pests, pathogens, and pesticides.

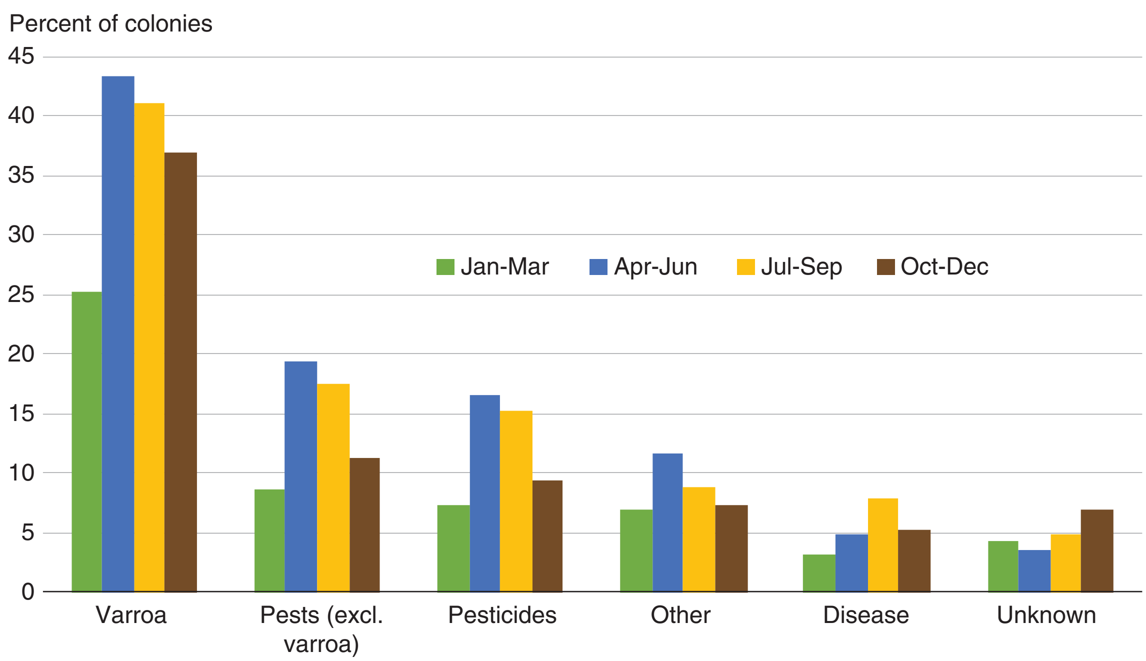
[5]See Steinhauer (2016) for a discussion of the differences between NASS and Bee Informed Project estimates of colony loss.

Figure 1
Managed honey bee colony numbers and loss estimates for the United States



Note: Annual colony loss estimates from the Bee Informed Partnership are for the period from October 1 to September 30 of the following year, and winter loss estimates are from October 1 to April 1 of the following year. Note that before 2010-11, data on summer losses were not gathered. The data on the number of honey-producing colonies are from the NASS Honey Report.
Source: USDA, Economic Research Service using Bee Informed Partnership (2016) and USDA, National Agricultural Statistics Service (NASS) Honey Report (USDA-NASS 2017).

Figure 2
Stressors affecting honey bee colonies, 2015



Note: A colony could be affected by more than one stressor simultaneously.
Source: USDA, Economic Research Service using USDA, National Agricultural Statistics Service, Colony Loss Survey (2016).

A Review of Land Use and Pollinator Health

While both wild bees and managed honey bees contribute to agricultural production, they in turn depend on the land to provide forage resources—the pollen and nectar of flowering plants that bees feed on to survive. The quality and quantity of pollinator forage available to pollinators depend on the land use and land cover (LULC). And, if forage resources provided by an LULC are inadequate, pollinator health may be poor.

The literature on LULC and pollinator health has grown rapidly over the last decade, and a number of literature reviews and meta-analyses that combine data from multiple studies are now available (see table 2).[6] Many of these studies link pollinator proclivities, especially those of native pollinators, with LULC characteristics, such as the amount and spatial configuration of land under various covers.

Native pollinators and honey bees: Land-use and land-cover needs

Native pollinators

During pollination season, the number and species mix of native pollinators depend on existing LULCs. Many native pollinator species have short life cycles and are dormant much of the year. Thus, a given pollinator species may not be active when a crop of interest (such as tomatoes) needs pollination. In general, native pollinators have shorter foraging ranges than do honey bees, and native bees require nesting habitat (Ricketts et al., 2008). Thus, pollinator-supporting LULCs need to be fairly close (often less than 500 meters) to the crops that need pollination services from native pollinators (Garibaldi et al., 2011).

On a per-individual basis, native pollinators often are more effective at pollinating crops than honey bees (Garibaldi et al., 2011); however, the densities of native pollinators may be low. It is typically difficult to increase the numbers of native pollinators on an as-needed basis.

Honey bees

Honey bees are not native to the United States and arrived with European settlers. They may be "wild" or "managed" (subject to beekeeper management). Since wild honey bees are no longer abundant (Kershner, 1999), this study considers managed honey bees only.

In some ways, honey bees are managed like livestock. In search of forage, given differences in weather and predominant vegetation, honey bees are moved around by beekeepers to find good "pasture." In other ways, honey bee management is like the provision of agricultural services: the bees are moved to areas where pollination services are required, and then they are moved again (fig. 3).

Honey bees forage throughout much of the warm seasons and, in colder months, will cluster together in their hives. While foraging, they consume available pollen and nectar and store any surplus. During the cold months or when forage opportunities are sparse, they consume pollen and honey from their stores. Consumption of available pollen and nectar occurs regardless of nutritional

[6]The studies used in these meta-analyses do overlap. Later meta-analyses tend to draw from a large set of studies, both due to their ability to use more recent studies and due to searches that examine richer citation databases. In addition to these meta-analyses, non-review-type articles that analyze forage requirements and landscape composition include Cusser and Goodell (2013), Härtel and Steffan-Dewenter (2014), and Jhaand Kremen (2013).

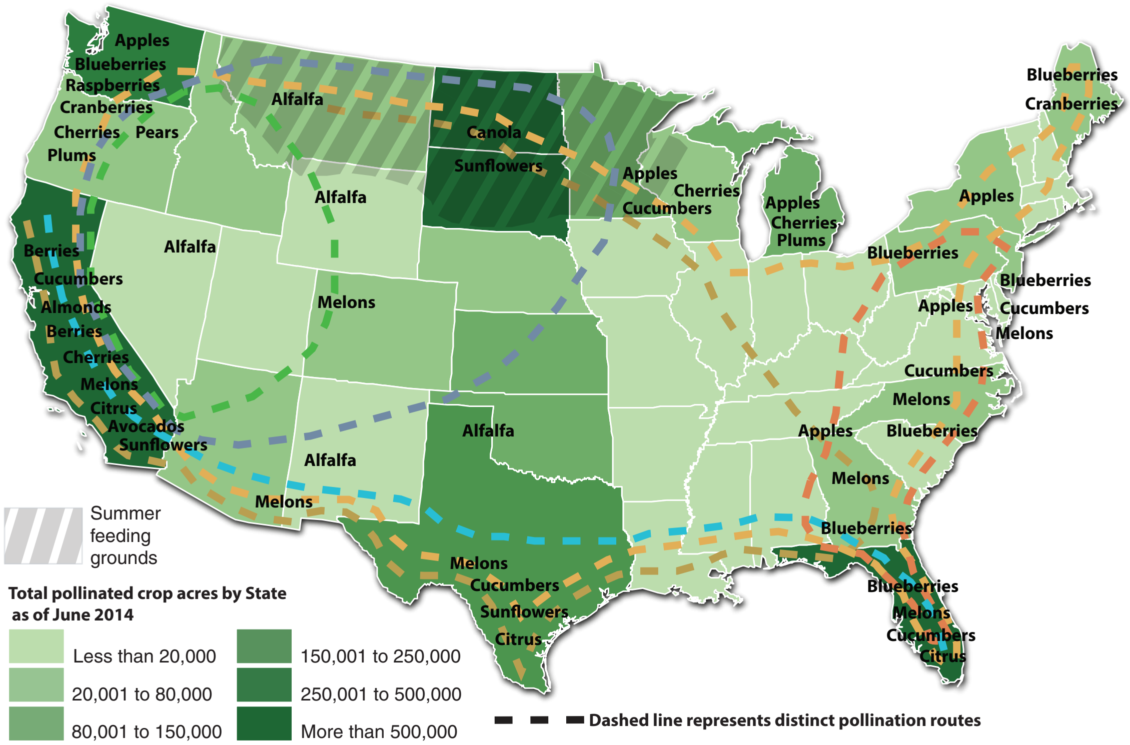
Table 2

Synopsis of selected literature reviews on land use/land cover and pollinator health (ordered by year of publication)

