Supplemental S1. Monarch-relevant North Central region land cover map generation.

The base layer for our monarch butterfly-specific milkweed map was the 2014 Cropland Data Layer (CDL). The first step in the development of a seamless land-cover map was to separate open/developed areas (CDL value 121) into two categories, linear and core. This was accomplished by first shrinking all open/developed areas by 1 cell (30 meters) and then subsequently expanding them back out by 1 cell. This process essentially removes open/developed areas just 1 cell large and extracts the larger core open/developed areas from the base CDL layer; the remaining open/developed areas not meeting this criterion were the smaller, more linear areas. The core open/developed areas were given a new value of 25 and the linear areas were given a value of 21 in the revised CDL.

Next, we identified core urban areas within the landscape by shrinking all developed areas (CDL values 121 (open/developed), 122 (low intensity developed), 123 (medium intensity developed), and 124 (high intensity developed) by 2 cells (60 meters) and then subsequently expanding them back out by 2 cells. This process identified the larger core developed (urban) areas from the base CDL layer. These areas were used to further reclassify roads, railroad rights of way, powerline rights of way, and low-intensity developed areas by their proximity to derived urban areas.

The CDL does not have separate classes for grassland and pasture although this is an important distinction when classifying the landscape according to milkweed densities. The 2011 National Land Cover Dataset (NLCD) does, however, have separate classes for grassland and pasture. We extracted pasture areas from the NLCD and replaced the overlapping areas within the CDL classified as grassland/pasture, alfalfa, or other hay/non-alfalfa with a new value denoting it as pasture/hay. These pasture/hay areas were then further subdivided using the 2012 Protected

Areas Database (PADUS) to denote those areas that are under conservation protection (value 79; Pasture/Hay (PADUS Protected)) and those not currently under conservation protection (value 78; Pasture/Hay). The grassland/pasture areas from the CDL that did not overlap the areas classified as pasture/hay in the NLCD were then subdivided using the PADUS into two classes, those areas that are under conservation protection (value 77; Grassland (PADUS Protected)) and those not currently under conservation protection (value 76; Grassland).

Conservation Reserve Program (CRP) data for 2014 were received from the Farm Service Agency and the individual field-level polygonal data were reclassified according to whether they contained quality milkweed habitat (Table S1). If they did, they were further reclassified according to whether they were considered to be "wet" or "non-wet." These polygons were then converted to a raster data set of the same resolution as the CDL. Next, areas in the revised CDL where these milkweed-amenable CRP polygons occur were reclassified to value 98 (CRP non-wet) or value 99 (CRP wet) if they did not overlap areas in the revised CDL delineating open water; low-, medium-, and high-intensity developed; deciduous, evergreen, and mixed forests; and woody wetlands since these classes were determined to have limited amenability to milkweed.

Using the urban area boundary created previously, low-intensity developed areas outside of this boundary were reclassified to value 26 (Exurban). Corn and soybean fields within the revised CDL were then further divided according to their crop productivity index. The National Commodity Crop Productivity Index, version 2.0 (Dobos *et al*. 2012), was used as the source for this metric. Index scores <40 were selected to represent those areas where the soil is considered to be marginal for crop production (Bandaru *et al*. 2013); the amount of land with scores <40 comprised ~14% of the landscape (Figure S1.1). Corn and soybean areas in the revised CDL overlapping marginal soils were reclassified as value 2 (corn – marginal) and value 15 (soybean – marginal), and areas not overlapping marginal soils were reclassified as value 1 (corn - high productivity) and value 14 (soybean - high productivity).

Linear features representing transmission lines, roads, and rails were converted from vector to raster data sets using a 30-meter cell size. Power lines (U.S. Department of Homeland Security 2010) were included in the seamless raster if they were classified as “in-service”. Then, using the urban area boundary, raster cells overlapping power lines outside of this boundary were reclassified to value 100 and those within the boundary were reclassified to value 101. Similarly, raster cells overlapping cells designating rail lines (U.S. Census Bureau 2013) outside of this boundary were reclassified to value 200 and those within the boundary were reclassified to value 201. Roads outside of the urban area were lumped into several different categories and reclassified; primary roads and ramps (110), secondary roads (120), local roads (140), and private roads (174). All raster cells overlapping roads, regardless of type, within the urban area boundary were reclassified as urban roads (180). Figure S1.2 displays a portion of this raster zoomed into an area without field-level CRP data or HSIP power lines due to the distribution rules associated with these data.

Hotspot analysis of the resulting monarch-relevant land cover map indicated that sector-specific opportunities varied across the region (not shown). Large concentrations of protected grass, CRP land, and agriculture occurred in the eastern Dakotas and western Minnesota. Urban environs were largely associated with the Twin Cities, Chicagoland, and western Lake Erie, but relatively depauperate in northern Missouri and southern Iowa. Large areas of northern Wisconsin and Michigan were relatively devoid of CRP land and agriculture. High concentration of agriculture in Illinois overlapped comparatively low concentration of CRP land.

Using results of milkweed density information gleaned from the literature (Supplement 2), 1.708 billion stems were estimated to occur in the Midwestern U.S. prior to the adoption of glyphosate-tolerant corn and soybean (Fig. S1.3). Post-application of glyphosate, 1.034 billion stems are predicted to occur (Fig. 1). This difference amounts to 674 million stems. But, because each milkweed stem in an agricultural field averages 3.92 times more eggs than a milkweed stem in non-agricultural habitats (Oberhauser *et al*., 2001, Pleasants and Oberhauser, 2013), the potential monarch population production loss pre- and post-application of glyphosate was 71% (Pleasants, 2016).

