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Chapter 1

Assessing Pollinator Habitat Services to Optimize Conservation Programs

The Council on
Food, Agricultural
& Resource Economics

Authors

Synthesis Chapter - The Valuation of Ecosystem Services from Farms and Forests: Informing a systematic approach to quantifying benefits of conservation programs

Project Co-Chair: L. Wainger, University of Maryland Center for Environmental Science, Solomons, MD, wainger@umces.edu
Project Co-Chair: D. Ervin, Portland State University, Portland, OR, dervin@pdx.edu

Chapter 1: Assessing Pollinator Habitat Services to Optimize Conservation Programs

R. Iovanna, United States Department of Agriculture – Farm Service Agency, Washington, DC, Rich.Iovanna@wdc.usda.gov
A. Ando, University of Illinois, Urbana, IL, amyando@illinois.edu
S. Swinton, Michigan State University, East Lansing, MI, swintons@msu.edu
J. Kagan, Oregon State/Portland State, Portland, OR, jkagan@pdx.edu
D. Hellerstein, United States Department of Agriculture - Economic Research Agriculture, Washington, DC, danielh@ers.usda.gov
D. Mushet, U.S. Geological Survey, Jamestown, ND, dmushet@usgs.gov
C. Otto, U.S. Geological Survey, Jamestown, ND, cotto@usgs.gov

Chapter 2: Ecosystem Service Benefits Generated by Improved Water Quality from Conservation Practices

L. Wainger, University of Maryland Center for Environmental Science, Solomons, MD, wainger@umces.edu
J. Loomis, Colorado State University, Fort Collins, CO, john.loomis@colostate.edu
R. Johnston, Clark University, Worcester, MA, rjohnston@clarku.edu
L. Hansen, USDA ERS, United States Department of Agriculture - Economic Research Agriculture, Washington, DC, lhansen@ers.usda.gov
D. Carlisle, United States Geological Survey, Reston, VA, dcarlisle@usgs.gov
D. Lawrence, Blackwooods Group, Washington, DC, doug.lawrence@blackwoodsgroup.com
N. Gollehon, United States Department of Agriculture - Natural Resources Conservation Service, Beltsville, MD, noel.gollehon@wdc.usda.gov
L. Duriancik, United States Department of Agriculture - Natural Resources Conservation Service, Beltsville, MD, lisa.duriancik@wdc.usda.gov
G. Schwartz, U.S. Geological Survey, Reston, VA, gschwarz@usgs.gov
M. Ribaudo, United States Department of Agriculture - Economic Research Agriculture, Washington, DC, mribaudo@ers.usda.gov
C. Gala, Council on Food, Agricultural and Resource Economics, Washington, DC, cgala@cfare.org

Chapter 3: Estimated Values of Carbon Sequestration Resulting from Forest Management Scenarios

R. Bluffstone, Portland State University, Portland, OR, bluffsto@pdx.edu
J. Coulston, United States Department of Agriculture - US Forest Service, Blacksburg, VA, jcoulston@fs.fed.us
R.G. Haight, United States Department of Agriculture - US Forest Service, St. Paul, MN, rhaight@fs.fed.us
J. Kline, United States Department of Agriculture - US Forest Service, Corvallis, OR, jkline@fs.fed.us
S. Polasky, University of Minnesota, St. Paul, MN, polasky@umn.edu
D.N. Wear, United States Department of Agriculture - US Forest Service, Raleigh, NC, dwear@fs.fed.us
K. Zook, United States Department of Agriculture – Office of the Chief Economist, Washington, DC, kzook@oce.usda.gov

Project Director: Caron Gala, Council on Food, Agricultural and Resource Economics

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Disclaimer

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Please note, the report and its chapters are intended to demonstrate a framework approach to ecosystem service valuation. The report or any chapter there within is not to be cited for the purpose of supporting or opposing any government or private program.

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R. Iovanna, United States Department of Agriculture – Farm Service Agency, Washington, DC, Rich.Iovanna@wdc.usda.gov
A. Ando, University of Illinois, Urbana, IL, amyando@illinois.edu
S. Swinton, Michigan State University, East Lansing, MI, swintons@msu.edu
J. Kagan, Oregon State/Portland State, Portland, OR, jkagan@pdx.edu
D. Hellerstein, United States Department of Agriculture - Economic Research Agriculture, Washington, DC, danielh@ers.usda.gov
D. Mushet, United States Geological Survey, Jamestown, ND, dmushet@usgs.gov
C. Otto, United States Geological Survey, Jamestown, ND, cotto@usgs.gov

ABSTRACT

Pollination services have received increased attention over the past several years, and protecting foraging area is beginning to be reflected in conservation policy. This case study considers the prospects for doing so in a more analytically rigorous manner, by quantifying the pollination services for sites being considered for ecological restoration. The specific policy context is the Conservation Reserve Program (CRP), which offers financial and technical assistance to landowners seeking to convert sensitive cropland back to some semblance of the prairie (or, to a lesser extent, forest or wetland) ecosystem that preceded it. Depending on the mix of grasses and wildflowers that are established, CRP enrollments can provide pollinator habitat. Further, depending on their location, they will generate related services, such as biological control of crop pests, recreation, and aesthetics. While offers to enroll in CRP compete based on cost and some anticipated benefits, the eligibility and ranking criteria do not reflect these services to a meaningful degree. Therefore, we develop a *conceptual value diagram* to identify the sequence of steps and associated models and data necessary to quantify the full range of services, and find that critical data gaps, some of which are artifacts of policy, preclude the application of benefit-relevant indicators (BRIs) or monetization. However, we also find that there is considerable research activity underway to fill these gaps. In addition, a modeling framework has been developed that can estimate field-level effects on services as a function of landscape context. The approach is inherently scalable and not limited in geographic scope, which is essential for a program with a national footprint. The parameters in this framework are sufficiently straightforward that expert judgment could be applied as a stopgap approach until empirically derived estimates are available. While monetization of benefit-relevant indicators of yield changes (crop and honey) and of habitat benefits due to enhanced pollination and pest bio-control services would be relatively straightforward, the merits of proceeding when other services cannot be valued now should be carefully considered.