Publication	Synopsis and general findings
Ricketts et al. (2008)	A synthesis of results from 23 studies estimating the relationship between pollination services and distance to natural habitats. Pollinator richness and visitation rates to crops exponentially decline with increasing distance from natural habitat, with evidence indicating overall decline in fruit and seed set (though landscape effects on pollination services can vary substantially).
Brown and Paxton (2009)	A synopsis of 12 reviews on the threats to pollinators suggesting that habitat loss is the major threat to pollinator diversity, while invasive species, emerging diseases, pesticide use, and climate change also have the potential to affect bee populations.
Winfree et al. (2009)	A meta-analysis of wild bee abundance and species richness using data from 130 effects (from 54 studies) and measures of human disturbance. Although both abundance and richness were affected by disturbance, the magnitude of the effects was not large: wild bee abundance and richness were significantly reduced by habitat loss only in systems experiencing extreme habitat loss (less than 5 percent natural-habitat cover or located 1 km from the nearest natural habitat). The study also notes that the abundance of managed honey bees is not associated with anthropogenic disturbance.
Potts et al. (2010)	A study describing the nature and extent of reported declines and reviewing the potential drivers of pollinator loss, including habitat loss and fragmentation. Evidence for decline in honey bees in the United States and Europe is noted, as is the lack of information about wild pollinators (whose contributions might be higher than assumed). The study notes several reviews that find negative effects of various types of disturbance (such as habitat loss and habitat fragmentation) on wild bee populations (though little evidence of impact on honey bees). The researchers note that "interactions between multiple drivers" are the most probable explanation for elevated over-wintering mortality in honey bee colonies.
Brodschneider and Crailsheim (2010)	Data inferred from over 20 articles that illuminate the nutritional demands of honey bees at 3 levels (colony, adult, and larval nutrition). Malnutrition can occur at any of these levels and can have long-term consequences. The authors note the importance, yet not well studied, of sub-lethal levels of larval and adult malnutrition and the substantial threat when malnutrition is combined with other stressors (such as parasitism and sub-lethal pesticide exposure).
Garibaldi et al. (2011)	A synthesis of data from 29 studies testing the effects of isolating bees from natural areas. The findings are consistent with the prediction that isolation from natural areas reduces both the stability and the mean levels of flower-visitor richness and visitation rate, with a lesser effect on fruit set in crop areas. The study notes that habitat loss is a major and consistent cause for the decline in richness and abundance of pollinating insects around the globe and that a negative association between isolation and crop fruit set was detected even though similar trends were not detected for related honey bee visitation. This suggests that pollination services provided by other (wild) insects are important even in the presence of A. mellifera.
Viana et al. (2012)	A 2011 survey of the Web of Science Citation Index yielded 219 studies; with only 10 before 2000 and peaking at over 45 per year in 2010. About three-fourths are observational studies, often appearing in purely scientific journals. Most studies are from temperate zones, and most focus on the "patch," rather than landscape level. Landscape-level work tends to consider land use in "buffers" around study sites. However, characteristics of the surrounding "inter-habitat matrix" have become more common. Overall, the review finds that "many authors demonstrated that the spatial organization of the landscape has a great influence on the survival and dispersal capacity of many pollinator species."
Kennedy et al. (2013)	A meta-analysis model of wild bee abundance, using data from the literature on over 600 sites covering 39 studies around the world (most from temperate biomes), including measures of local farm management (such as extent of organic farming) and landscape composition and configuration. The study reports that the most important factors enhancing wild bee communities in agro-ecosystems were the amounts of high-quality habitats surrounding farms in combination with organic management and local-scale field diversity. The quality of the surrounding landscape, the local diversification of farmland, and organic management can act as substitutes (with shortcomings in one enhancing the benefits of the others).
Paudel et al. (2015)	A broad review of honey bee and pollination issues, including land use and forage. The authors review trends in honey bee populations and the effects of declines on ecology and the agricultural economy. They note that "habitat loss might be one of the biggest factors impacting honey bee declines and the agricultural landscape changes after the Second World War."

Figure 3

Honey bee movements and crops requiring pollination in the United States



Source: USDA, Economic Research Service using Bond et al. (2014).

completeness, as honey bees tend to consume the pollen and nectar currently available by plants surrounding their hive, even if this source of food is of lower quality than the food in their stores (personal communication, Jeff Pettis, retired research entomologist, USDA-ARS Bee Research Laboratory). Thus, when honey bees are foraging, the availability of a diverse mix of forage—one that is likely to provide a balanced set of nutritional factors—is beneficial. On the other hand, episodic abundance of a single source of high quality forage (e.g., a mass flowering of canola) is beneficial as well, as it helps a honey bee colony build up reserves (both in terms of the number of workers and the amount of stored food).

While supplemental feeding is a common practice, the long-term efficacy of such foods as nutritional supplements is unknown (Brodschneider, 2010). The benefits of a diverse mix of quality forage (the pollen and nectar from flowering plants) seem to be difficult to duplicate—as such a mix can provide a complete suite of amino acids needed by honey bees (deGroot, 1952), along with fatty acids and trace nutritional factors (DiPasquale et al., 2013).

A survey of 5,937 beekeepers, collectively managing 15 percent of honey bee colonies in the United States, showed that the majority of honey bee colonies (87 percent) are managed commercially by beekeepers with more than 500 colonies (1.4 percent of beekeepers) (BIP, 2015). Most commercial colonies are transported from location to location to provide pollination services for producers of a variety of crops throughout the year. Over half the Nation's colonies are transported to pollinate almonds in California in February.[7] Many of these colonies over-summer in the Northern Plains—a landscape that historically includes pollinator-friendly crops, such as sunflowers, canola, and alfalfa, and that contains large areas of native grassland and conservation covers. In the summer, commercial beekeepers typically transport their colonies to the Dakotas to rebuild their populations and their resources so as to better withstand the stresses of over-wintering and long-distance transport throughout the spring.

When commercially managed honey bees are under contract to provide pollination services to landowners, the honey bee colonies are placed near the crops to be pollinated. However, the forage quality of the target crops may not provide optimal nutrition. In such cases, locating pollinator-friendly habitat near target crops can help augment both the quality and quantity of available forage (London-Shafir et al., 2003; Pernal and Currie, 2001).

During times in which honey bees are not in high demand for pollination services, the precise location of good forage land is less important. Honey bees can exploit good forage within a few miles of their colony, although forage closer to hives is beneficial as it reduces the amount of energy bees expend in flight. Moreover, beekeepers can move their colonies to be closer to beneficial forage in the off-season. As such, the overall quantity (e.g., acres of flowering plants) and quality (e.g., pollen diversity and nectar quality) of forage may matter more than the exact placement of the pollinator-friendly land cover.

Partially due to the ability of beekeepers to move colonies around the landscape, there is less information on the effects of landscape features on the long-term health (i.e., over-winter survival) of managed honey bee colonies (Smart et al., 2016).

Land-use policy for native and managed pollinators

To enhance pollination of crops by wild pollinators, a broad assemblage of good-quality LULC near actively pollinated agriculture is needed, one that shortens the distance between crop fields and natural habitat. For some crops, such as tomatoes and blueberries, it may be useful to adjust adjacent LULCs, either by modifying agricultural lands or by altering natural habitat, so as to encourage wild pollinator species most beneficial for these crops (i.e., those active when the crop is flowering).

For honey bees, the dependency on any particular plot of land is lower than that of native pollinators, both because of their naturally longer flight radius and because hives can be relocated. Many commercial honey bee colonies are transported to the Northern Plains where they spend the summer collecting honey and improving colony health (Gallant et al., 2014). Land uses across the Nation (fig. 3) can thus affect a honey bee colony's health, not just in regions where pollination services are being provided. Thus, LULC impacts on honey bee health may take longer to recognize than those on native pollinator health, manifesting as changes in survival probabilities as a function of the LULC spread across a rather broad landscape (i.e., within a 2-mile radius of a hive).

While most existing research on the impacts of LULC on pollinators considers native pollinators, there is a growing body of work that focuses on honey bees. Gallant et al. (2014) constructed a spatially explicit model that identifies sites with the potential to support large apiaries based on local-scale land-cover requirements. Maps of potential apiary locations for North Dakota were produced using land-cover maps representing current conditions and a realistic scenario of land

[7]For example, in 2015, the California Almond Board reported that 1.6 million colonies of honey bees were used for almond pollinations (www.almonds.com/pollination).

change. The scenario highlights the importance of conservation lands in landscapes intensively and extensively managed for crops.

Smart et al. (2016) assessed how land use affects the health and survivability of commercial honey bee colonies, or apiaries, in the Prairie Pothole Region of North Dakota. Specifically, this research considered the colony population size, pollen and honey stores, queen status, and the level of parasites and diseases as measures of colony health. Results suggest that the greater the area of uncultivated land near an apiary, the greater the level of apiary survival.

Otto et al. (2016) find that landscape features favored by beekeepers for apiary locations are decreasing in the Great Plains, and crops actively avoided by beekeepers, such as corn and soybeans, are becoming more common in areas with higher apiary densities. They applied a habitat selection model to predict the impacts from changes in biofuel crop production and grassland land covers surrounding 18,000 registered apiaries in North and South Dakota from 2006 to 2014. They find an increase in "biofuel crops" of around 3 million acres—crops that beekeepers avoid when siting their hives. Furthermore, grasslands favored by beekeepers are becoming less common.

USDA land-use and pollinator programs

Several USDA conservation programs exist that help producers provide habitat and forage to native and commercial pollinators. These include the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), and the Agricultural Conservation Easement Program (ACEP) administered by USDA's Natural Resources Conservation Service (NRCS). A total of 37 conservation practices can be used under EQIP to create or enhance pollinator habitat (USDA, 2015), including planting cover crops, planting wildflowers and native grasses in buffers, and improving management of grazing lands. In 2015, NRCS began actively targeting the over-summering grounds in the Northern Plains (USDA-NRCS, 2015).

USDA's Farm Service Agency administers the Conservation Reserve Program (CRP), which pays farmers a yearly rental payment in exchange for removing environmentally sensitive land from agricultural production and planting species that improve the land's environmental quality. While most CRP land can be considered beneficial to pollinators, one of the conservation practices that farmers can implement under the program is designed specifically to provide habitat for honey bees and native pollinators (see box "Pollinator-Friendly Land Covers on CRP Land").

Box 1

Pollinator-Friendly Land Covers on CRP Land

As of September 2016, the over 30-year-old Conservation Reserve Program (CRP) administered by USDA's Farm Service Agency (FSA) covers 23.9 million acres of retired cropland (USDA-FSA, 2016). Landowners volunteer to participate in the program and in return receive yearly payments for removing environmentally sensitive land from agricultural production. Parcels enrolled in the program are planted with land covers intended to provide soil and water protection, erosion reduction, and wildlife habitat.

Although most conservation practices can provide forage for pollinators, seed mixes designed specifically for pollinators offer additional and more diverse pollen and nectar sources (Pollinator Partnership, 2009). For these reasons, the Food, Conservation, and Energy Act of 2008 incorporated support for development of pollinator habitat within USDA conservation programs. As outlined by FSA (2013), the CP42 Pollinator Habitat practice comprises a diverse mix of at least nine species of pollinator-friendly wildflowers, legumes, or shrubs. In addition, the mix should provide at least three species in each of the following bloom periods: April-June, June-July, and August-October.

Land in CP42 (or equivalent practices[1]) grew since 2011—with 45,000 acres under contract in 2011, 65,000 acres in 2012, 95,000 acres in 2013, 108,000 acres in 2014, and 135,000 acres in 2015. As of September 2016, CP42 enrollments have continued to accelerate, reaching 342,000 acres, or 1.4 percent of acres under CRP contract.

While CP42 is designed for supporting pollinators, other land covers can also be beneficial. In a June 2016 analysis,[2] FSA estimated that over 15.7 million acres under CRP contract are in conservation practices (including CP42) deemed to be beneficial to pollinators, including 7.8 million acres in grass plantings that include forbs and/or legumes, 1.1 million acres in buffer and filter strips, and 4.7 million acres in wildlife habitat. These totals, however, are down from 22.1 million acres in 2007.

