Supplementary Information Text

Methodology

Objective 2: Determining the fate of CRP around apiaries

We estimated annual conversion rates of CRP fields within forage distance to registered apiary locations. We obtained data on registered locations for apiaries from the North Dakota (ND) and South Dakota (SD) Departments of Agriculture. Locations were in the form of legal descriptions in the U.S. Public Land Survey System (1) at the resolution of a quarter section (1 quarter section = 0.25 mi^2 or approximately 65 ha). We obtained boundaries of CRP polygons for 2006, our baseline year, through a data-sharing agreement with the US Department of Agriculture (USDA), Farm Service Agency. We built buffers of 1.6-km distance around centroids of the registered quarter sections, then extracted all CRP polygons that fell within the buffers to represent CRP lands within forage distance to apiaries. For baseline land cover we intersected the within-buffer CRP polygon boundaries for 2006 with data from the USDA Cropland Data Layer (CDL; (2) data available from https://nassgeodata.gmu.edu/CropScape) for 2006. We did the same for subsequent years with CDL maps for 2007–2016 to track changes in CRP cover from the baseline. The annual CDLs provide a source of wall-to-wall land cover, although the principal interest and mapping efforts of the USDA are focused on the cropland pixels. We used the majority (by area) land cover class for each CRP polygon to represent its cover type from 2006 through 2016.

Because metadata for the annual CDL maps revealed that their accuracy varied greatly by cover class across ND and SD over time (https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/meta.php), we implemented screening measures to help control for effects of misclassification error on our change-detection analysis. First, we removed from further analysis all within-buffer CRP polygons having majority land-cover types in 2006 that were unlikely to represent conservation cover (e.g., any crop type or urban/developed land). Land cover types we accepted as representing conservation cover were those associated with grassland, shrub, and tree cover, as well as water or wetland cover (these latter two are discussed further below). Second, we imposed a requirement that any polygon that changed from CRP land cover to crop cover needed to remain in crop cover for at least 5 consecutive years (see examples in Table S1). Our rationale was that the expense invested by a landowner to convert land from conservation use back to crop use would insure consistent continuation of crop cover for at least that many years. Thus, it would be infeasible for polygons to switch in and out of crop cover on an annual basis, and polygons doing so likely represented mapping errors rather than true land conversions. When land conversion was detected and met the 5-year criteria, we logged the year of the conversion and whether the initial crop was corn, soybeans, or another crop type.

A special consideration for studying land-cover change is that landscapes of the Northern Great Plains (NGP), particularly in the Prairie Pothole Region, are prone to major intra- and interannual differences in standing water due to characteristically highly variable climate (3). Portions of crop fields (especially in depressional wetland areas) may be covered by water in some years and dry (and thus cropped) in others. These water

dynamics will be captured in the satellite data used by the USDA to develop the annual CDL maps and will be reflected as changes in land cover. To address the effects that the temporary presence of water on the landscape could have on our change-detection analysis, we made the following assumptions: (1) if the majority land-cover type of a CRP polygon was water or wetland in 2006, it likely represented a conservation cover; (2) CRP polygons that changed to water/wetland after 2006 most likely represented temporary changes in landscape conditions, rather than CRP land conversion; (3) CRP polygons that changed to crops, but then were covered by water/wetland during the subsequent 5-year screening period were accepted as conversions to cropland unless they failed to be mapped as cropland again in years after the water/wetland dried up. Some example cases are provided below:

Example trajectories of CRP polygons and our associated interpretations.

	Year									
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Interpretation**
General Cover Type	Grassland	Grassland	Wetland	Wetland	Grassland	Grassland	Grassland	Wetland	Grassland	Began as CRP cover and remained in conservation cover.
	Wetland	Wetland	Wetland	Wetland	Wetland	Wetland	Wetland	Wetland	Wetland	Began as CRP cover and remained in conservation cover.
	Corn Soybean	Corn Soybean	Water	Grassland	Grassland	Grassland	Grassland	Grassland	Grassland	Failed initial screening as CRP cover in 2006. Observation excluded from analysis.
	Grassland	Grassland	Water	Corn or Soybean	Corn or Soybean	Other crop	Water	Other crop	Other crop	Began as CRP cover and was converted to corn or soybean by 2009.
	Grassland	Grassland	Grassland	Corn or Soybean	Corn or Soybean	Grassland	Grassland	Grassland	Grassland	Began as CRP cover and failed conversion screening, so was considered to remain in conservation cover.

Objective 4: Evaluating land suitability for honey bees under different CRP scenarios

For each CRP scenario we reapportioned the national caps to each state based on observed 10-year high and low percentages of national CRP hectares. In 2007, CRP area

in ND and SD constituted 9.22% and 4.24%, respectively, of the national area of CRP, representing historical highs for each state. In 2015, ND dropped to 6.3%, and in 2010, SD dropped to 3.56%, representing their respective historical lows. As a result, 0.11 M ha (0.27 M ac) and 0.1 M ha (0.26 M ac), respectively, were removed from the current (2016) CRP map to meet the 7.7 M ha national cap proposed for our 7.7 M ha CRP scenario. Similarly, 0.79 M ha (1.94 M ac) in ND and 0.26 M ha (0.63 M ac) in SD were prescribed to be added to meet the 15 M ha alternative national cap proposed for our two 15.0 M ha CRP scenarios. The state caps were further reallocated to each county using county level CRP data describing the proportion of CRP within each county and known area of CRP within each state. This allowed us to develop realistic area distributions of CRP within each county for each CRP scenario.