PROGRAM ACTIONS EVALUATED

The program action for this case study is the establishment of pollinator-friendly habitat via the Conservation Reserve Program (CRP), a voluntary private lands conservation program. If a landowner's offer to enroll land into the program is selected during signup, the landowner receives technical and financial assistance to take this marginal or environmentally sensitive cropland out of production for at least ten years. In lieu of growing annual crops, the landowner instead establishes and maintains a "conservation cover," which is typically a mix of perennial grasses and forbs (wildflowers). In other words, the program incentivizes prairie restoration to varying degrees. While other programs with similar outcomes are administered at the federal and other levels of government, as well as by non-governmental organizations (e.g., land trusts), the CRP is the largest of its kind.

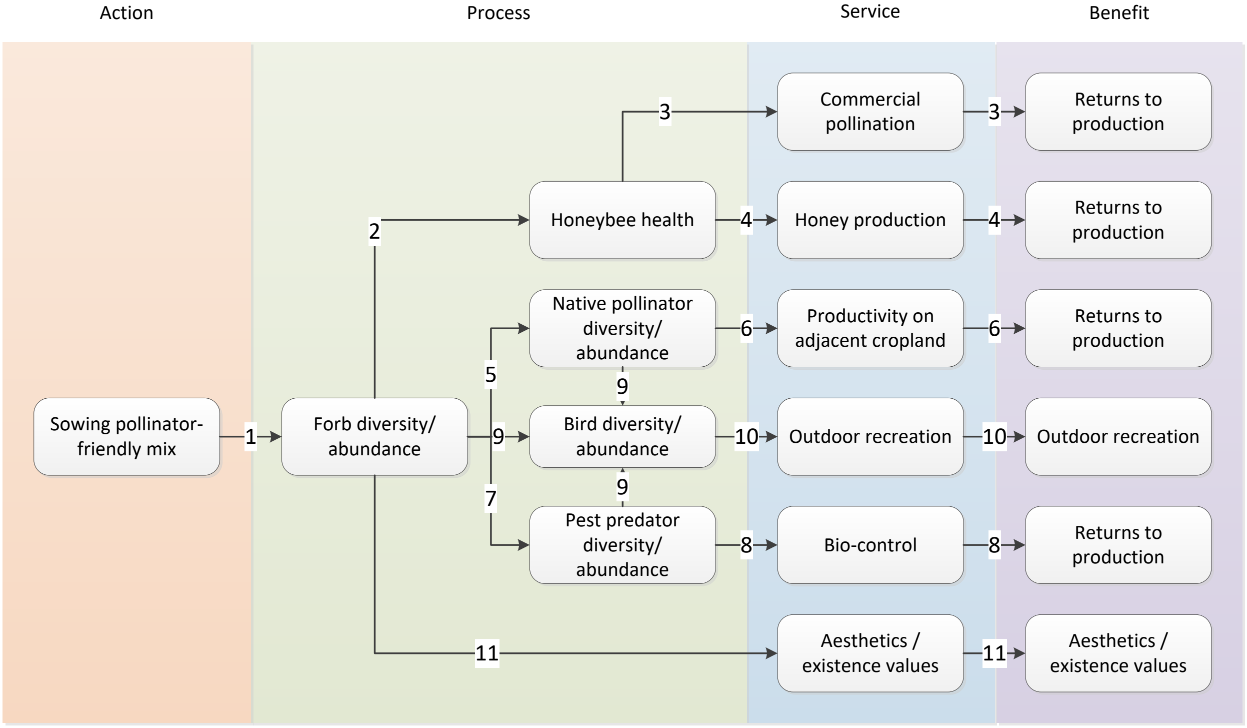
The resource concern that led to the program's creation in 1985 was soil erosion. Since then, the impact of the program on other resource concerns has been recognized and incorporated into policy. For example, water quality improves as the conservation covers reduce sediment and nutrient loadings, net greenhouse gas emissions decline as carbon is stored in biomass and soil, fertilizer and fuel use are reduced, and habitat is created for migratory waterfowl, shorebirds, and songbirds. Most recently, the support that CRP provides to native pollinators and honeybees by providing forage habitat (i.e., the floral resources from which bees and other pollinators obtain pollen and nectar) became a priority of the program and is being taken seriously (USDA's 2015 Colony Collapse Disorder and Honeybee Health Action Plan, 2015 National Strategy to Promote the Health of Honeybees and Other Pollinators, and 2016 Pollinator Partnership Action Plan).

Salient ecosystem services

The project team was tasked with assessing the ecosystem services provided by pollinator habitat, and the CRP was determined to be an apt fit, given that establishing pollinator habitat is a mandated recognized resource concern for the program. Rather than narrowly focusing on pollination services, the team elected to consider multiple services generated by pollinator prairie habitat on CRP land, relative to a baseline of a generic perennial grass stand that lacks wildflowers.

Put another way, this case study investigates how otherwise similar offers by landowners to enroll land in CRP can be compared based on pollinator habitat-related services. The comparison is between competing offers, because the CRP is explicitly acreage constrained by statute and the USDA manages the program to maintain full enrollment. Thus, the question is not whether to enroll an additional acre, but rather which acre to enroll and what to do with it. This baseline is useful, both because it happens to be a common CRP practice and because it enables otherwise important soil health, water quality, and net GHG emission benefits to be netted out. In other words, there is no appreciable difference for these ecosystem services between a baseline cover and pollinator habitat characterized as having an abundance (i.e., the number of stems per unit area) and diversity (i.e., the number of species) of forbs. The framework for our analysis is depicted in the conceptual value diagram of ecosystem service values (Figure 1) that links the program action to ecological process changes, ecosystem service changes, and economic values.

Figure 1. Conceptual value diagram of ecosystem service values from pollinator habit



Scope of case study

Landowners can voluntarily offer parcels for enrollment in CRP via a competitive process, requesting an annual payment amount when doing so. From the offers received, the USDA selects those with the most favorable combination of cost and anticipated benefits. Since there is usually more land offered than the program can accept, offer selection is a fundamental aspect of CRP. The program is national in scope, with a presence in forty-seven states, and the USDA must be able to evaluate offers wherever cropland exists that is eligible for enrollment.