The Northern Plains has a high density of CRP land and is the summer location of many of the Nation's honey bee colonies. FSA has established a Monitoring, Assessment, and Evaluation project to quantify and document the multiple benefits generated when lands are placed into the CRP and to identify successful innovative practices. For example, honey bee colonies established on CP42 land in Iowa, Montana, Nebraska, and Washington are producing more honey than those on CRP land planted with grasses, and a greater variety of native pollinators live around CP42 land (Wojcik, 2015). However, the average cost of converting agricultural land to CP42 land is substantially greater than that of converting to CRP grassland. For example, as of 2015, the national average CP42 establishment cost was $248 per acre, compared with an average of $68 per acre and $85 per acre for grass practices in CP1 and CP2, respectively.[3]

In addition to ongoing research, a number of planning tools are available to landowners. For example, Pheasants Forever (2015) supports a seed-mixture calculator designed to enable resource professionals to build and recommend seeding mixtures that improve environmental quality while reducing costs.

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[1]Equivalent practices include several under the State Acres for Wildlife Enhancement Initiative and acres enrolled in 2010 (during signup 39) using a "pollinator beneficial" seeding mix of existing practices.

[2]http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=2016/06/0153.xml

[3]See https://www.nass.usda.gov/Publications/Ag_Statistics/2015/Chapter12.pdf (Table 12-14). Note that average CP42 establishment costs ranged from $49 per acre in Montana to $900 per acre in North Carolina.

Trends in Pollinator Forage Suitability in the United States

A number of observers have noted a long-term trend in the landscape of the United States toward less forage for bees (Kremen et al., 2002). The National Research Council (2007) notes that floral resources and nesting sites are at risk through disruption caused by row-crop agriculture, grazing, and fragmentation of habitat into patches too small to support diverse communities of pollinators. Spivak et al. (2013) note that intensification of U.S. agricultural production that began after World War II relies on the application of agricultural chemicals that have reduced the floral resources available to bees.

This section presents an exploratory analysis to examine and quantify the trend in forage availability for honey bees. Using 30 years of land-use data, we develop a pollinator forage index that allows for the aggregation of LULC changes into a single measure of pollinator forage quality. While this index cannot provide definitive statements, it can illustrate broad trends in land-use changes and highlight topics for further research.

The core of this index is the assignment of a pollinator forage suitability index (FSI) that is based on LULC. This index is motivated by complex efforts (Koh et al., 2016; Kennedy et al., 2013; Lonsdorf et al., 2009), detailed further below, to predict pollinator habitat quality using LULC measures that are disaggregated by season and separated into "honey bee" and "native pollinator" values.

Data

To extend our analysis back in time, we use USDA's National Resources Inventory (NRI—see USDA-NRCS, 2016b; USDA-NRCS, 2016d). NRI provides 30 years of data covering the Nation but does not have the spatial resolution of the CDL and similar datasets. Thus, we consider broad-scale patterns in LULC, abstracting from more micro-level measures. Factors that are not considered include the diversity of vegetation within each land cover type, pesticide use, field size and extent of uncultivated edges, seasonal variability, and annual weather conditions.

The complete NRI dataset consists of over 1 million points, with each point representing a parcel of land. A "land cover/use" (LCU) variable is assigned to each point for the years 1982, 1987, 1992, 1997, and each year between 2000 and 2012. The LCU variable can take 1 of 59 values (such as corn, soybeans, grazed forestland, marshland, pasture, and CRP). We use data from the conterminous United States that account for 1.44 billion acres.[8]

Methods

Each LCU is assigned a forage suitability index of bee forage quality that can range from 0 to 1. The FSI comes from research initially published in Lonsdorf et al. (2009) and further refined in Koh et al. (2016). In Koh et al. (2016), the floral resources estimated to be available for each LULC category in the Cropland Data Layer (CDL) are based on expert assessment of floral resources by a panel of 14 experts. The NRI LCU categories differ from the CDL LULC categories. Therefore, we spatially matched the CDL LULC to the NRI LCU for 2012 and used the index for the most

[8]Because urban land is not likely to be affected by land-use policies, we removed NRI points with an "urban" land use. In addition, NRI points identified as being on Federal land were removed, as these points do not include land-use information. After these removals, 987,000 points are retained.

common CDL LULC within a given NRI LCU. The FSI measure used in this analysis is specific to bees and consists of a single value for each land cover that abstracts from seasons.[9]

The FSI measures how well a land cover/use provides forage for honey bees. It does not consider other stressors (such as pesticide exposure). An index of 0 is used for LCUs that provide no forage, such as open water, while an index of 1 is a hypothetical land use that provides highly diverse and quality forage. Grain crops (e.g., corn, wheat, rice, and barley) have low FSI scores of 0.16-0.17, most fruits and vegetables have FSI scores of 0.31-0.35, and pasture, forest, and grasslands have FSI scores of 0.45-0.48.

CRP land is assigned an FSI score of 0.45, even though land enrolled in CRP can have a variety of land covers that have different forage suitability for bees. The NRI data, however, do not distinguish between different conservation practices on CRP lands, and CRP contract data can not readily be matched to NRI points. Given that most CRP land is planted with grasses, we assume all points assigned with a "CRP" LCU is in a grassland cover and assign these points an FSI of 0.45. To illustrate the robustness of our results to this assumption, appendix 3 simulates how average FSI scores could change under different FSI scores for CRP acres.

FSI estimates are also affected by the availability of accurate data. Not all land cover/uses are contained in the NRI data. For example, canola, a honey bee-friendly LULC that accounts for over 1 million acres in the Northern Plains, is not one of the 59 land LCU codes of the NRI—hence, canola acreage cannot be specifically identified.[10]

Appendix 1 presents detailed information on the FSI assigned to the 59 LCU categories of the NRI data. While we use these 59 LCU categories in our analysis, to simplify the presentation of our results, these 59 land cover/use categories in the NRI dataset are aggregated into 9 broad categories, where LCUs in a category have similar FSI values. Table 3 lists the acreage under these nine broad categories over time, while appendix 2 provides maps illustrating LCU changes from 1982 to 2002 and from 2002 to 2012.

Farmland with very low FSI, which provides poor forage for pollinators, declined by 24 percent from 1982 to 2002 but rebounded by 5 percent after 2002. Farmland acreage with low FSI declined by 10 percent between 1982 and 2012. This change was offset by increases in farmland acreage with medium FSI scores. Acreage enrolled in the CRP increased from 0 in 1982 (the program began in 1986) to over 32 million acres in 2002 and declined to approximately 24 million acres in 2012.[11]

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[9]Given the coarseness of the NRI LCU classification, in this analysis, we used a simplified version of the expert assessments. In contrast, Koh et al. (2016) factor in seasonal variation in FSI and construct robustness measures that consider variations in expert assessments.

[10]Canola acreage increased by over 800 percent (1.3 million acres) between 1991 (first year of data) and 2002. Between 2002 and 2012, canola acreage increased by 20 percent (300,000 acres). Canola was not assigned a forage suitability index score in Koh et al. (2016) and so cannot be compared with other land-use types in the area. In addition, canola is rotated with other crops (mostly wheat), and it is not clear which type of land use canola is displacing.

[11]These values are based on the 987,000 NRI points used in this analysis. For example, total CRP enrollment in 2002 and 2012 was 33.9 million and 29.5 million acres, respectively.

Table 3

Summary of trends in land-cover/use area by broad (similar FSI values) category

Land-cover/use category	Major land covers in category	Range of FSI scores assigned to points in this land cover category	Area (million acres)		
			1982	2002	2012
Farmland: very low FSI	Corn, wheat, rice, barley, sorghum	0.16 - 0.19	219.8	168.1	176.4
Farmland: low FSI	Soybeans, cotton, nuts, grapes	0.20 - 0.29	90.6	100.3	99.3
Farmland: medium FSI	Citrus, melons, potatoes, strawberries	0.30 - 0.39	91.3	90.2	82.4
Farmland: high FSI	Sunflowers, berries (other)	0.40 - 0.54	4.0	2.8	2.3
Conservation Reserve Program	Grassland	0.45	0.0	31.7	24.2
Forestland		0.48	388.5	406.9	409.9
Pasture & rangeland		0.45	533.6	523.8	524.2
Other high FSI land	Rural roadsides	0.45	36.1	38.7	41.8
Other low FSI land	Barren, water	0.0 - 0.25	74.9	76.8	78.5

FSI=forage suitability index. NRI = National Resources Inventory.

Source: USDA, Economic Research Service using non-Federal, non-urban NRI data (using 987,000 non-Federal, non-urban points). See appendix 1 for a listing of land use/cover codes used to create these categories, and appendix 2 for maps showing regional changes in acreage.

Results

Given the variety of land cover/use changes, it is useful to consider a measure based on point-by-point changes in the index over this time period. Table 4 summarizes the changes in the index across the United States. From 1982 to 2012, most of the U.S. landscape (about 75 percent) had no change in the index. About 11 percent of acreage had a decrease in FSI, and about 14 percent saw some increase. However, a different story emerges when considering more recent trends. From 1982 to 2002, the index improved on about twice as many acres as it declined. And from 2002 to 2012, the index declined on more acres than it improved (table 4).

No change in FSI does not imply that land cover/uses did not change—only that the FSI score did not change over time. The FSI score is an LCU-based estimate of the quality of honey bee forage. For example, a switch from corn to sorghum would have no effect on FSI in this analysis—both of these LCU are assumed to provide similar (very low) quality of honey bee forage. Conversion of land cover/uses with higher FSI scores (such as hay and sunflowers) to cropland (such as corn and soybean) is often the cause of index decreases. Conversely, conversion of cropland to CRP lands is often the cause of index increases.

This national summary masks regional differences. Figure 4 displays a comparison of the change in FSI across the United States from 1982 to 2002 and from 2002 to 2012.[12] As also shown in table 4, increases were more prevalent between 1982 and 2002, while decreases were somewhat more prevalent between 2002 and 2012. Note: Data are not displayed in hexagons that have less than 10 NRI points (blank with no border). Note the “over-summering” area of the Dakotas is outlined in black.