15.0 M ha (37 M ac) CRP Scenarios

Because CRP is a program that targets privately owned agricultural lands, we needed to identify lands that have historically been in crop production and are currently available for potential enrollment in CRP under our 15.0 M ha scenario. To identify cropland across ND and SD, we reclassified all CDL pixels as either "cultivated" or "non-cultivated" following the criteria used to produce the USDA 2016 Cultivated Layer (https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/2016_cultivated_layer_metadata.htm, last accessed Nov. 2017). We performed this reclassification on annual CDL maps from 2011 to 2016. We stacked the reclassified CDL maps and assigned a "cultivated" status to each CDL pixel if it had been reclassified as cultivated in four of the six years spanning from 2011 to 2016. We grouped "cultivated" pixels into small management units using polygon boundaries from USDA Common Land Units (CLU; https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-products/common-land-unit-clu/index). Suitable CLU polygons were identified for potential new CRP enrollment if >50% of the area within a given polygon was classified as "cultivated." We excluded federal or state-owned or managed lands, as well as Native American tribal lands.

To maintain consistency with the enrollment focus of CRP, which is to target environmentally sensitive lands or marginal cropland, we used the USDA Soil Survey Geographic database (SSURGO; https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053627) as a reference for agricultural productivity. We determined the productivity of each suitable CLU polygon based on the Land Capability Class (LCC) of the soil type covering the majority of the polygon. The LCC allowed us to locate the least productive farmland, land that we considered as having the highest likelihood of being enrolled in CRP under a 15.0 M ha national cap. To add CRP area (hectares) to the current baseline map under the 15.0 M ha scenario, we randomly placed suitable polygons in LCC 8 (soil considered the least productive for growing general crops) into the CRP, thereby signifying a conversion from agricultural land to grassland. Once all suitable polygons in LCC8 were converted to CRP, we drew additional polygons, as needed, from LCC 7. This process continued until the sum of new and existing CRP area met each county's reapportioned cap.

For the 15.0 M ha strategic placement scenario, we gave CRP enrollment priority to all "cultivated" polygons that were within 3.2 km of registered apiary locations. We

used 3.2 km because it corresponds to the core flight distance of foraging honey bees (4). The strategic placement scenario represented a situation where establishing habitat for pollinators was given top priority for new CRP enrollments. To implement this, we created a buffer around each registered apiary site with the distance determined according to three sets of evaluation criteria (i.e., refer to section below on “Evaluating Forage Criteria for CRP Scenarios”). We then randomly placed suitable polygons of LCC 8 into a CLU polygon within each buffer to represent new enrollments in the CRP. Once all LCC 8 polygons in the buffered areas were exhausted within each county, we used progressively more productive polygons (i.e., LCC 7, then LCC 6, etc.) within the buffers until the existing CRP area and new CRP area met each county’s reapportioned cap. When the availability of suitable polygons within buffered areas was not sufficient to meet a county’s cap, we randomly selected additional suitable polygons from adjacent counties following similar procedures (approximately 6,500 ha (16,000 ac) for 7 counties and 4,000 ha (10,000 ac) for 4 counties were needed from adjacent counties to fulfill the CRP scenario requirements under the 1.6 km and 3.2 km buffers, respectively).

7.7 M ha (19 M ac) CRP Scenarios

We used an approach similar to that applied for the previous scenarios to remove CRP lands from our landscape; however, to meet the 7.7 M ha national cap, we instead targeted the most productive farmland, LCC 2 (soil considered the most suitable for growing crops), for removal from the CRP. We continued removing CRP lands randomly through progressively less productive farmland until the CRP hectares remaining on the baseline map met each county’s reapportioned cap.

For the 7.7 M ha strategic removal scenario, we gave priority to all current CRP enrollments within 3.2 km of registered apiaries and allowed enrollment outside this distance to expire first. As with the strategic placement scenario, we gave priority to CRP within 3.2 km of apiaries because this distance corresponds with the core foraging distance of honey bees (4). This scenario represented a national reduction in CRP while recognizing the value CRP as pollinator habitat in the NGP. To implement this, we first removed CRP polygons residing on progressively less productive soils (i.e. LCC 8, then LCC7, then LCC6, etc.) and existing outside the 3.2km buffer, until all CRP enrollments were exhausted within each county. If needed, we continued the same CRP removal process inside the 3.2km buffer until the area of CRP met each county’s reapportioned cap.