The case study involves developing a capacity to account for the additional benefits of enrolling parcels with land cover that provides high quality pollinator habitat, versus a more generic cover, in a prairie setting. Equivalently, this approach expands the set of benefits that USDA can consider when selecting offers to include those that vary per cover quality. This is particularly true for wildlife and pollinators, which may have specific structural and biological diversity requirements associated with the cover. In contrast, soil erosion and water quality are greatly improved when perennial cover is established on the enrolled cropland. Differences in these impacts attributable to the specific composition of the cover are more muted, hence the baseline definition.

Ideally, the metrics generated by the approach would be scalable over regions, enabling the USDA to track and report overall program performance over time to the public and decision makers. For example, the total market value at today's prices of the yield effects of native pollinators who nest on CRP could be reported.

RESULTS

In the body of this report, the eleven links in the conceptual value diagram (depicted in Figure 1) are identified and the equations, data requirements, and assumptions of each are described in turn. Of relevance is the intermediate output generated by each link, since it must be used in the next link in the cause and effect chain. The links to services also include discussion on the prospects and challenges in quantifying each service; computing a benefit-relevant indicator, or BRI, for the service, which accounts for beneficiary populations; and valuation of the benefits.

Link 1: From superior seed mix selection to greater floral diversity and abundance

While Link 1 is the foundation to all the processes and services that follow in the diagram, the team could not identify any literature on establishment success, and treated it as a given that using a seed mix with more forb (and other pollinator-friendly plant) seeds will yield a landscape with more forbs. Part of the problem relates to policy: there is no requirement to document in a CRP contract or associated conservation plan the exact seed mix that is ultimately applied. Similarly, monitoring of the condition of enrollments is not sufficiently intense to enable the composition of the cover to be tracked over time.

Link 2: From greater floral diversity and abundance to improved honeybee health

While information on the general associations between land cover and pollinator health has grown over the last two decades, much of this has focused on wild pollinators. Partially due to the ability of beekeepers to move colonies around the landscape, these studies provided less information on how landscape features impact the long-term health (i.e., overwinter survival) of managed honeybee colonies. For example, a daily count of honeybees at a test site is likely to be affected by the placement of transient colonies in the vicinity, and these placements are not necessarily solely driven by land use changes.

Research is now emerging that demonstrates a clear association between land use and honeybee colony survival (Smart et al. 2016a), individual bee physiology (Smart et al. 2016b), diet (Requier et al. 2015), and large-scale habitat suitability (Gallant et al. 2014, Otto et al. 2016); however, more work is needed to understand how diverse CRP plantings influence honeybee health. Recent research shows that beekeepers in the Northern Great Plains favor CRP land when selecting locations for pasturing honeybee colonies (Otto et al. 2016), but fine scale information on how the quality of CRP plants influences beekeeper perceptions is lacking.

The USGS and USDA are currently collaborating on a research and monitoring project that will quantify the associations between forb diversity and abundance, diet and nutrition, and honeybee colony health, with a specific focus on USDA conservation covers. Honeybee-host plant observations are being made on CRP and other USDA conservation covers across North Dakota, South Dakota, Minnesota, and Michigan.

While there is considerable research in process, little of that research has yet been completed and is actionable. However, an expedient approach to estimating how a landscape's floral resources impact honeybee health does exist, suggested by Lonsdorf and Davis' (2016) managed bee model. The model specifies a direct relationship between floral resource quality within the foraging area of honeybees and the health of their colony. Lonsdorf and Davis validated their model using honey production data. The model captures the fact that the contribution of a forage source (e.g., CRP enrollment) diminishes as distance to the honeybee colony increases.

Let honeybee colony j be within foraging distance (the "kernel" distance for analytical purposes) from the land offered for CRP enrollment. Forage resources available to a honeybee colony P_j at pixel j are a function of forage quality F_k of the pixels k within foraging distance of the offer, which diminishes with distance D_{jk}. We can quantify this ecosystem service by summing the difference in F_k across CRP offer pixels. Going further to a BRI, the total forage resources available to pixel j can be specified as

$$P_j = \sum_{k=1}^{K} F_k e^{\frac{-D_{jk}}{\alpha}} \bigg/ \sum_{k=1}^{K} e^{\frac{-D_{jk}}{\alpha}}$$

Equation 1

where α is the kernel distance for honeybees, two miles. Note that P_j for honeybees is not necessarily proportional to floral diversity: Honeybees with ample access to clover alone, with its long blooming period, would equate with a relatively high P_j value.

At first blush, the input data requirements of the equation are appealingly modest: a detailed land-cover raster, which is already available with national coverage (e.g., the NASS Cropland Data Layers, which have thirty-meter resolution). However, the equation is predicated on the availability of values for the 0–1 scaled forage quality parameters, which are specific to land cover type and consider the quality of floral resources throughout the spring-fall forage season. Expert elicitation has been used to determine these values, although they can be replaced with values that have been empirically determined through field or lab research.

Assuming a direct relationship, on average, between available floral resources and honeybee colony health, P_j can be rescaled so that it becomes a factor that converts the number of colonies at the onset of forage season into the number of healthy colonies at the end of it.

To estimate the impacts of changes in land cover (such as conversion of CRP land from a baseline cover to a pollinator habitat), the model is run for two scenarios, one reflecting current conditions (such as existing cover on CRP-offered acreage) and one assuming a new suite of land covers (such as converting existing cover into pollinator habitat). Taking the difference of the two scenarios yields the BRI. Note that the resulting amount will tend to be extremely small: A typical CRP offer is about eighty acres, which amounts to one tenth of one percent of the foraging area for a honeybee. What matters, however, for offer selection, is the relative, rather than the absolute, amount.

Unsurprisingly, several factors must be considered to use this approach: First and foremost, the set of expert elicitation-based parameters is incomplete for our purposes: a uniform value for the forage quality parameter is currently applied to all grassland.