Overall, with the data and assumptions presented here, a story emerges that, in most places in the conterminous United States, broad LULC changes between 1982 and 2012 did not lead to decreases in estimated honey bee forage quality. However, the geographic scope and the time period over which changes in FSI are measured matters. Several locales show a recent decline in estimated

Table 4
Distribution of the percentage change in estimated point-by-point FSI scores

	Percentage of acres with a change in FSI		
	Decrease	No change	Increase
1982 to 2012	11.0	75.0	14.0
1982 to 2002	8.8	77.1	14.1
2002 to 2012	7.3	85.8	6.9

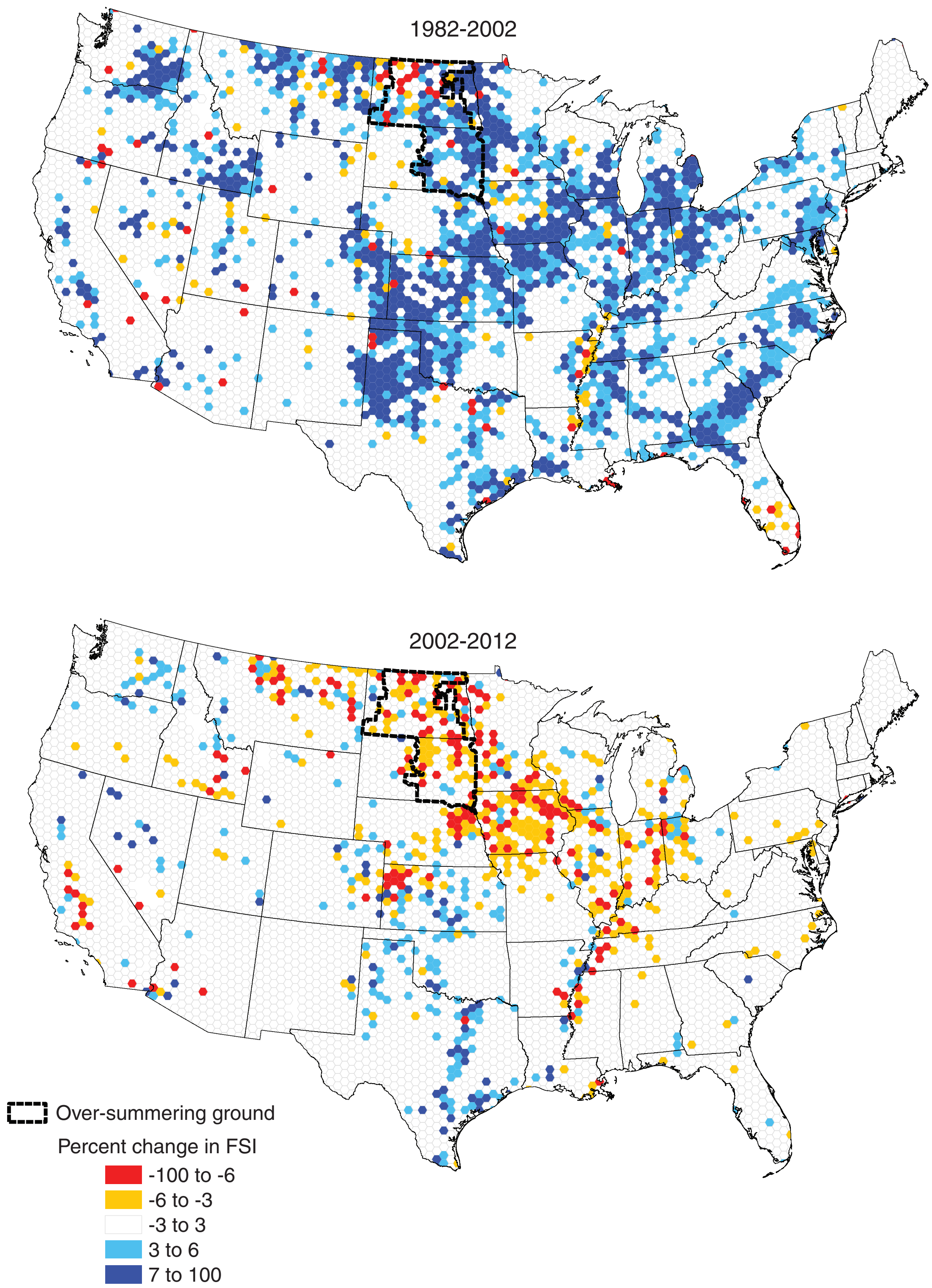
FSI = forage suitability index.

Source: USDA, Economic Research Service using National Resources Inventory. Note that when minor changes (a change less than 0.02 in either direction) were treated as a “No Change,” qualitatively similar results were obtained (the No Change categories increased by about 2 percent).

[12]The surface was interpolated using inverse distance weighting of the FSI changes for the 987,000 NRI points used in this analysis.

Figure 4

Changes in 2012 forage suitability index (FSI) over time



Note: Data are not displayed in hexagons that have less than 10 NRI points (blank with no border). Note the "over-summering" grounds of the Dakotas are outlined in black. FSI = forage suitability index.
Source: USDA, Economic Research Service analysis of USDA, Natural Resources Conservation Service, National Resources Inventory (NRI) data.

forage suitability. In particular, Central North and South Dakota (outlined in figure 4)[13], which is an important summering ground for honey bee colonies, has seen a decline in forage suitability since 2002 (fig. 5).

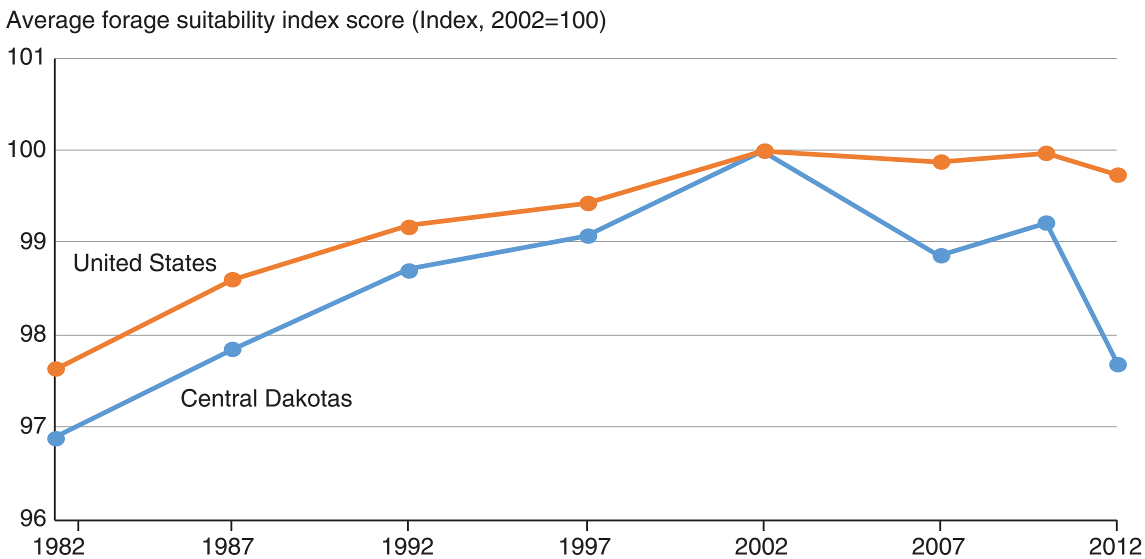
While our analysis sheds light on trends in forage suitability due to changes across broad land-use and cover categories, it does not capture changes in forage suitability arising from within-category changes, such as changes in pesticide and herbicide use, changes in field size, or changes in conservation practices installed on CRP acreage. For example, changes in prevailing patterns of herbicide and pesticide use as well as field size could mean that a corn field's actual value to pollinators may improve or deteriorate between 1982 and 2012, even though its index remained the same.

As noted earlier in this section, there is a perception that the U.S. landscape has undergone changes that have had a negative effect on pollinators over the last several decades. What may account for the divergence between this perception and the findings presented here? First, our analysis is based on a fairly simple LULC classification necessitated by the available data, which can reduce the accuracy of FSI scores.

More generally, the point structure of the NRI data cannot encompass agricultural landscape phenomenon (Potts et al., 2010; Meehan et al., 2011) and other subtle changes in LULC that have occurred over the study period. For example, they do not capture linear features such as roadside

Figure 5

Average FSI scores over all NRI points for the United States and Central Dakotas (index, 2002=100)



FSI=forage suitability index. NRI=National Resource Inventory.
Note: FSI is normalized so that 2002 is equal to 100 for both Central Dakotas and the United States. The Central Dakotas, an important summering ground for honey bee colonies, is outlined in fig. 4.
Source: USDA, Economic Research Service analysis of USDA, Natural Resources Conservation Service, National Resources Inventory Data.

[13]The "over-summering" grounds special region was constructed from 87 of the 119 counties in North and South Dakota. These 87 counties had a relatively larger high density of apiaries (see figure 3). Note that this is an imprecise allocation and is based on apiary density maps from South Dakota (http://arcgis.sd.gov/server/ag/sensitivesites/default-map.aspx) and North Dakota (https://apps.nd.gov/ndda/mapping/).

edges, field edges, and natural windbreaks that can provide excellent habitat for bees. As farm machinery has gotten larger and as farms have increasingly consolidated (MacDonald, Korb, and Hoppe 2013), agricultural fields have increased in size (White and Roy, 2015) and have fewer natural elements embedded in them. Less-managed land covers and hedgerows are fewer (Landis, 2016). Yet, for honey bees and other pollinators, those features are critical to their well-being.[14]

Similarly, NRI data do not account for changes in in-season land management, such as pre-flowering cutting of alfalfa, changes in pesticide use, such as the growth in neonicotoids, and reductions in forage from weeds both within and alongside agricultural fields and roads due to the expansion of nonselective herbicide application (USGS, 2016).

The actual impact of LULC changes on the health of honey bee colonies in the United States is a function of the biophysical impacts of LULC changes as well as the ability of beekeepers to adapt, such as by changing pollination routes or the over-summering location. The perception of a decrease in pollinator habitat may be driven by observed changes in LULC in areas with a substantial number of honey bee colonies but may not be reflective of national-level LULC changes.