Evaluating Forage Criteria for CRP Scenarios

For each scenario, we conducted a suitability evaluation by overlaying the centroids of registered apiary locations on the resulting CRP maps under each scenario. We determined the number of registered sites supported by the surrounding CRP area based on three published sets of forage criteria: 380 ha within a 3.2 km (two mile) buffer of an apiary site (5), 210 ha within a 1.6 km (one mile) buffer (6), and 130 ha within a 3.2 km (two mile) buffer (7). These studies provided quantitative evidence of the benefits of CRP and other grassland to honey bee colonies and the commercial beekeeping industry in the NGP. A land use and bee health study by Smart et al. (5) showed honey bee colonies situated in apiaries with >380ha of uncultivated forage land, such as grassland, pasture and CRP cover, had >70% annual survival rates. A land cover modeling study by

Otto et al. (6) demonstrated that beekeepers were 30% more likely to use a site as a registered apiary if that site had >210 ha of CRP land within 1.6 km, compared to sites with no CRP lands within that forage range. A spatially explicit model developed by Gallant et al. (7) identified multiple landscape criteria professional beekeepers use to place honey bee colonies in the NGP. A criterion identified in the model was that >130 ha of CRP land within 3.2 km forage range was needed to support a 100-colony apiary in North Dakota. We calculated the number of registered apiaries that met the forage criteria identified by these three studies for each CRP scenario and the 2016 baseline CRP map. We then calculated the relative change in the number of apiaries that met forage criteria under each scenario with respect to the number of apiaries that met forage criteria under the 2016 baseline CRP map.

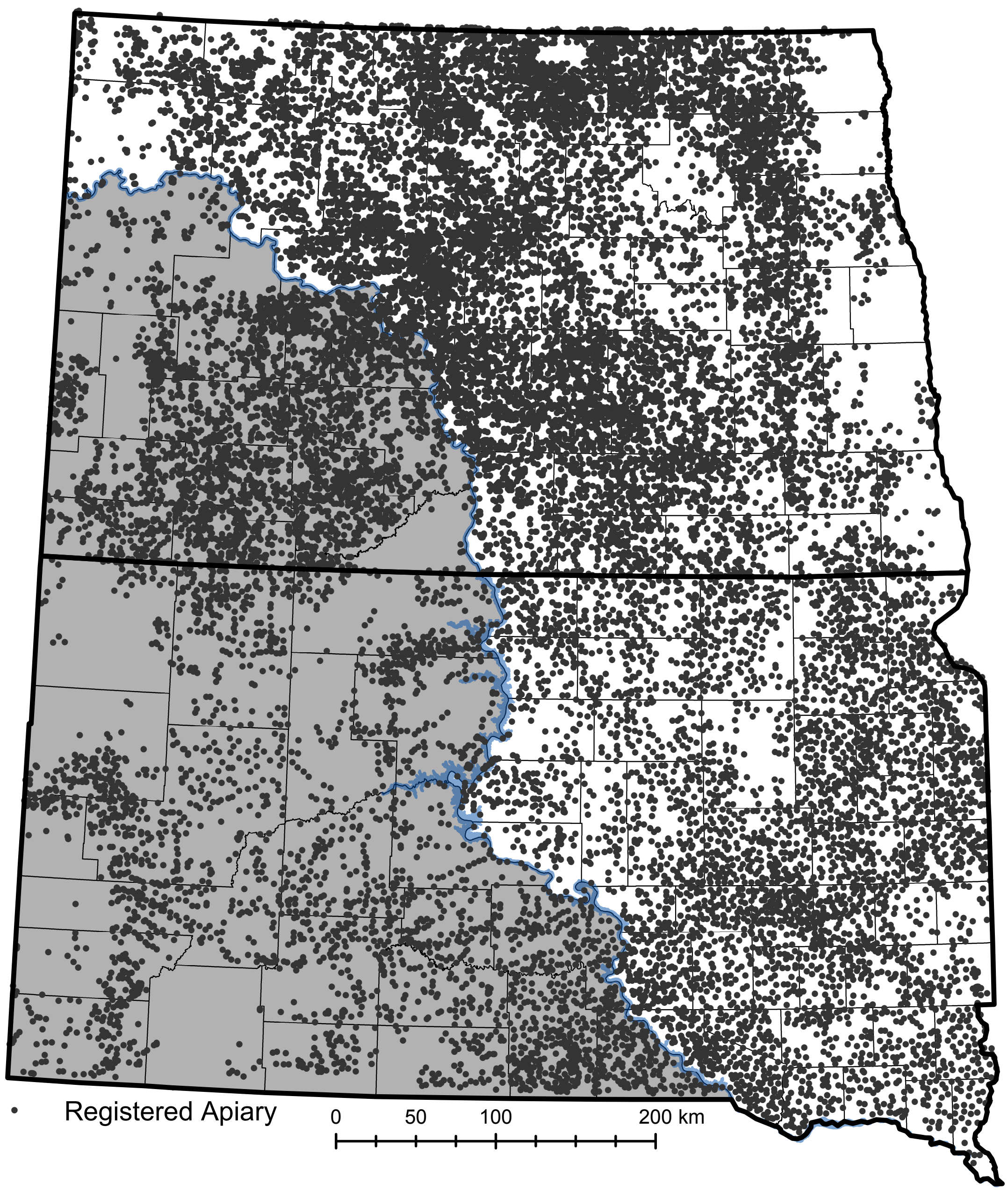

Fig. S1. Registered apiary locations in North Dakota and South Dakota. Counties within the Prairie Pothole Region (north and east of the Missouri River, which is indicated in blue) have a white background, whereas those outside of the Prairie Pothole Region (south and west of the Missouri River) have a grey background.