Second, the relationship between forb diversity and abundance (hence, estimated floral resource quality) and honeybee health is estimated using measures of honey production gathered from a small sample of colonies. Currently, data are being collected in the Northern Plains to improve model calibration. It is also possible to portray parameter uncertainty to some degree by using Monte Carlo techniques and a distribution of expert judgments, rather than a point estimate (Koh et al. 2016).

Third is model abstraction: while the equation is appealingly straightforward, it does not account for such important factors as weather, pathogens, pests, and pesticides. Climate can be incorporated into the equation as necessary as a multiplicative factor. Unless pathogens, pests, and pesticides are related to location or seed mix, they can be disregarded, since a relative measure is all that is needed to estimate honeybee colony health.

Fourth, it is not obvious whether it is more appropriate to take the current spatial distribution of honeybee colonies as given (as described, above) or step back to equate the summed changes in forage quality F_k with *potential* benefits, as honeybee colonies can be moved to where floral resources are developed.

Link 3: From improved honeybee health to more bee colonies

To analyze this link, it is useful to have some sense of the U.S. beekeeping industry. Many U.S. beekeepers are migratory in nature: during the summer, the primary objective of beekeepers is to place their colonies in safe pasturing areas so their bees can produce a valuable honey crop and bolster colony health. Over 40 percent of all U.S. honeybee colonies are transported to the Northern Great Plains to spend the summer (USDA-Honey 2014). During the fall, beekeepers then transport their bee colonies to parts of the U.S. that have relatively mild winters. Typically, the bees are transported during the late winter and early spring to agricultural regions requiring pollination services, often starting in the February almond bloom in California.

Because healthier colonies pollinate crops more efficiently, leading to higher yields on the farm, they are more valuable. In the case of California almond growers, honeybee colony strength (i.e., health) is quantified when colonies arrive at an orchard, and payment per colony by the orchard owner is based on the health of colonies, e.g., $200 for a strong colony, $140 for a weak colony. On the beekeeper side of the equation, trucking costs, etc. are likely the same for both strong and weak colonies.

The USGS and USDA are gathering data to explore the link between summer habitat quality, including CRP, in the Northern Great Plains, honeybee colony health, and pollination services in California almonds. These data could be used to connect floral resources all the way to the number and health of the pollinators that reach the cropland at which they are dispensing their services. The change in the number and health of colonies could then be multiplied by the colony prices inferred from market data. For example, if CRP plantings of forbs increase the number of strong colonies that were formerly weak by 100,000, then the value of added pollination services could be approximately $6 million ($200 less $140 times 100,000), if the increase in strong colonies does not drive the market price down significantly.

Until the data are available for empirical analysis, we would need to rely on expert judgment for the mapping of forage resources to colony strength. Among other things, initial estimates are unlikely to reflect the fact that the strength of honeybee colonies can be impacted by the forage available while providing pollination and honey production services (DeGrandi et al. 2016). Thus, forage can matter both during the summer (e.g., in the Dakotas), and the winter (e.g., in central California).

Also, note that the simple approach, above, is not as well suited for generating dollar estimates at the program level as a *partial equilibrium* model that accounts for the shift in supply and the drop-in pollination costs associated with the CRP pollinator habitat.

Link 4: From improved honeybee health to higher honey output

Recent research shows that land-cover quality is directly related to honey production (Smart et al. 2016) and foraging efficiency (Danner et al. 2016). Both the initial approach to quantifying honeybee services and the BRI, discussed above, apply to honey output as well. By associating a change in available forage resources (the BRI from Link 2), to honey production data, we can value this service. Current efforts at forty sites in North Dakota, South Dakota, Minnesota, and Michigan collect the needed spatially explicit beekeeper records to do so. The considerations discussed above apply to this link as well, including the relevance of partial equilibrium modeling, if monetization is desired for program performance reporting.

Link 5: From greater forb diversity/abundance to greater native pollinator diversity/abundance

There are several studies, summarized in Table 1, along with syntheses and meta-analyses, that find the availability of habitat to favorably impact pollinator diversity (i.e., number of species) and abundance (i.e., number of individuals), the extent of which depends on the crop, specific pollinator, and pollinator habitat. There are over 4,000 species of native bees in North America with diverse life histories. This diversity, although critical for supporting ecosystem function, makes it difficult to make broad generalizations about how habitat enhancement will lead to greater pollinator diversity and abundance. For example, the home range for many small, native bees is less than 0.5 kilometers (Olsson et al, 2015; Lonsdorf et al, 2009). Shorter distances between nesting habitat and forage are critical. Alternatively, large, colonial, native bees, such as bumble bees, have home ranges well beyond five kilometers, distances even greater than for honeybees. For these species, access to distant forage plots should be less difficult; however, landscape context becomes an important factor to consider, as pesticides can be encountered during long aerial flights (Rundlof et al. 2015, Stanley et al. 2015).

Table 1. Meta-analyses and survey articles on land use and native pollinator health.

Brodschneider and Crailsheim (2010)	*Data inferred from over 20 articles illuminates the nutritional demands of honeybees at three levels (colony, adult, and larval nutrition). Malnutrition can occur at any of these levels and can have long-term consequences.*
Brown and Paxton (2009)	*A synopsis of 12 reviews on the threats to pollinators suggests 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 impact bee populations.*
Garibaldi et al. (2011)	*A synthesis of data from 29 studies tested the effects of isolation from natural areas. The findings were 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.*
Kennedy et al. (2013)	*A meta-analysis of wild bee abundance, using data from the literature on over 600 sites, covering 39 studies around the world, including measures of local farm management and landscape composition and configuration. The study reports that the most important factors enhancing wild bee communities in agri-ecosystems were the amounts of high quality habitats surrounding farms in combination with organic management and local-scale field diversity.*
Paudel et al. (2015)	*A broad review of honeybee and pollination issues, including land use and forage. The authors review trends in honeybee populations, and how declines impact ecology and the agricultural economy. They note that "habitat loss might be one of the biggest factors impacting honeybee declines and the agricultural landscape changes after the Second World War."*
Potts et al. (2010)	*Evidence for the decline in honeybees in the U.S. and Europe are noted, as is the lack of information about wild pollinators (whose contributions might be higher than assumed). The authors note 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 honeybees).*
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 decline exponentially with increasing distance from natural habitat, with evidence indicating an overall decline in fruit and seed set (though landscape effects on pollination services can vary substantially).*
Vianna et al. (2012)	*Using 219 studies; with only 10 before 2000, and over 45/year in 2010; with about three quarters observational studies often appearing in purely scientific journals. 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."*
Winfree et al. (2010)	*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 were negatively 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. The authors also note that the abundance of managed honeybees is not associated with anthropogenic disturbance.*