Honey bee colonies are concentrated in different parts of the country in the course of a year, such as in California during the February almond bloom. As the number of honey-producing colonies has declined from 5.9 million in 1947 to a low of 2.3 million in 2008 before recovering to 2.8 million in 2016, some regions of the United States have experienced greater-than-average increases or declines in colony counts (see box "Distribution of Honey Bee Colonies"). Of particular interest is the above-noted decline in forage provision in the important over-summering grounds in Central North and South Dakota, as noted by Wright et al. (2013), Otto (2014), Koh et al. (2016), Smart et al. (2016), and Otto et al. (2016). The decline in the index in the region since 2002 is driven by a 42-percent decrease in CRP land, a 30-percent decrease in "high FSI" farmland, a 14-percent decrease in "medium FSI" farmland, and a 33-percent increase in "low FSI" farmland (fig. 3, table 5).

Table 5

Changes in land use, by FSI category, for 87 selected counties in the Central Dakotas that constitute important over-summering grounds for honey bees

Land-cover category	Major land covers in category	Change, 2002-12 (%)
Farmland: very low FSI	Corn, wheat, rice, barley, sorghum	3.3
Farmland: low FSI	Soybeans, cotton, nuts, grapes	32.8
Farmland: medium FSI	Citrus, melons, potatoes, strawberries	-14.0
Farmland: high FSI	Sunflowers, berries (other)	-30.0
Conservation Reserve Program	Grassland	-42.0
Forest		3.1
Pasture and range		1.2
Other high FSI land	Rural roadsides	5.2
Other low FSI land	Barren, water	1.9

FSI=forage suitability index.

Source: USDA, Economic Research Service using USDA, Natural Resources Conservation Service, National Resources Inventory Data.

[14]Deguines et al. (2014) state that "There is abundant local-scale evidence that both pollinator diversity and pollination services decrease with increasing agricultural intensification."

Box 2

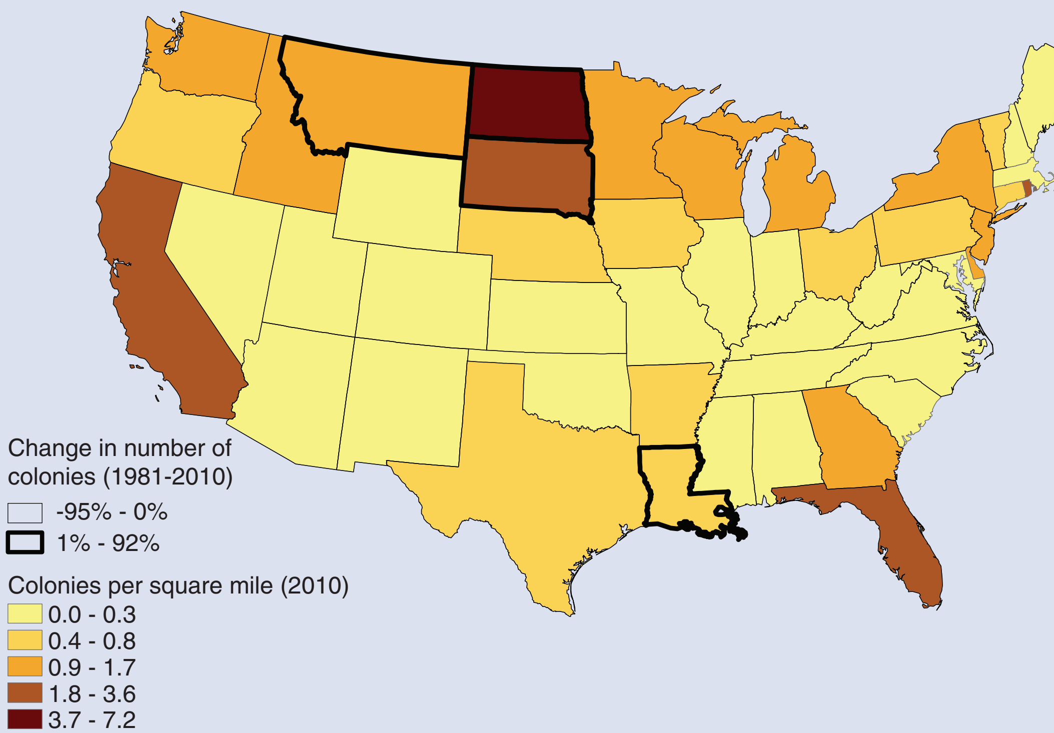
Distribution of Honey Bee Colonies

The availability of forage for managed honey bees depends in part on where and when beekeepers choose to locate their honey bees. When honey bees are providing pollination services, the location of the colony is limited by the location of the crop(s) that require pollination. Later in the season, beekeepers can choose locations to optimize honey production and health of the colony. Box figure 2.1 shows the density of honey-producing colonies by State in 2010 and percent changes in the number of colonies over time from 1981 to 2010. For the United States as a whole, honey-producing colonies declined from 4.21 million in 1981 to 2.69 million in 2010 (USDA-SRS 1982, USDA-NASS 2017), while figure 1 in the main body of the report shows that colony numbers have increased since 2008. Locations where honey bees only provide pollination services and do not produce sellable honey (e.g., almond farms in California) are not accounted for in these maps. Honey-producing colony density is highest in the two citrus-producing States (California and Florida) and summering grounds in the Northern Great Plains. Four States—Montana, North Dakota, South Dakota, and Minnesota—account for about 40 percent of the honey-producing colonies.

Not only does the Northern Great Plains have a high density of colonies, but it is also one of two regions with an increase in the number of honey-producing colonies from 1981 to 2010. In the Dakotas and Montana, the number of colonies increased 69 percent during this time period; in most of the rest of the States, the average number of colonies dropped by about half (51 percent) (USDA-NASS, 2017).

Box figure 2.1

Density of honey-producing honey bee colonies in 2010 and percentage change over time from 1981-2010



Source: USDA, Economic Research Service using USDA, National Agricultural Statistics Service (2017) and USDA, Statistical Reporting Service (1982).

An Economics Perspective: Markets and the Role of Public Policy

As discussed earlier in the literature review, evidence suggests that some changes in LULC and land management can have a positive effect on the provision of pollination services from both wild and managed bees. But what does that imply about public policy—what options are available for USDA policymakers?

A key perspective of economics is how market mechanisms coordinate the choices made by individual actors. Under certain conditions, markets do this well—markets lead to an outcome where no one can be made better off without making someone else worse off.

From this point of view, an economist might ask "where is the need for intervention in the pollinator world?" Beekeepers, growers of pollinator-dependent crops, and landowners should be able to resolve their needs through market mechanisms. For example, if changes in LULC may enhance the delivery of pollination services (either by increasing the number of native pollinators near crops or by protecting the health of honey bees)—one should expect trades between beekeepers, crop producers, and landowners to occur that bring forth these modifications.

The ongoing growth in the importance of commercial pollination exemplifies this expectation. Historically, pollination services were provided by native pollinators and locally managed honey bees. However, a national pollination-services market has emerged in conjunction with intensification of agricultural production. In particular, the growth in almond production has led to a need for externally provided pollination services, and beekeepers have responded by trucking their hives to the desired locations and entering into pollination contracts.

A pollination contract can specify the condition that colonies should be in when they arrive to service the contract, including the number of brood frames, the pounds of honey stores, and the number of hive stores.[15] Similarly, the contract can stipulate that the grower refrain from applying pesticides considered toxic to honey bees immediately before and while the honey bees are pollinating the crop (Sanford et al., 2003).

More generally, with a robust demand for pollination services for a variety of crops at different locations throughout the year, beekeepers can invest in the health of their bees in numerous ways, such as by monitoring and treating disease and pest infestation and by placing their hives in locations rich in forage opportunities when not servicing pollination contracts. Should lack of high-quality forage emerge as an issue, a beekeeper could obtain access to such lands through compensation to a landowner. Although obtaining such access might increase beekeeper costs, in theory market mechanisms should induce optimal purchase of access to quality forage land, in terms of equating marginal costs and marginal benefits.

Evidence shows that beekeepers have been able to adjust to changes in the pollinator environment. In particular, despite the increase in threats and elevated colony mortality, there is little indication of major shortages of honey bee colonies in pollinator markets, although the price of pollination

[15]For example, a typical almond pollination contract specifies a target strength of eight frames covered in adult bees. See http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/19777/pnw623.pdf or http://beesource.com/point-of-view/joe-traynor/pollenation-guidelines-for-commercial-beekeepers/ for examples of recommendations.

services has increased (particularly for almond bloom) due to the increase in demand and cost of production (Rucker et al., 2012; Rucker and Thurman, 2012; Rucker et al., 2014). Moreover, the number of honey-producing colonies has increased since 2008 despite high colony mortality (USDA-NASS, 2017).

However, is it reasonable to always expect these markets to function optimally, especially if environmental factors are changing unpredictably? Are there market failures (Ledyard, 2008) that undermine the conditions where markets do well? The next section considers conditions that are germane to the interaction between LULC and pollinator health—conditions that can hinder the success of market solutions and that illustrate when Government policy may be useful.

Land for pollinators provides a positive externality

The provision of pollinator habitat is an example of a *positive externality* (Cheung, 1973). When the cost of a good is borne by one economic agent while multiple agents benefit, the good is often under-provided.[16] When the foraging range of a pollinator (native or managed) extends beyond the property boundaries of a landowner, the pollination services of pollinators (whose health is enhanced by forage land) may benefit other landowners.

> Consider a hedgerow that provides forage for both honey bees that service cropland belonging to the hedgerow owner and honey bees that service the lands of an adjacent farmer. In the absence of some means of sharing expenses with the neighbor, the incentive to provide the hedgerow is reduced since the landowner investing in the hedgerow does not reap all of its pollination benefits. If a means of sharing expenses were adopted, the farmer would install more hedgerows.

In some cases, this may not be a problem. For example, for native bees, which typically have a short flight radius, it is more likely that both components (land that benefits from pollinators and land that benefits pollinators) can be accommodated within a single ownership unit (e.g., if farmers install good-quality pollinator forage on borders between their fields). For sufficiently large farms, even pollinators with long flight ranges (such as honey bees) may not fly far afield. Alternatively, social norms may reduce "free riding" (Cheung, 1972), as when neighboring almond growers maintain standard colony-stocking densities or maintain equal ratios of planted and natural land (Champetier, 2011).

Land for commercial honey bees: Open access considerations

For the majority of the year that honey bees are not needed for pollination services, land providing forage need not be associated with land that requires pollination. Thus, it can make sense to locate forage lands where opportunity costs (e.g., the cost of not farming a parcel) are low. Consequently, the beneficiaries of pollination services may be quite different from the providers of pollinator forage, such as almond growers in California and landowners in North Dakota.