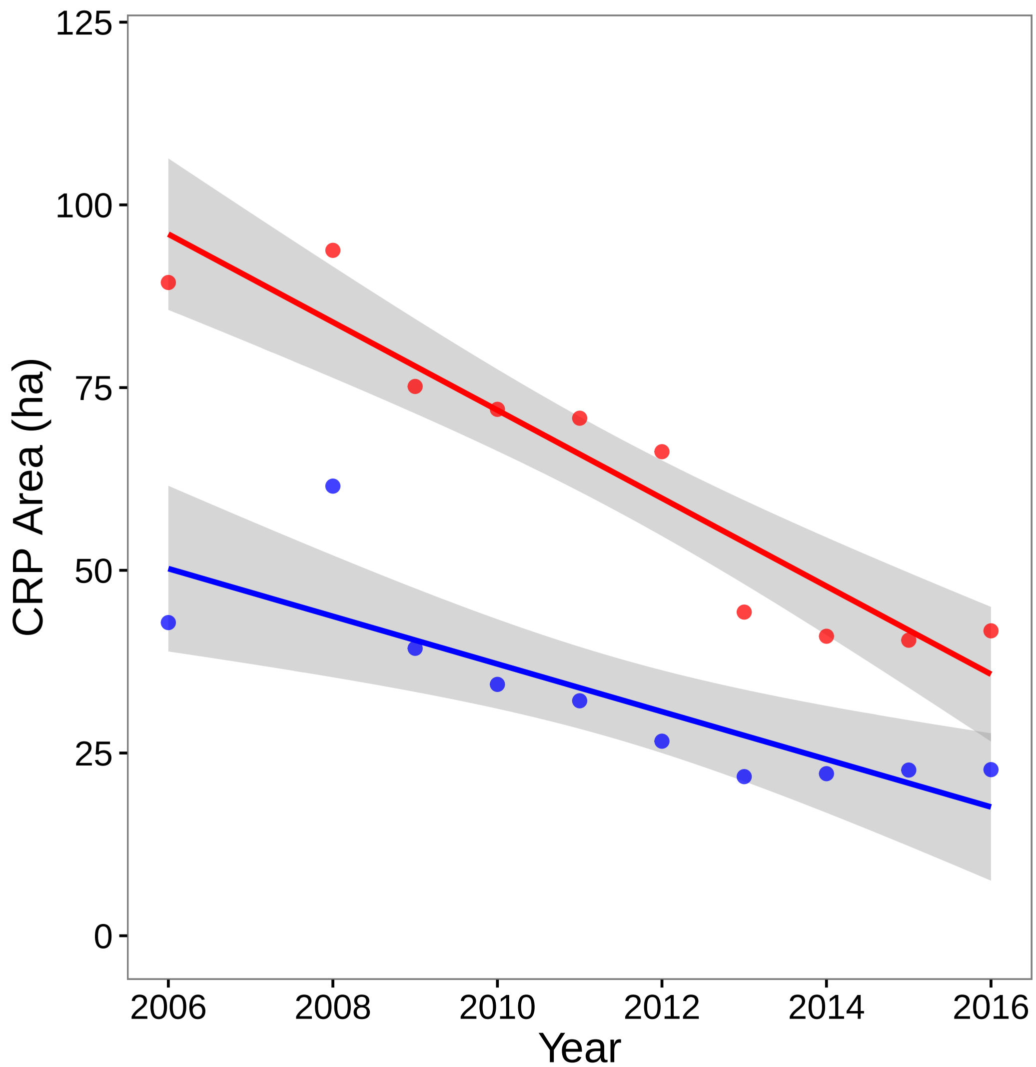

Fig. S2. Area of CRP land within 1.6 km of 18,363 registered apiaries in ND and SD from 2006 to 2016 (see Fig. S1 for apiary map). Each point represents the average area of Conservation Reserve Program (CRP) land among all apiaries within each region (Prairie Pothole Region= red, all other area = blue). Lines were generated from a linear trend model, with 95% confidence intervals shown in gray. Both covariates (i.e., *Year* and *Region*), and their interaction term, were statistically significant: β_{Year}= -3.3 ±0.8 (±1SE), t value= -4.3.8, p <0.001, β_{Region}= 48.5 ±7.6, t value= 6.4, p <0.001, $\beta_{Year*Region}$= -2.8 ±1.1, z value= -2.6, p =0.02.