Overall, few models were found in the literature search that yield a direct prediction of pollinator diversity/abundance as a function of land cover change at the appropriate scale and scope. Nevertheless, a promising approach to assess the impact of enrolling land in CRP to establish pollinator habitat was used in several studies (Lonsdorf et al. 2009, Kennedy et al. 2013, Koh et al. 2016). The approach builds upon what was described for honeybees, above, and is based on the InVEST Model of Crop Pollination (see website).

As with the model relating land cover to honeybee health (discussed under Link 2), this approach uses land cover data along with a set of expert-determined parameters, and predicts the change in supply of native pollinators within range of a target agricultural field. As a start, we can quantify this service P_k at CRP offer pixel k using a nesting suitability parameter that varies per land cover type and pollinator guild (a group of species with similar requirements that play a similar role within a community). These parameters are simply summed across guilds, weighted by the background population level, and summed across CRP offer pixels:

$$P_k = \sum_{i=1}^{I} G_i N_{ik}$$

Equation 2

where N_{ik} is the nesting suitability of pixel k with respect to pollinator guild i. G_i refers to a set of weights, which sum to 1, that reflect background relative guild populations.

To develop a BRI, the set of parameters expands to include forage quality for each land cover type and pollinator guild combination, along with kernel distance. In the resulting equation, pollination services P_{ij} supplied by the population of guild i within foraging distance to crops on pixel j:

$$P_{ij} = \sum_{k=1}^{K} N_{ik} F_{ij} e^{\frac{-D_{jk}}{\alpha_i}} \Bigg/ \sum_{k=1}^{K} e^{\frac{-D_{jk}}{\alpha_i}}$$

Equation 3

where N_{ik} is the nesting suitability of pixel k and F_{ij} is the forage quality of pixel j with respect to pollinator guild i. These vary according to both land cover type and pollinator guild. As with the honeybee equation, pollination services diminish with distance. Note that, in this case, kernel distance will also vary by pollinator guild. Analogous to Equation 2, total pollination services supplied to the pixel j crop is given by

$$P_j = \sum_{i=1}^{I} G_i P_{ij}$$

Equation 4

As was the case for honeybees, this equation is solved for two scenarios, one reflecting current conditions and one if the CRP land is enrolled in forb-rich habitat. The difference is a rough benefit-relevant indicator.

Such an approach has, in fact, been calibrated by Koh et al. (2016), who use wild bee abundance data from several studies covering 343 sites across the nation and identify regions where both agriculture benefits from native pollinators and pollinator habitat are worsening. The authors do note that the spotty spatial coverage of the data they used is a concern. Also, the USGS Pollinator Library has data from several studies of native bee observation on CRP plantings throughout the Great Plains. These data may be useful for empirically determining parameter estimates.

Note that the concerns raised for Link 3 are all relevant here: Reliance on expert judgment, given the greatly expanded number of parameters involved, is a greater concern. The equation can be readily operationalized only because other factors are unaddressed. In addition to abiotic factors, along with pests, pathogens, and pesticides, the fact that managed honeybees are often used in the same locations as native pollinators is unexplored. Finally, the approach takes the current spatial configuration of crops as given and does not account for the likelihood that producers respond to the increase in habitat by changing the mix of crops they plant.

Link 6: From pollinator diversity/abundance to agricultural productivity

Since pollinators only have value to crops that depend to some degree on animal pollination, the approach factors in the distribution of pollinator-dependent crops within the range of pollinators residing on the CRP source field (Robinson et al. 1989, Morse and Calderone 2000). Among the major U.S. field crops, grass crops like corn, wheat, and sorghum do not need animal pollinators; their pollinator dependency is zero. Soybean and cotton have low pollinator dependencies. By contrast, most fruit and vegetable crops have high pollinator dependency: forb-enriched CRP plantings are likely to generate the greatest crop pollination services where such horticultural crops abound.

How changes in the abundance of pollinators, driven by changes in land cover considered in this case study, translate into economic impact due to better crop yields depends on several factors: the distance of CRP enrollments from crop fields, how dependent those crops are on pollinators (how crop yields respond to the additional pollination), and crop price. Furthermore, the relative value of a change in pollinator population depends on how abundant pollinators were in the vicinity in the first place. Where pollinators are few, new pollinator habitat may make a big difference; where pollinators abound, it may not.

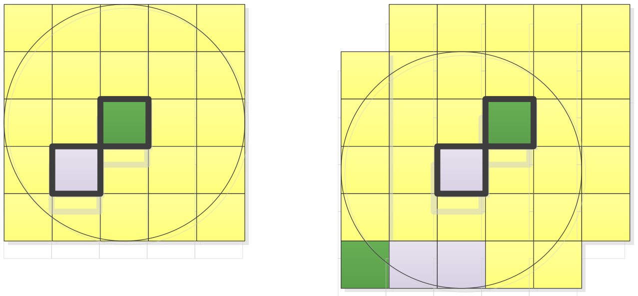
Once the amount of native pollination services has been estimated, above, the next step is to convert this to a change in crop yield, perhaps a more refined BRI, per Equation 5:

$$\Delta Y_j = w\left(\frac{P_j}{P_j + c} - \frac{P_{jB}}{P_{jB} + c}\right)$$

Equation 5

where ΔY_j is the change in yield (relative to the maximum) at pixel j and P_{jB} the baseline (without offer) scenario calculation, with w being the proportion of the crop yield dependent on animal pollination and c a crop-specific constant. This functional form reflects diminishing returns to yields from pollination services.