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[16]In 1920, A.C. Pigou discussed the private provision of public goods (Pigou, 1932, chapter II.IX.11): "Among these examples we may set out first a number of instances in which marginal private net product falls short of marginal social net product, because incidental services are performed to third parties from whom it is technically difficult to exact payment…. It is true, in like manner, of resources devoted to afforestation, since the beneficial effect on climate often extends beyond the borders of the estates owned by the person responsible for the forest." (http://www.econlib.org/cgi-bin/searchbooks.pl?searchtype=BookSearchPara&id=pgEW&query=forest). For further discussion of externalities, in an agricultural context, see Ribaudo et al., 2008.

An operation could internalize this by maintaining pollinator habitat on land that has less agricultural value, perhaps land that is far from its productive fields. Alternatively, beekeepers could efficiently maintain their hives by purchasing access to, and hence encourage creation of, land with good forage (e.g., native prairie in the Northern Great Plains).

Open access may make these transactions difficult to sustain—how can a beekeeper control access to the pollinator habitat he or she paid to create? That is, how can someone paying to create pollinator habitat exclude "free riders"—such as other beekeepers who could place their hives near such pollinator habitat and reap the benefits without the costs (in other words, benefit from the positive externality). Unless the benefits of this free riding can be captured, incentives for any beekeeper to incur the costs of managing pollinator forage are lessened.

A related issue is that the use of land set aside for pollinators by one colony can reduce the available resources for other colonies because the quantity of pollen and nectar provided on a parcel is limited. As additional colonies are placed near a parcel, the marginal benefits (additional nectar and pollen gathered) decrease. Thus, honey bee forage land is *nonexcludable,* because other beekeepers can use the forage, but *rival*, since any honey bee that visits the forage will reduce the quantity of forage for all other honey bees. Although this does not meet the definition of a pure public good, which is both nonexcludable and nonrival, it can still lead to market failure (Gravelle and Rees, 2004).

Beekeeping has traditionally been an adventitious operation, where managers of stinging insects seek opportunities to reap the bounties of nature. As such, landowners are not necessarily notified when hives are placed near their lands. However, informal means (such as shares of honey) are often used to "secure" access to staging areas where hives can be situated. Moreover, anecdotal evidence (Nordhaus, 2011) suggests that beekeepers have informal "territories" in which they operate, which can serve to reduce over-exploitation pressures.

More formally, a variety of States regulate apiaries (see table 6). Many States require that beekeepers register the locations of their hives. Montana, South Dakota, and Wyoming create exclusionary zones—so that no commercial beekeeper can place hives within a few miles of a currently registered commercial beekeeper's hives.

Ecosystem services and co-products: Opportunity for collaboration in the provision of public goods

Lands that provide pollinator habitat can simultaneously provide a variety of ecosystem services, such as biodiversity, soil protection, open space, and wildlife habitat. For example, CRP land selected due to erodibility concerns can also be managed for pollinators by the planting of pollinator-friendly covers, although this is not currently the case for most CRP parcels.

Though not necessarily producing revenue, such beneficial ecosystem-service impacts may be valued by a number of people, as they are public goods. Public goods are often difficult to supply via markets.[17] In particular, for native bees pollinating noncommercial plants, there is little financial incentive for property owners (both farmers and nonfarmers) to provide pollinator forage—even though many people would benefit from the ecosystem services such forage would sustain.

[17]See Ribaudo et al. (2008) for a discussion of public goods in an agriculture setting.

Table 6
Regulation of apiaries in States with more than 100,000 colonies at the start of the summer on July 1, 2015

State	Regulation of apiaries	Exclusive rights to land (distance requirement to other apiaries)
California	Commercial and noncommercial beekeepers in California are required to register their honey bee colonies with the agricultural commissioner in the county where their colonies are placed. Registered beekeepers can request advance notification of pesticide applications.	No
Florida	Beekeepers with honey bee colonies must register with the Florida Department of Agriculture and Consumer Services and submit to inspection by the Department for the detection of honey bee pests.	No
Georgia	Apiary registration is not required by the Georgia Department of Agriculture. The Georgia Bee Law (O.C.G.A. 2-14-40) requires beekeepers selling bees, queens, and nuclei commercially to be licensed. All other beekeepers (e.g., hobbyists, pollinators, honey producers) are not required to be licensed or inspected by the Plant Protection Section.	No
Minnesota	Effective July 1, 2006, the annual apiary registration requirement with the Minnesota Department of Agriculture was discontinued. However, the Department still retains full authority to regulate pesticides and, as such, will continue to investigate reports of pesticide misuse or misapplication and take appropriate regulatory action.	No
Montana	Commercial beekeepers (with more than five hives) are required to register apiaries with the Montana Department of Agriculture. A registered apiary must be 3 miles from the next site of another registered beekeeper. This is to prevent the spread of diseases and pests from apiary to apiary and to limit the over-exploitation of pollen and nectar resources by foraging honey bees. A site registered for pollination is not subject to the 3-mile buffer-zone requirement but is limited in size and established only for the period in which pollination provides a benefit to the specific crop.	Yes
North Dakota	The locations of all apiaries must be reported to the State. Inspection, quarantine, and other actions may be taken by the agricultural commissioner.	No
South Dakota	No apiary may be located within 3 miles of any other apiary. However, any beekeeper who owns property may locate an apiary anywhere on that property.	Yes

Source: USDA, Economic Research Service using Apiary Inspectors of America (2015) and (USDA-NASS, 2016b).

Sustainability and marginal decisions

What if society's preferences differ from the preferences of participants in an important market? For example, individual landowners, farmers, and beekeepers may make decisions optimizing near-term financial needs. Sustainability goals, such as maintaining a robust and nutritionally diverse food supply for future generations, may not be fully aligned with the goals of the participants in these markets. For example, land-use policies to ensure pollinator health may be a sensible endeavor when the consequences of failure—the costs to the general public—exceed the policy cost.

Considering the participants

It is useful to consider the issue of pollinator forage provision from the point of view of four stylized sets of participants: pollinator-dependent farmers (e.g., almond growers), beekeepers, landowners (who can provide land for forage), and the Government (representing broader public interests).[18]

For farmers, beekeepers, and landowners: what are the benefits of improving pollinator habitat?

Farmers	Creating habitat for native pollinators can: • Reduce or eliminate the need for commercial pollination • Enhance the effectiveness of honey bees (Brittain et al., 2013) Creating habitat for honey bees can: • Attract beekeepers, who may be willing to accept lower rental payments
Beekeepers	Pollinator habitat near pollination contracts can: • Provide forage when few alternatives are available (i.e., in the weeks before almond bloom) Pollinator habitat at other times and places (e.g., summertime in the Dakotas) can: • Increase honey production • Build colony strength after the bees have been transported around the country to pollinate crops
Landowners	Landowner may be able to collect fees from beekeepers to plant pollinator-friendly habitat that these beekeepers will then place their hives on.

What barriers impede these three participants from providing an efficient amount of pollinator habitat?

Farmers	*Free riders:* habitat created for pollinators that will work your crops may also support pollinators that work some other farmer's crops. *Opportunity cost*: land set aside for pollinator habitat is not available for crop production. For example, in almond orchards even though the per-acre rental rates for honey bees are high (about $300 acre), they are only 10 percent of gross revenues (Klonsky, 2011). If there were no opportunity costs, the dissipation of benefits due to free rider and open access issues would be less important.
Beekeepers	*Open access:* beekeepers may be unwilling to pay for better honey bee forage if they worry that other beekeepers (who are not paying) will be reaping much of the benefit.
Landowners	*Free rider:* beekeepers may be unwilling to pay landowners to install pollinator habitat if they think that other landowners will provide the habitat for free (and their bees can then visit these lands). Similarly, farmers growing pollinator-dependent crops can avoid the cost of installing pollinator habitat on some of their lands if they think that nearby landowners will provide the habitat for free—and the bees visiting these nearby lands will also visit their crops.

In addition, lack of information on cost-effective provision of pollinator habitat may dissuade investment in providing habitat to native pollinators. For example, land set aside for native pollinators should support pollinator species that are active when the crop needs pollination. Furthermore, untimely plant efflorescence, or flowering, can be detrimental: growers who rent honey bees may prefer to limit the amount of plants growing near their crops that might attract honey bees (i.e., that compete with the crop for honey bee attention).

[18]To simplify this discussion, we assume that landowners are also land managers. Note that landowners can be non-farmers or farmers of crops that do not need honey bee (or other animal) pollination. We also abstract from other benefits due to improving pollinator habitat, such as biocontrol of pests.

Government actions

The Government can take a variety of actions to alleviate shortages of good pollinator forage. These include:

- Organizing or improving markets for better quality forage. For example, systems that assign exclusive zones (such as the State regulations listed in table 6) may encourage beekeepers and landowners to form contracts to improve land cover. However, such an assignation will create winners and losers (i.e., landowners with an existing apiary versus beekeepers who are new to an area).

- Installing improved access to forage on existing public lands. For example, by planting beneficial flowers rich in nectar or nutritious pollen in highway and railroad right-of-ways. A more complex example is allowing colonies to be placed in undeveloped public lands, such as national parks or Bureau of Land Management and U.S. Forest Service range and forestland. While these lands could provide substantial forage, other issues include potential impacts on public access and the risk of overwhelming natural systems with colonies of non-native honey bees.

- Paying for better forage on private lands. For example, as of 2016, the CRP has about 342,000 acres (out of about 24 million total program acres) enrolled in pollinator-targeted land covers (see box "Pollinator-Friendly Land Covers on CRP Land" on page 11).

- Conducting research on cost-effective land covers, such as analyzing the additional benefits, as compared with the costs, of a superior seed mix (see box "Pollinator-Friendly Land Covers on CRP Land" on page 11).

- Conducting education and outreach on how to effectively increase pollinator forage for both native pollinators and honey bees.

While these Government actions may improve pollinator well-being, their implementation challenges and cost effectiveness are largely unstudied.

Conclusions

Honey bees and native pollinators contribute to the pollination of crops annually worth about $15 billion and $3 billion, respectively (USDA-NRCS, 2016d; Losey and Vaughan, 2006). Both face a number of synergistic stressors including diseases, parasites, pesticides, and loss of nesting and foraging habitat. High honey bee colony mortality raises concerns that the quantity and diversity of agricultural goods may be reduced over the long term should these stressors continue to have the same effects on pollinators and should the management practices used by beekeepers to keep up the number of colonies fail.