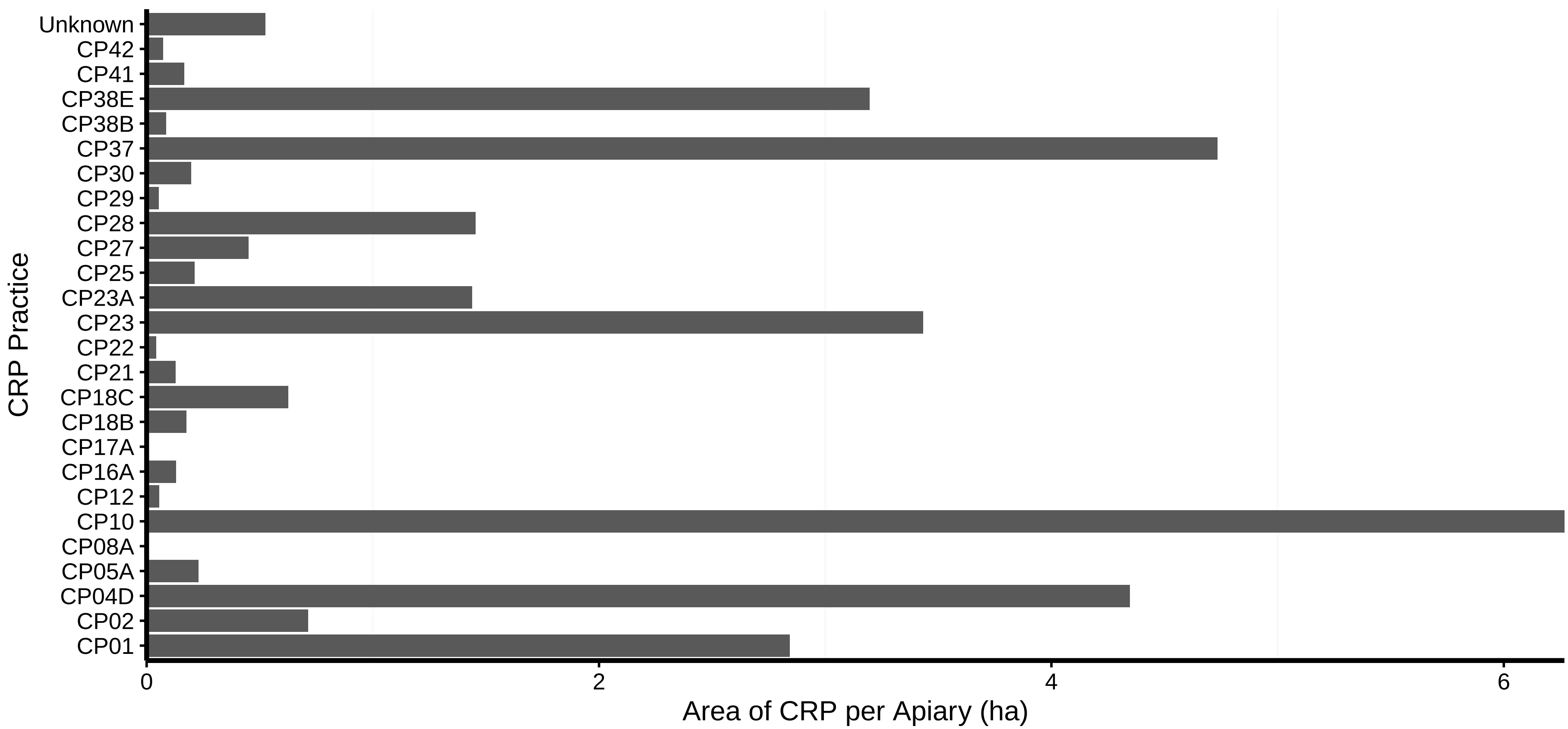

Fig. S3. Average hectares of Conservation Reserve Program conservation practices (CP) within 1.6 km of registered apiaries in North Dakota and South Dakota, 2016. We reported conservation practices constituting >0.01ha per apiary. CP01=Establishment of Permanent Introduced Grasses and Legumes, CP02=Establishment of Permanent Native Grasses, CP04D=Permanent Wildlife Habitat, Noneasement, CP05A=Field Windbreak Establishment, Noneasement, CP08A=Grassed Waterways, CP10=Vegetative Cover, Grass, Already Established, CP12=Wildlife Food Plot, CP16A= Shelterbelt Establishment, P17A=Living Snowfence, Noneasement, CP18B=Establishment of Permanent Vegetation to Reduce Salinity, Noneasement, CP18C=Establishment of Permanent Salt Tolerant Vegetative Cover, Noneasement, CP21=Filter Strips, CP22=Riparian Buffer, CP23=Wetland Restoration, CP23A=Wetland Restoration, CP25= Rare and Declining Habitat, CP27=Farmable Wetlands, CP28=Farmable Wetland Buffer, CP29=Marginal Pastureland Wildlife Habitat Buffer, CP30=Marginal Pastureland Wetland Buffer, CP37=Duck Nesting Habitat, CP38B=State Acres for Wildlife Enhancement, Wetland Restoration, CP38E=State Acres for Wildlife Enhancement, CP41=Farmable Wetland Program, Flooded Prairie Wetland, CP42=Pollinator Habitat establishment, Unknown=Practice code not available. Additional information on specific practices can be found at https://www.fsa.usda.gov/programs-and-services/conservation-programs/crp-practices-library/index.