Figure 2. Native pollination BRI example: (a) New pollinator habitat (green) adjacent to a field of berries (gray) in a matrix of corn (yellow) and (b) depicts the pixels that are within foraging distance of the berry field.



(a) (b)

Figure 2a depicts an offer scenario in which a pixel of corn converted to new pollinator habitat (green) is adjacent to a field of berries (gray) in a matrix of corn (yellow). For simplicity's sake, there is a single pollinator guild to consider and, accordingly, a single forage distance and set of nesting suitability and forage quality parameters. Having identified the berry field as being within foraging distance (indicated by the circle) of the population of pollinators nesting in the new pollinator habitat pixel, we shift our attention to it.

Figure 2b depicts the land cover of those pixels that are within foraging distance (circle) of the berry field under the CRP offer scenario: twenty pixels of corn with negligible nesting suitability and forage quality (N_c=0; F_c=0), three pixels (including the field in question) of berries with nesting suitability of 0.2 and forage quality of 0.8 (N_c=0.2; F_c=0.8), and two pixels of habitat with optimal nesting suitability and forage quality (N_h=1; F_h=1). Inserting these values in Equation 3 and calculating distances between pixels, the total pollination services under the offer scenario, i.e., P_{offer}, equals 0.08. The pollination services provided to the berry pixel under a baseline scenario in which the new pollinator habitat pixel remains in corn, P_{bl}, equals 0.05. If w=1 and c=0.1, Equation 5 (Equation 4 is skipped because there is a single guild to consider) generates a yield increase of 14%, i.e., ΔY=0.14.

ΔY_j can then be multiplied by a market price and summed over all crop pixels j to provide a measure of potential benefits. A useful source of current agricultural prices is the USDA Agricultural Marketing Service (AMS) Market News, while the leading source of U.S. futures market prices that reflect expected conditions in future periods is the CME Group. InVEST will spatially distribute the resulting economic values of changes in crop yields due to wild pollinators back to the source CRP enrollment.

Link 7: From forb diversity/abundance to pest predator diversity/abundance

Land cover that is beneficial to pollinators may also benefit other beneficial insects. This and the subsequent link are relevant to the extent that "forb-enriched" CRP differs from "baseline" CRP's habitat quality for (non-pollinator) beneficial insects. Several studies link the presence of flowers, nectar, and flowering plant diversity or abundance, to the survival and the population sizes of beneficial predatory insects (e.g., Gardiner et al. 2009, Isaacs et al. 2009). Most of the studies are local, reflecting the impacts to productivity of crops locally grown in the parts of the U.S., the U.K., New Zealand, and other countries in which the studies were undertaken. Most studies focus on a specific group of insects, parasitic beetles and wasps that prey on crop pests. The studies look at how these habitat attributes increase winter survival of these insects and increase their population sizes during the time crops are present and vulnerable to predation.

Based on this literature, there appears to be little doubt that increasing the abundance of forb, flowers, and nectar will increase the population size and survival of beneficial insects. The results of the studies also show that predatory insect populations vary seasonally. However, while there are sufficient studies for some types of crops to be modeled, it is not clear that there is enough information to support broader generalizations; the available studies cover a relatively narrow range of physical settings (Florida, Montana, Oregon, England, and New Zealand) and ecosystem-insect relationships. To date, none of the ecosystem service models have directly attempted to extend their models outside their primary area of data collection.

Link 8: From pest predator diversity/abundance to biological pest control

While it is possible to quantify services in the same manner as for native pollinators, we will proceed directly to the more meaningful BRI: Economic benefits of increasing pest predator populations can be estimated by quantifying changes in production when insecticides are avoided, if the farmer alters applications as part of an integrated pest management strategy. Although expert judgment will again be necessary in the short term, Meehan et al. (2012) do present an approach based on the bio-control index (BCI), which is the proportion of crop pests that would be killed by natural enemies. Gardiner et al. (2009) and Meehan et al. (2012) calculate BCI as a function of crop type (corn or other) and proportion of grassland in the encircling landscape around each crop field.

Along these lines, we can reframe Equation 3 so that it generates BCI values:

$$BCI_j = \sum_{k=1}^{K} N_k F_j e^{\frac{-D_{jk}}{\alpha_i}} \Big/ \sum_{k=1}^{K} e^{\frac{-D_{jk}}{\alpha_i}}$$

Equation 6

where the BCI_j value for pixel j is the distance-weighted average of the product of N_k and F_j, the nesting suitability of pixel k land cover (the CRP offer is among the k pixels), and the prey suitability of pixel j land cover, respectively. Unlike native pollinators, all pest predators are considered jointly; research estimates have set the kernel distance in this context at one and a half kilometers (Gardiner et al. 2009). The BCI values are calculated with and without the CRP offer scenarios.

Just as the value of additional pollinators hinges on the pollinator dependency of the crop, the value of additional pest predators similarly depends on crop vulnerability to pests and the presence of pest outbreaks.

The economic value of pest predators in U.S. commercial agriculture is realized when farmers allow a crop that would have needed pesticide treatment to go without (i.e., the averting expenditures approach to economic valuation). The BCI values for the two scenarios are multiplied by estimates of pest damages absent any pest control and compared to pest damage thresholds at which pesticide applications make economic sense. The difference between the scenarios in the number of pixels exceeding the threshold reflects how the new forb-rich habitat increases the natural bio-control of the pest population, a BRI. Combining this with the cost per unit area of pesticide inputs and application provides an estimate of the economic value of increased biocontrol.

Not only are there a significant number of parameters to consider for this link, but few if any of them have been determined to date, either by expert judgment or empirical analysis. Additionally, this methodology does not quantify the additional benefit to bees of reduced insecticide use.

Link 9: From greater insect diversity to greater wildlife diversity and abundance

Not unlike what was discussed above for native pollinators, a healthy prairie ecosystem supports song and game bird diversity and abundance by offering nesting and forage opportunities to song and game birds, impacting their diversity and abundance. In addition to the contribution of its structure to nesting habitat, the vegetation provides seeds and fruits, and supports insect populations that are consumed by birds.