Improved nutrition for pollinators can be part of the solution: a body of research suggests that if pollinators eat better, they can better withstand other stressors. This can be achieved by modifying the Nation's land-use/land-cover (LULC) patterns so as to provide pollinators with higher quality forage—the pollen and nectar from blooming plants. LULC can affect both native pollinators and managed honey bees. While more research is needed on these topics, a strategy that is best for one may not be best for the other.

Native pollinators and managed honey bees can have different LULC needs and thus may be best served by different sets of policies designed to improve access to nutritious forage and nesting habitat. Native pollinators, if only due to their greater variety of species, may not be as susceptible to one of the main honey bee stressors—varroa mites—but may be more susceptible to others, such as pesticide exposure. A widely dispersed array of pollinator-friendly habitat, which may not require a large number of acres, could yield a robust ensemble of species that provide pollination services.

The health of honey bees is managed primarily by beekeepers. Improving the living environment for honey bees, such as by enhancing the extent and quality of honey bee-friendly land covers in the Northern Great Plains, may provide important insurance against sudden and widespread colony losses. The extent to which beekeeper inputs, such as mite-killing insecticides, supplemental feed, and new queens, complement or even substitute for better forage remains uncertain. Is there really a crisis that requires LULC change intervention? If so, will market solutions arise? If Government participation is needed, a suite of actions—ranging from changes in current agricultural management to setting aside natural habitat—can be considered (Aguire-Guitterez et al., 2015).

In a review of the literature on the effects of LULC on pollinator health, we report the results of several studies and meta-analyses. The general consensus is that nearby quality habitat can lead to enhanced pollination in pollination-dependent crops by native pollinators. For managed honey bees, the situation is more complex, as they are moved around the country to provide services. Managed honey bees' forage needs change at different points in space and time. However, expanding access to high-quality forage, perhaps in locations far from where honey bees are providing pollination services, is one of many possible means of improving honey bee health that may or may not be as cost-effective as more careful management of colonies.

As an exploratory exercise, we developed estimates of nationwide trends in pollinator forage quality from 1982 to 2012 using NRI data in combination with a metric that links LULC to bee forage suitability. The results reveal that the geographic scope and the time period of analysis matter. In our analysis, which includes a number of simplifying assumptions, overall changes across broad LULC categories (such as the establishment of the CRP) have led to a small net positive effect on overall honey bee forage quality over the conterminous United States from 1982 to 2012. However, forage quality has decreased somewhat since 2002, and in some regions, such as Central North and South Dakota, this decline since 2002 has been more pronounced. Given the simplicity of the metric—which uses rough measures of LULC and does not account for management changes in pesticide and herbicide use as well as field size—these results highlight the need for more detailed analyses.

A number of research initiatives are underway to better understand the impacts of LULC change on pollinator health. These include developing broad-scale models of hive health and LULC change, investigating the contribution of specific floral resources to honey bee health, and trying to understand how land use and management decisions incorporate market and policy conditions as well as how the existence of a pollination-service market makes it possible for beekeepers to invest in protecting and expanding their colonies.

We included an economics discussion of markets and pollinators; one that considers the question of when land-use policy designed to improve pollinator health may be useful. For an agricultural operation to set aside land for pollinators is akin to providing a semi-public good, as neighbors receive pollination services (if needed) without needing to compensate the landowner for providing pollinator habitat. Similarly, from the perspective of beekeepers, the incentive to purchase or rent land for the purpose of providing their honey bees with optimal access to pollen and nectar is reduced as honey bees from other beekeepers in close proximity cannot be excluded from the land (although steps to do so can be undertaken such as with South Dakota and Wyoming apiary registries).

Public good and open-access arguments, alongside others, such as the role of agriculture as a whole to support native pollinators for the benefit of society, may provide a rationale for Government intervention to support pollinator health through policies affecting LULC. Alternatively, information on flowering periods, nutritional value of plants to pollinators, and sensitivity of pollinators to pesticides could induce growers of pollination-dependent crops to set aside land to support native pollinators while lowering their own costs of pollination services by managed pollinators. Other candidate policies include giving growers of commodity crops that are not dependent on pollination services an incentive to reduce pesticide use during the times when pollinators are most vulnerable, or to provide pollinator habitat in buffer strips or as cover crops.

Our review focuses on LULC but recognizes other important stressors, such as pesticide/herbicide use, pests, and diseases. A motivation for modifying LULC to support better forage is the notion that such changes can counteract or at least mitigate these stressors. But the effects can be synergistic. For example, growers are careful to avoid exposing to pesticides the commercial honey bees that descend on their crops for a few weeks each year.[19] However, the benefit of setting aside land for native pollinators may require a greater (perhaps year-round) level of care.

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[19]By law, pesticide applicators are required to follow label instructions. For those pesticides toxic to bees, label language designed by the U.S. Environmental Protection Agency ranges from the vague to the specific, such as, "protect bees" to "do not apply while bees are actively foraging." (http://www.clemson.edu/public/regulatory/pesticide_regulation/bulletins/bulletin_5_protecting_honey bees.pdf

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Appendix 1: FSI Scores for NRI Land-Use Categories

The forage suitability index (FSI) values assign nine categories in table 3—of similar (in FSI terms) land covers—created by combining NRI "land cover/use" codes. The FSI scores in appendix table 1.1 were assigned to each land cover/use:

Appendix table 1.1

FSI scores assigned to NRI LULC categories

Forage suitability index (FSI)	Land-use, land-cover (LULC) categories in NRI (category number in parentheses)
0	Water (900-920)
0.157	Corn (11), Sorghum (12)
0.169	Wheat (111), oats (112), rice (113), barley (114), all other close grown (116)
0.224	Vineyard (3)
0.227	Nuts (2), peanuts (15)
0.250	Sugar beets (17), other row crops (20)
0.253	Barren (611-620)
0.260	Cotton (14)
0.268	Tobacco (16)
0.269	Soybean (13)
0.307	Other veg/truck crops (19)
0.317	Summer fallow (170), aquaculture (171), other set aside (160)
0.322	Berries (5), potatoes (18)
0.332	Hayland (140)
0.351	Fruit (1)
0.434	Sunflower (21)
0.441	Brush fruit (4)
0.450	Pastureland (210), rangeland (250), other land (401), CRP (410), all other land (650), rural transportation (800)
0.474	Marshland (640)
0.482	Forestland (341-342)
0.495	Other horticultural (6)
0.537	Farmsteads (400)

FSI=Forage suitability Index. NRI=National Resource Inventory. CRP=Conservation Reserve Program.

Source: USDA, Economic Research Service using Lonsdorf et al. (2009) and Koh et al. (2016). The index in Koh et al. (2016) is based on a 14-member panel's expert assessment of floral resources for each LULC category.

The nine categories in table 3—of similar (in FSI terms) land covers—are created by combining these NRI "land cover/uses."

Appendix table 1.2

Assignation of NRI land cover/uses to FSI category

Broad category	Contains NRI points with the following land cover/uses:
Other low FSI land	Various barren lands (i.e., sand dunes, beaches, and exposed rock), water bodies
Farmland: very low FSI	Corn, sorghum, wheat, oats, rice, barley, other close grown
Farmland: low FSI	Nuts, vineyard, soybeans, cotton, peanuts, tobacco, sugar beets, other row crops
Farmland: medium FSI	Hort/fruit, berries, potatoes, other veg/truck crops, hayland, other crop/summer fallow, aquaculture, other crop
Farmland: high FSI	Hort/bush fruit, hort/other, sunflower, other farmland, farmstead
Forestland	Forestland (grazed and not grazed)
Pasture & rangeland	Pasture, rangeland
Conservation Reserve Program	CRP
Other high FSI land	Other rural/marshland, all other land (includes pasture and forest), rural transportation

NRI=National Resource Inventory. CRP=Conservation Reserve Program.
FSI=Forage suitability index.

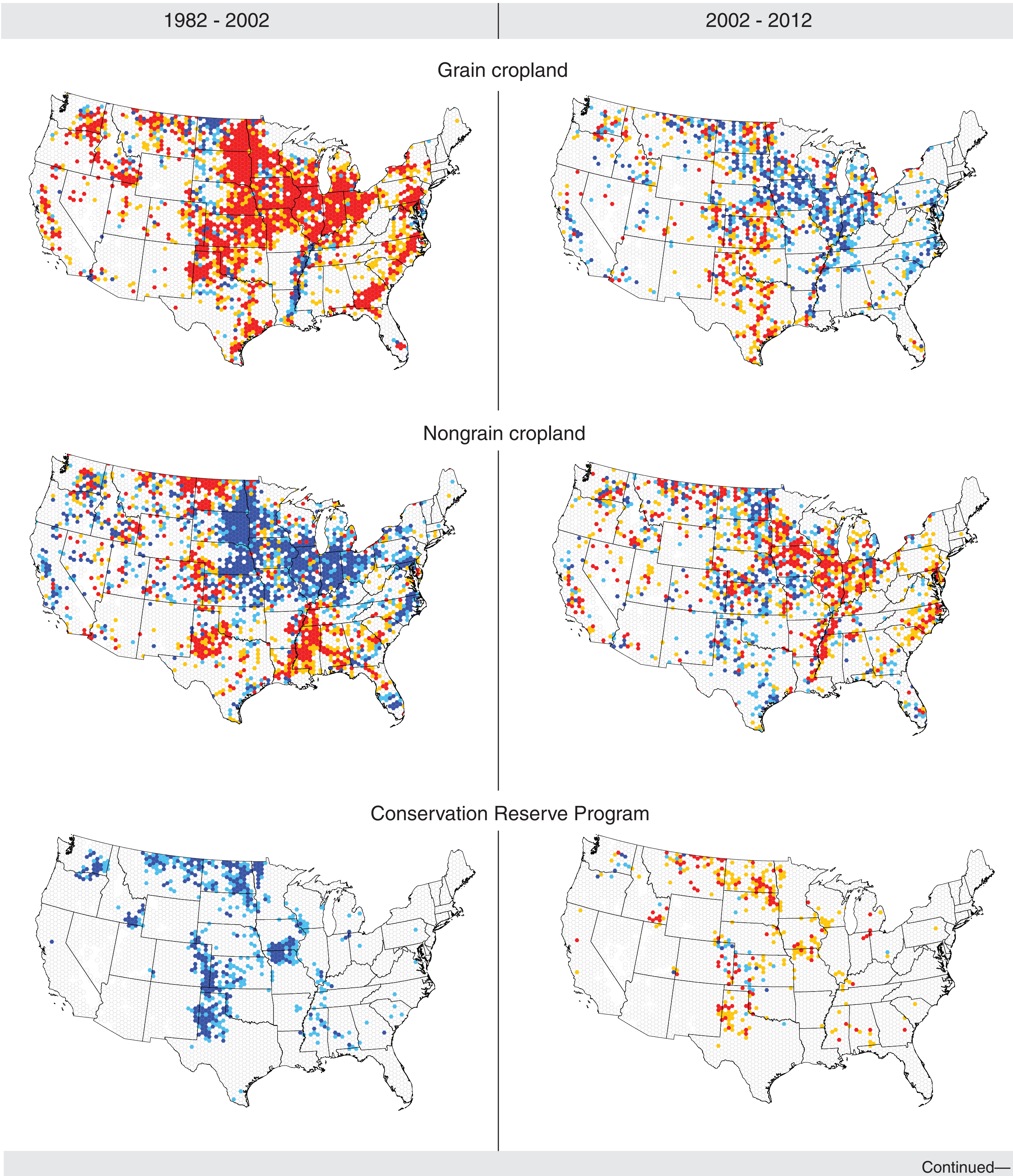
Source: USDA, Economic Research Service using non-Federal, nonurban NRI data.