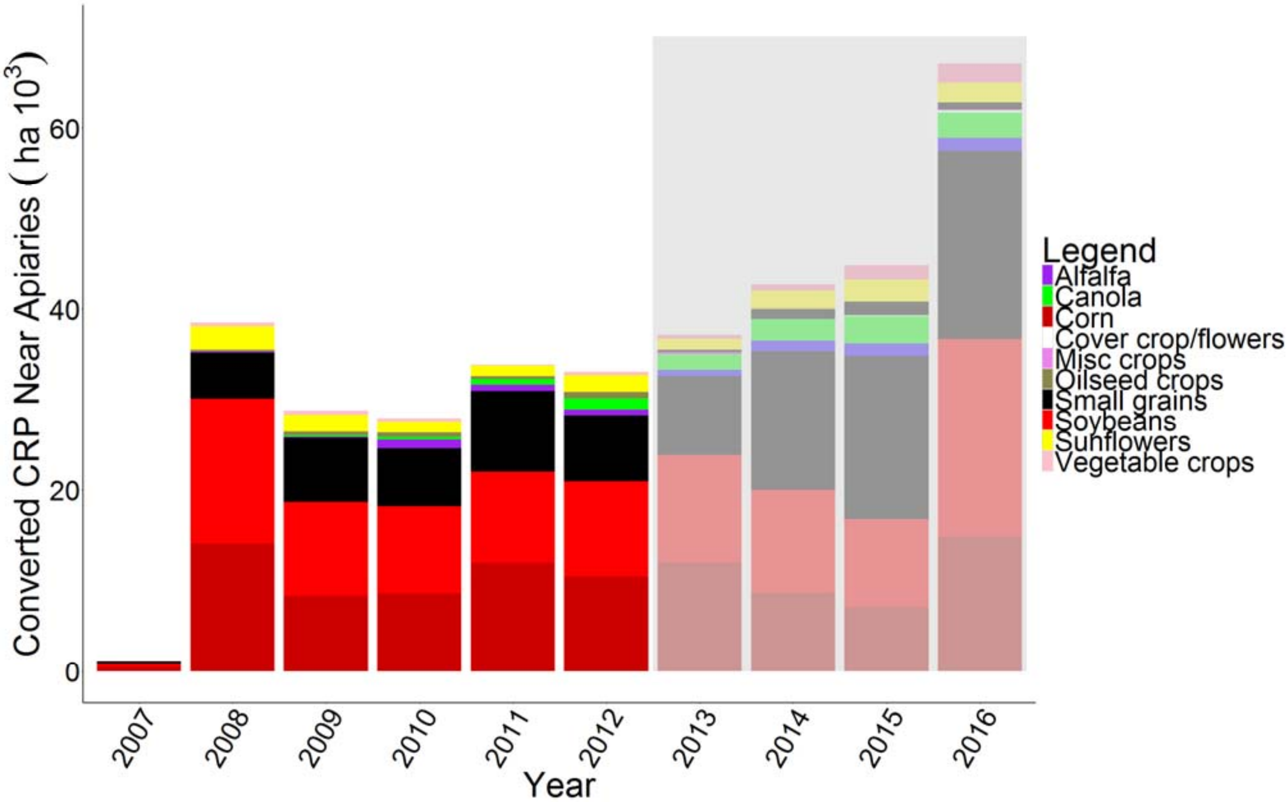

Fig. S4. Hectares of Conservation Reserve Program (CRP) land converted to alfalfa (purple), canola (green), corn (dark red), cover crops/wildflowers (white), miscellaneous crops (violet), non-sunflower oilseed crops (khaki), small grains (black), soybeans (red), sunflower (yellow), and vegetable crops (pink) within 1.6 km of registered apiaries in ND and SD from 2007 to 2012 that remained mapped as crops for ≥5 years. Estimates of converted CRP land for 2013 to 2016 are also shown, but there was progressively less than 5 years of post-conversion information to corroborate these estimates; hence, the rate of change shown for 2013-2016 represents limited control for mapping error.