Insectivory by birds in agroecosystems is well documented in the literature (Vickery et al. 2009, Benton et al. 2002, and Birds of North America on-line: http://bna.birds.cornell.edu/bna). Attempts to document the contribution of insects to ecosystem services, including food chain support for songbirds and other bird groups, have shown the importance of insects in supporting bird diversity (Losey and Vaughn 2006). Diversity of CRP grassland plantings have also been shown to correlate with greater diversity of insects consumed by grassland breeding birds (McIntyre and Thompson 2003).

Songbird diversity and abundance are largely a function of habitat structure and availability at both local and landscape scales. Habitat structure provides necessary bird species-specific food (both plant and animal), cover, and space needed for relevant life requisite elements. While bird species distribution models exist that are largely driven by landscape content and habitat availability (see National Gap Analysis Program (GAP) Species Data Portal http://gapanalysis.usgs.gov/species/), quantitative models that directly link insect abundance and diversity to songbird abundance and diversity are lacking.

However, the literature supports this link in the conceptual value diagram (Figure 1). In lieu of attempting to directly link bird populations to insect populations, we can quantify this service by adapting Equation 3 to birds:

$$B_{ij} = \sum_{k=1}^{K} N_{ik} F_{ij} e^{\frac{-D_{jk}}{\alpha_i}} \Bigg/ \sum_{k=1}^{K} e^{\frac{-D_{jk}}{\alpha_i}}$$

Equation 7

B_{ij} represents the likelihood of occurrence for bird species i on pixel j. The forage quality and nesting suitability parameters have the same meaning as in Equation 3, albeit as applied to birds. Summing across species generates the expected bird diversity on pixel j. Although this approach again requires expert elicitation to populate the parameters, the literature may provide considerable support. Drum (2015), for example, generates pixel-level occurrence estimates for waterfowl.

Link 10: From bird diversity/abundance to enhanced outdoor recreation

Grassland bird abundance and diversity contribute value to several kinds of recreational activity, most notably hunting and bird watching. While both represent significant benefits, we focus on bird watching for this case study, since the most recent (2011) national data indicate that the number of bird watchers is significantly larger than that of bird hunters: 46.7 million versus 2.6 to 5.7 million (depending on the degree of overlap between waterfowl and small game hunters) in 2011 (NFWS 2016).

Bird watchers seek successful sightings and photo shoots, and watching is certainly more enjoyable if there are more birds to see. Furthermore, species diversity has high value to bird watchers. A serious birder often has a "life list" of the species of birds he or she has seen, and diversity increases the likelihood of being able to add a new species to that list. Bird abundance and diversity increases the utility a birder gains from visiting a site and thus increases the frequency with which he or she will visit.

The approach for Link 10 will use data on where and how often people go bird watching, and data on bird diversity and abundance across the landscape, to estimate equations that describe how recreational behavior will change if bird populations change.

On the recreation side, the USFWS National Survey of Fishing, Hunting and Wildlife-Associated Recreation (NFWS 2016) is a nationally representative survey on participation (including the number of participants, number of trips, and number of people-days) in bird watching around the home and away from it. The micro-data include information about bird guild, along with where people live and recreate. Promising new social media and citizen science data sources about recreation choices that are spatially explicit are also becoming available, with the eBird Survey (http://ebird.org/content/ebird/) being particularly relevant (e.g., Kolstoe and Cameron 2015).
For a BRI, these recreation data can be combined with the output from Equation 7, averaged at the appropriate spatial resolution, in a model estimating the relationship between bird abundance and diversity and recreation frequency, controlling for other influences. The equation would then be applied at a finer scale to with- and without-CRP offer scenarios to estimate the potential impact on bird watching frequency from the CRP offer. This represents a conservative BRI, in that it accounts for the change in recreation quantity but not quality.

There are established estimation techniques for monetizing such a BRI that make use of the fact that recreation decisions are based on both travel costs and the quality of the recreation experience to infer the dollar value of a change in the latter at one or more sites. However, the lack of information on alternative bird watching sites in the context of valuing competing CRP offers is likely to preclude the explicit use of such an approach. Moreover, the literature on the value of bird watching is scant enough that not even benefits transfer is possible. Doing so would involve transferring the estimated value of a person-day of bird watching from existing studies to the context at hand. The Benefit Transfer Toolkit developed by Loomis et al. (2014), for example, does provide unit values for wildlife viewing but does not make finer distinctions for bird watching, let alone for bird abundance or diversity.

Link 11: From greater forb diversity/abundance to enhanced aesthetics and other cultural services

Simply stated, a diverse stand of wildflowers and grasses may be more interesting and pleasing to look at. This aesthetic value is over and above species-specific recreation values. However, without an objective measure of how attractive pollinator habitat is, a reasonable strategy for quantifying the service (or, put another way, the potential aesthetic value) is to assume it to be proportional to the species richness of the cover and sum the change in species richness across CRP offer pixels. While more sophisticated metrics exist that reflect species richness, as well as abundance and evenness (species' relative proportions), such as Shannon's Index or Rao's Q, simplicity and clarity may be desirable in this policy setting.

The BRI for aesthetic value incorporates the number and proximity of people around to appreciate the service. Like that of the other services, the BRI for aesthetics is the distance-weighted—and now population-weighted—average of the diversity of floral resources near the viewer (the kernel distance set to the extent of a typical viewshed). Specifically,

$$V_j = \sum_{k=1}^{K} POP_k F_j e^{\frac{-D_{jk}}{\alpha}} \Big/ \sum_{k=1}^{K} POP_k e^{\frac{-D_{jk}}{\alpha}}$$

Equation 8

where V_j represents the aesthetic impact of offer pixel j on the population in pixel k, POP_k. This equation is considered with- and without-offer scenarios and the difference taken. Note that the simple relationship, as currently conceived, assumes constant returns to the aesthetic value of improvements to the viewshed.