Appendix 2: Changes in Acreage for Broad Categories (of Land Uses/Covers With Similar FSI)

As displayed in appendix figure 2.1, between 1982 and 2002 the grain cropland area declined in the Central Feed Grains and Great Plains regions. Over this same time period and in these same regions, nongrain cropland increased. The trend reversed itself from 2002 to 2012 in the Northern Great Plains and Central Feed Grain regions. Introduced in 1986, the CRP enrolled acreage primarily in the Northern and Western Great Plains and the Central Feed Grain regions. These are the same regions that saw a decline in CRP acreage between 2002 and 2012. The area of pastureland has been declining in the Northern Great Plains and Central Feed Grain regions. In the West, pastureland has become more common. Between 1982 and 2002, the Eastern and Southern United States experienced an expansion in forestland acreage.

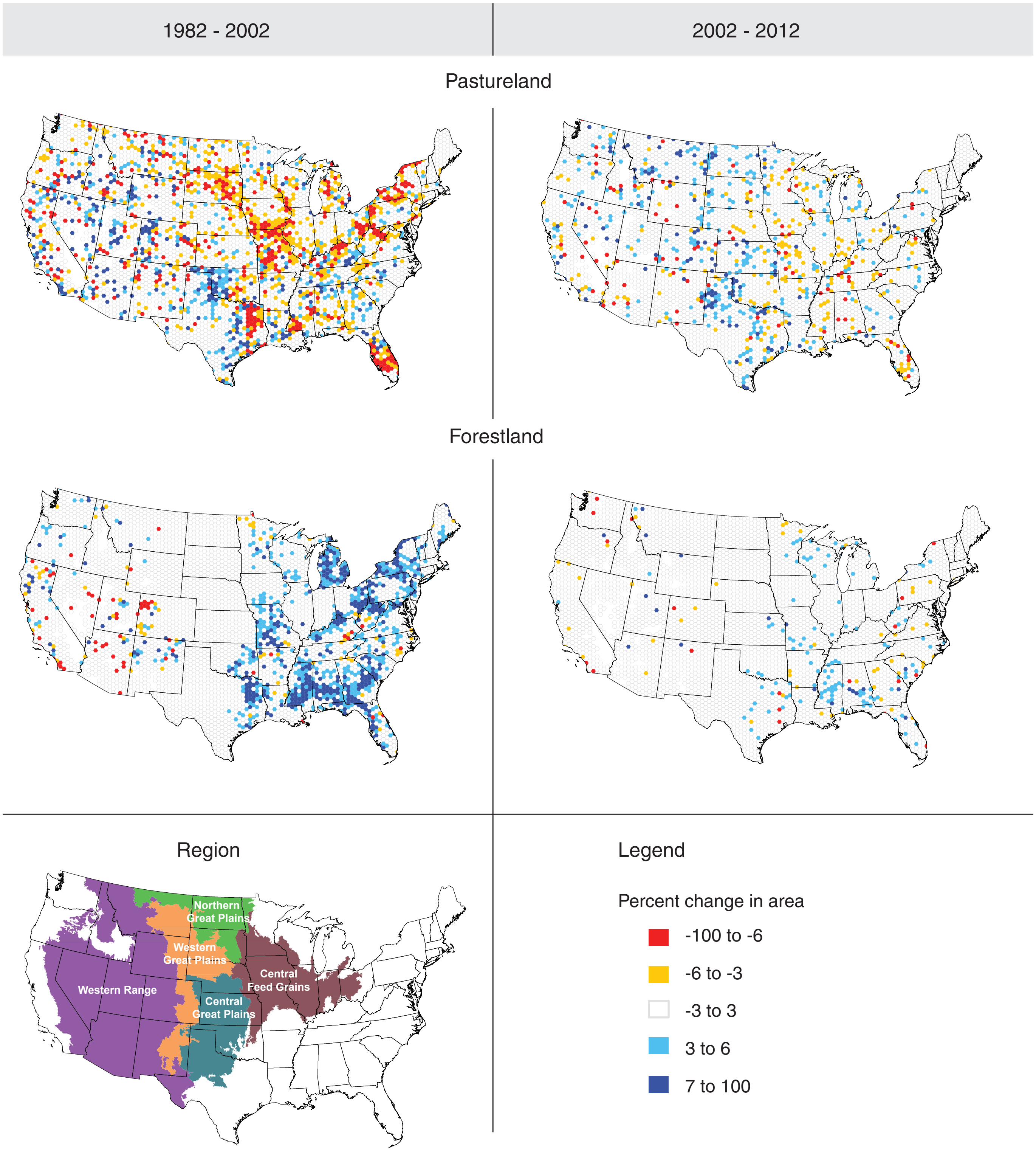
Appendix figure 2.1

Changes in acreage, by broad category from 1982 to 2002 and 2002 to 2012



Appendix figure 2.1

Changes in acreage, by broad category from 1982 to 2002 and 2002 to 2012—continued



Source: USDA, Economic Research Service using USDA, Natural Resources Conservation Service, National Resources Inventory.

Appendix 3: Sensitivity Analysis: Changing the FSI of CRP Acreage

In the analysis earlier, an FSI value of 0.45 is assigned to all National Resources Inventory (NRI) points identified as Conservation Reserve Program (CRP). However, the forage suitability index (FSI) of land enrolled in the CRP depends on conservation practices installed on the land. Some practices (such as native grasses installed under CP2) are likely to provide better pollinator habitat than others (such as softwood trees installed under CP3). Thus, a more accurate measure should differentiate CRP acreage by the conservation practice installed.

However, due to the limitations of the NRI data, it is not straightforward to assign a conservation practice to NRI points assigned a land cover/use (LCU) of CRP. This is especially true for earlier years, where other USDA data (such as Common Land Unit) are not readily available.

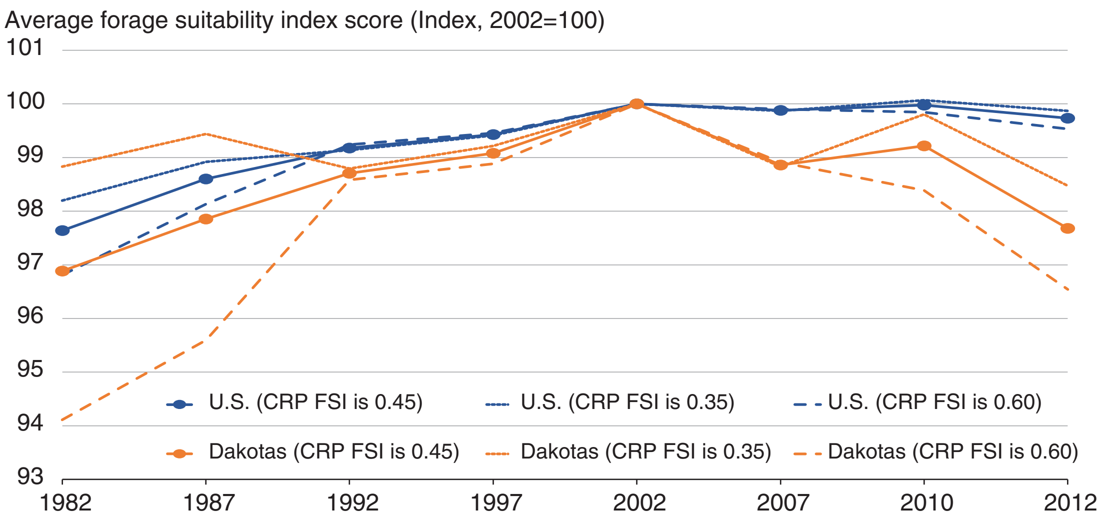
To examine the implications of choosing an FSI value of 0.45 for all CRP lands, two alternative models were created: one with a CRP FSI of 0.35 (a moderately high value) and one with FSI values of 0.60 (well above the current maximum FSI for the land use/covers considered in this analysis).

As illustrated in appendix figure 3.1, the overall qualitative results do not change. Under all three FSI estimates, the average FSI scores peak in 2002, and the "Dakotas" region (the 87 counties deemed as prime over-summering grounds) has a sharper peak. With an FSI score of 0.35, the peak is attenuated. Conversely, with an FSI score of 0.60, the peak is sharper, especially in the "Dakotas."

Going beyond these qualitative findings requires more sophisticated research that uses finer grained land-use coverages and incorporates additional variables.

Appendix figure 3.1

Trends in average FSI scores for the United States and the Central Dakotas under different FSI scores for CRP



Note: Forage suitability index (FSI) is normalized so that, in 2002, it is equal to 100 for both the Central Dakotas and the United States. Note that the Central Dakotas contain a lower share of noncropland than the U.S. average. The solid lines show trends in the United States and the Central Dakotas with an FSI score of 0.45 for Conservation Reserve Program (CRP), as is assumed in the main analysis. The dotted and dashed lines show the trends in forage suitability assuming FSI scores of 0.35 and 0.60, respectively, for CRP. In both cases, forage suitability in the Central Dakotas has declined to a greater degree than in the United States as a whole.
Source: USDA, Economic Research Service using non-Federal, nonurban NRI data.