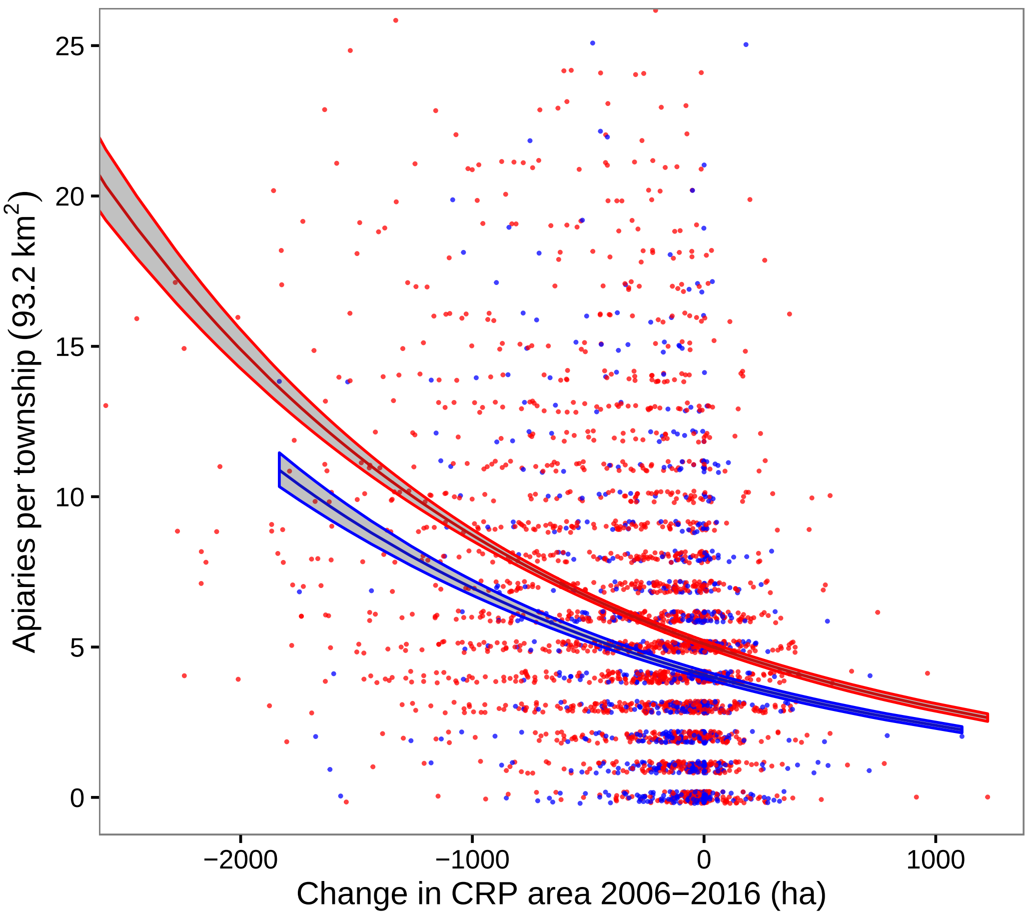

Fig. S5. Association between the number of registered apiaries and change in Conservation Reserve Program area (ha) per township (93 km^2) from 2006 to 2016. 3,644 townships from North Dakota and South Dakota were included in this analysis. We partitioned townships located within (red) and outside (blue) the Prairie Pothole Region because of their distinct land characteristics.

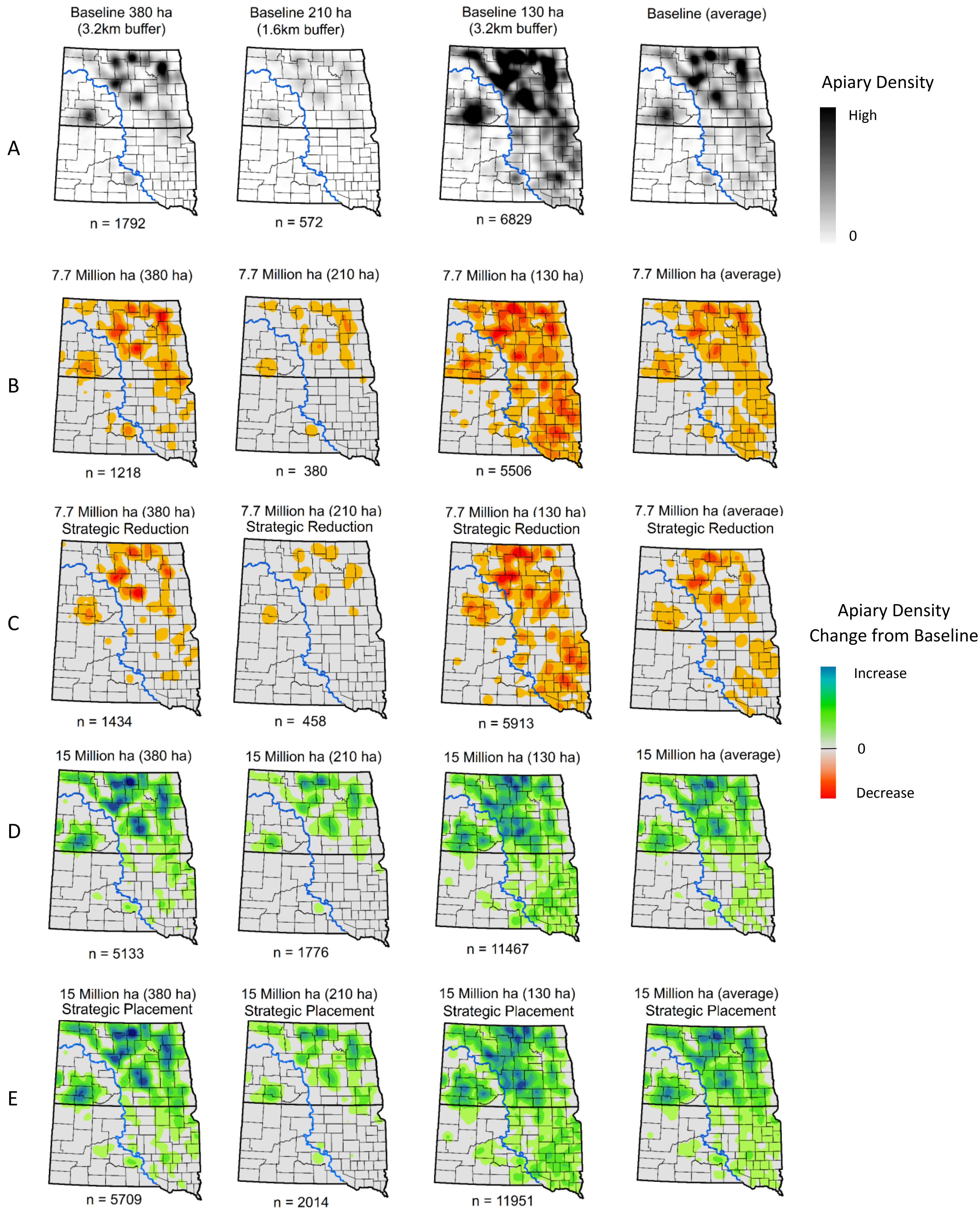
Baseline 380 ha (3.2km buffer)
Baseline 210 ha (1.6km buffer)
Baseline 130 ha (3.2km buffer)
Baseline (average)
A
n = 1792
n = 572
n = 6829
Apiary Density
High
0
7.7 Million ha (380 ha)
7.7 Million ha (210 ha)
7.7 Million ha (130 ha)
7.7 Million ha (average)
B
n = 1218
n = 380
n = 5506
7.7 Million ha (380 ha) Strategic Reduction
7.7 Million ha (210 ha) Strategic Reduction
7.7 Million ha (130 ha) Strategic Reduction
7.7 Million ha (average) Strategic Reduction
C
n = 1434
n = 458
n = 5913
Apiary Density Change from Baseline
Increase
0
Decrease
15 Million ha (380 ha)
15 Million ha (210 ha)
15 Million ha (130 ha)
15 Million ha (average)
D
n = 5133
n = 1776
n = 11467
15 Million ha (380 ha) Strategic Placement
15 Million ha (210 ha) Strategic Placement
15 Million ha (130 ha) Strategic Placement
15 Million ha (average) Strategic Placement
E
n = 5709
n = 2014
n = 11951