Very limited research exists to support moving from the BRI to an estimated value of increased wildflower abundance on restored grasslands. The choice experiment analysis in Dissanayake and Ando (2014) estimates WTP of households in Illinois for attributes of restored grasslands. It identifies a significant positive WTP for increasing the percentage of a grassland that is covered by wildflowers; the average household in Illinois places a value of about fifty cents per percentage point of the area covered by wildflowers—crudely, a benefit of twenty-five dollars per household for increasing from none to half of the hypothetical grassland.

Additionally, a number of state Department of Transportation agencies, such as the Texas Department of Transportation, have created wildflower programs in response to pollinator needs, and have found that the public supports and is willing to pay for this program.

Characterizing the value of this support remains an open research question. Economists could approximate a lower bound estimate via measurements of how much transportation authorities pay to plant flowers instead of just grass on roadsides. However, data on that are not systematically collected, and studies of the values of roadside beautification projects are, to date, largely qualitative (Froment and Domon 2006, Domon et al. 2011).

People may also have an “existence value” for healthy ecosystems, of which pollinators are a vital component. However, the existence value of pollinators is mostly due to their role in maintaining vegetation, rather than their intrinsic attractiveness. Currently, there is no ready means to separate out how much pollinators contribute this value."

SUMMARY AND DISCUSSION

The policy context chosen for this pollinator services case study could not be more apt, yet it is challenging. A twenty-four-million-acre program present in forty-seven states, the CRP has considerable size and scope. The CRP targets and selects offers from private landowners to enroll in the program based on anticipated conservation benefits. While habitat-related benefits can offer a strong rationale for a program that takes vulnerable cropland out of production for restoration, estimates of them have yet to be incorporated explicitly into the offer selection process. This is particularly true for pollinators and other beneficial insect species for which CRP enrollments provide habitat. Not only have the contributions of these species been overlooked until recently, but the large number of species and their competing habitat requirements make accounting for habitat-related benefits difficult. The USDA is currently working toward incorporating these benefits into enrollment decisions.

The initial task was to develop a conceptual value diagram linking pollinator services to CRP. Not only did this help to identify data and modeling needs for quantifying pollinator services, but it revealed several ancillary benefits associated with establishing diverse cover providing forage and nesting for pollinators. For example, an enhanced seed mix established through CRP enrollment leads to a greater abundance and diversity of forbs, resulting in a greater abundance and diversity of both pollinators and natural enemies of agricultural pests, as well as a greater abundance and diversity of grassland birds, increasing the recreation services that benefit nearby residents.

The case study reviewed the current availability of data and tools for identifying, quantifying, and valuing many of the services generated by pollinator habitat, including commercial pollination and honey production by honeybees, pollination by native pollinators, biological pest control, non-consumptive recreation, and aesthetics. We did not consider CRP benefits that are not associated with enhancing the seed mix so that a diverse landscape with wildflowers is established, including soil health, water quality, and carbon sequestration. For the sake of keeping the case study to a reasonable length, hunting and existence values were not considered in any detail, either.

CRP is implemented at the field scale, has landscape-level impacts, and is national in scope. For example, the pollination benefits that may be provided by an offer will depend on the pollinators it supports, along with the composition of the surrounding landscape. This offer competes for enrollment with other offers, some of which may be hundreds or even thousands of miles away, that generate a different set and magnitude of benefits. While published ecological or economic research has been identified for most of the links, the study contexts tend to be quite narrow, focusing on a species, crop, or location. Accordingly, their relevance to the national policy context is limited.

Fortunately, the literature provides an approach to quantifying pollination services and their benefits that can be adapted to address services associated with pollinator habitat. While this approach is clearly first generation, and depends on a willingness to accept a high level of abstraction, it translates land-cover changes, irrespective of type, magnitude, and location, into a set of potentially meaningful BRIs for relevant services. Further, the simple functional form has modest input data requirements (a land-cover raster), encourages the use of expert judgement-based parameter estimates, and enables additional factors to be incorporated into the approach in a straightforward manner. Note that, while empirical estimates may be preferred to, and ultimately replace, those based on expert judgement, the uncertainty associated with the latter can at least be characterized using the empirical distributions of responses underlying the estimates.

We discuss how or what might be required to quantify each service, quantify the associated benefit (the BRI), and monetize that benefit. While there are strong arguments for developing the BRI when possible, it is worth pointing out that doing so will inevitably take the current use of the service as given (e.g., the spatial configuration of apiaries, cropland, or beneficiary populations). In this light, quantifying the service might be tantamount to quantifying *potential* benefits because such assumptions are not in play, and might be considered a preferred alternative to the BRI, rather than an intermediate step to it.

If a BRI is estimated, we found monetization to be relatively straightforward for most services, at least if the impacts are not large enough to affect market prices: multiplying productivity increases by prices (or, in the case of pest predators, multiplying avoided pesticide costs by acres of impacted cropland). Table 2 summarizes what may be possible to achieve for each service within a few years:

Table 2. Benefit-relevant indicators by service.

Commercial pollination by honeybees	*Change in likelihood that hive will be weak/strong at point of service (monetized)*
Honey production	*Change in honey output (monetized)*
Pollination by native pollinators	*Yield increases on neighboring cropland (monetized)*
Biological control of pests	*Cost savings from reduced pesticide use (monetized)*
Birding	*Change in the quantity of birding*
Aesthetic value	*Change in floral species richness, weighted by human populations*

A large part of the appeal of monetization is that it has the potential to summarize the anticipated benefits generated by a policy action. As discussed, above, monetization could at least corral some of the pollinator habitat benefits, those associated with crop production. However, the fact that cultural services, along with soil health, water quality, carbon sequestration, and other benefits common to all CRP lands, have not been monetized (in this policy context) to date undercuts the case for monetization where possible.

That there may effectively be a single “slot” available to incorporate pollinator habitat benefits in the CRP offer selection process reveals a tradeoff between precision and simplicity. In addition to considering a more sophisticated approach using BRIs and even valuing them, it may also be worth considering and testing the merits of assuming all pollinator habitat benefits are proportional to a species richness metric applied to the mix of grasses and wildflowers being established, rescaled so that it falls between zero and one.

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