Fig. S6. Density maps of registered apiaries that met forage criteria for honey bees (see Methods) under existing (2016) Conservation Reserve Program (CRP) area (A) and four CRP scenarios (B, C, D, E). We used estimates from published studies to establish the forage criteria and determine which of the 18,363 registered apiaries met the forage criteria based on the availability of CRP grassland under each scenario: 1) 380 ha grassland within a 3.2 km buffer of an apiary site (5), 2) 210 ha within a 1.6 km buffer (6), and 3) 130 ha within a 3.2 km buffer (7). We provide maps of the average outcomes across all forage criteria in the right column. A) Existing CRP lands (2016) under a 9.7 M ha national cap; B) 7.7 M ha national CRP cap; C) 7.7 M ha national CRP cap where CRP was strategically removed to minimize forage loss around apiaries; D) 15.0 M ha national cap; and E) 15.0 M ha national cap with strategic placement of CRP land within 3.2 km of existing apiaries.

Table S1. CRP acreage cap scenarios and how they may affect landscape suitability for supporting apiaries in ND and SD. We evaluated four plausible CRP scenarios —1). 7.7 M ha national cap, 2). 7.7 M ha national cap + strategic reduction, 3). 15.0 M ha national cap, and 4). 15.0 M ha national cap + strategic placement — and compared them with the existing (2016) distribution of CRP lands. "Area of Simulated CRP" represents the total area of CRP land distributed across ND and SD. "CRP Within 1.6 km" is the area of CRP land within 1.6 km of an apiary. We determined how many apiaries met CRP forage criteria published from three different studies (5-7; see Supp. Mat. Objective 4). We also calculated the percent increase or decrease of apiaries that met the forage criteria, relative to the area of CRP existing in 2016.

			Gallant et al. (7) 130 ha within 3.2 km		Smart et al. (5) 380 ha within 3.2 km		Otto et al. (6) 210 ha within 1.6 km	
CPR Scenario	Area of Simulated CRP (ha)	CRP Within 1.6 km (mean +/- SD; ha)	% Change in Apiaries	# Apiaries	% Change in Apiaries	# Apiaries	% Change in Apiaries	# Apiaries
2016 Baseline 9.7 M ha; 24 M ac	1.0 M	35.6 +/- 62.5	NA	6,829	NA	1,792	NA	572
7.7 M ha; 19 M ac	0.8 M	28.4 +/- 53.7	-19.3	5,506	-32.0	1,218	-33.5	380
7.7 M ha; 19 M ac + Strategic Reduction	0.8 M	29.0 +/- 53.7	-13.4	5,913	-20.0	1,434	-19.9	458
15.0 M ha; 37 M ac	2.0 M	68.8 +/- 90.9	67.9	11,467	186.4	5,133	210.5	1,776
15.0 M ha; 37 M ac + Strategic Placement	2.0 M	74.6 +/- 96.3	75.0	11,951	218.6	5,709	252.1	2,014

References

1. Stewart LO (1935) Public land surveys, reprinted 1976 (The Meyers Printing Co., Minneapolis), 202 p.
2. Boryan C, Yang Z, Mueller R, Craig M (2011) Monitoring US agriculture: the US Department of Agriculture, National Agricultural Statistics Service, Cropland Data Layer Program. Geocarto International 2011: 1–18.
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5. Smart, MD, JS Pettis, NH Euliss Jr, M Spivak (2016) Land use in the Northern Great Plains region of the U.S. influences the survival and productivity of honey bee colonies. Agri, Eco, & Envir 230: 139-149.
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