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Table S1.1. Conservation Reserve Program practices divided by type (non-wet, wet, and treed), along with practice identifier.

Practice	Type	Practice Identifier
Grass Plants (introduced)	Non-Wet	CP1
Grass Plants (native)	Non-Wet	CP2
Wildlife Habitat	Non-Wet	CP4D
Wildlife Corridors	Non-Wet	CP4B
Existing Grass	Non-Wet	CP10
Wildlife Food Plots	Non-Wet	CP12
Contour Grass Strips	Non-Wet	CP15
Rare and Declining Habitat	Non-Wet	CP25
Marginal Wildlife Pasture Buffer	Non-Wet	CP29
Upland and Bird Habitat Buffers	Non-Wet	CP33
State Area for Wildlife Enhancement	Non-Wet	CP38
Pollinator Habitat	Non-Wet	CP42
Grass Waterways	Wet	CP8
Shallow Water	Wet	CP9
Contour Grass Strips	Wet	CP15
Filter Strips	Wet	CP21
Wetland Restoration	Wet	CP23
Farmable Wetland	Wet	CP27-28

Marginal Pasture Wetland	Wet	CP30
Duck Nesting	Wet	CP37
Farmable Wetland	Wet	CP39-41
Tree plantings	Excluded	CP3
Field windbreaks	Excluded	CP5
Existing trees	Excluded	CP11
Shelterbelts	Excluded	CP16
Living snow fences	Excluded	CP17
Salinity reducing vegetation	Excluded	CP18
Riparian buffers	Excluded	CP22
Cross wind trap strip	Excluded	CP24
Bottomland hardwoods	Excluded	CP31
Expired hardwoods	Excluded	CP32
Longleaf pine	Excluded	CP36

Figure S1.1. Distribution of National Commodity Crop Productivity Index values, with marginal cropland identified as those lands with values below 40.

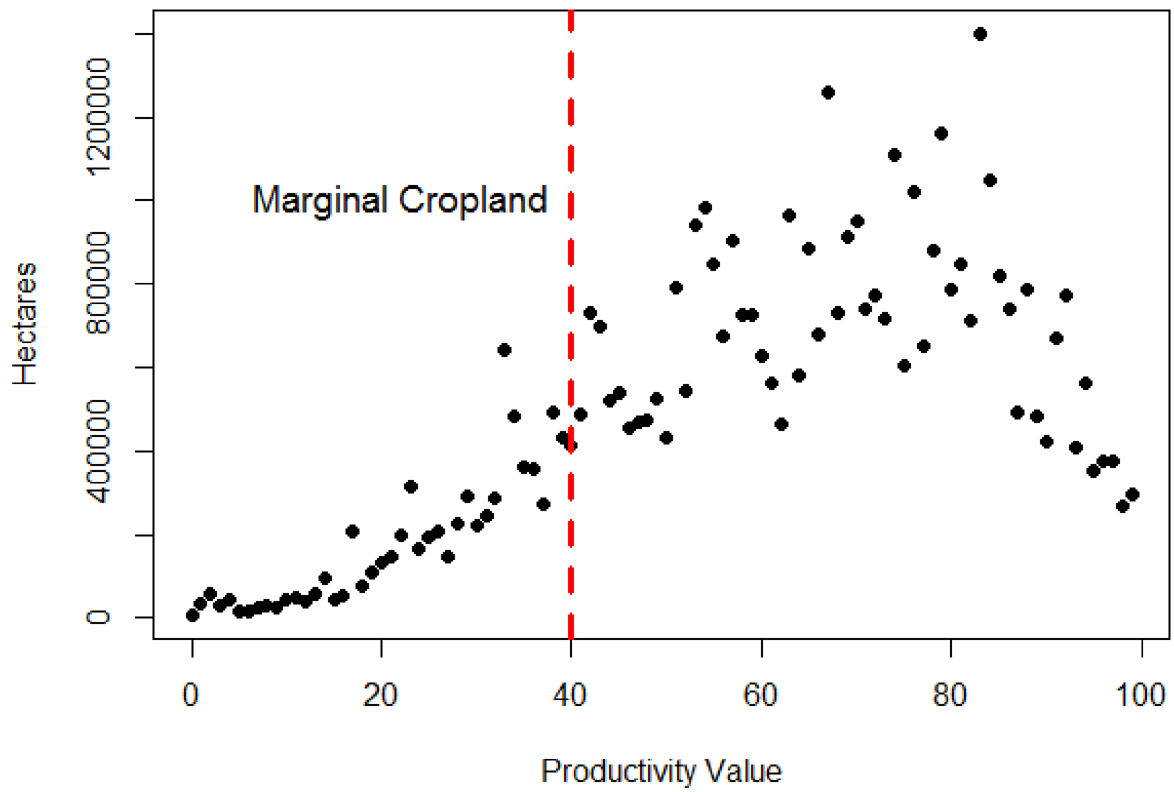


Figure S1.2. Portion of the land cover map used in depicting storylines of milkweed amendment in the North Central region of the United States.

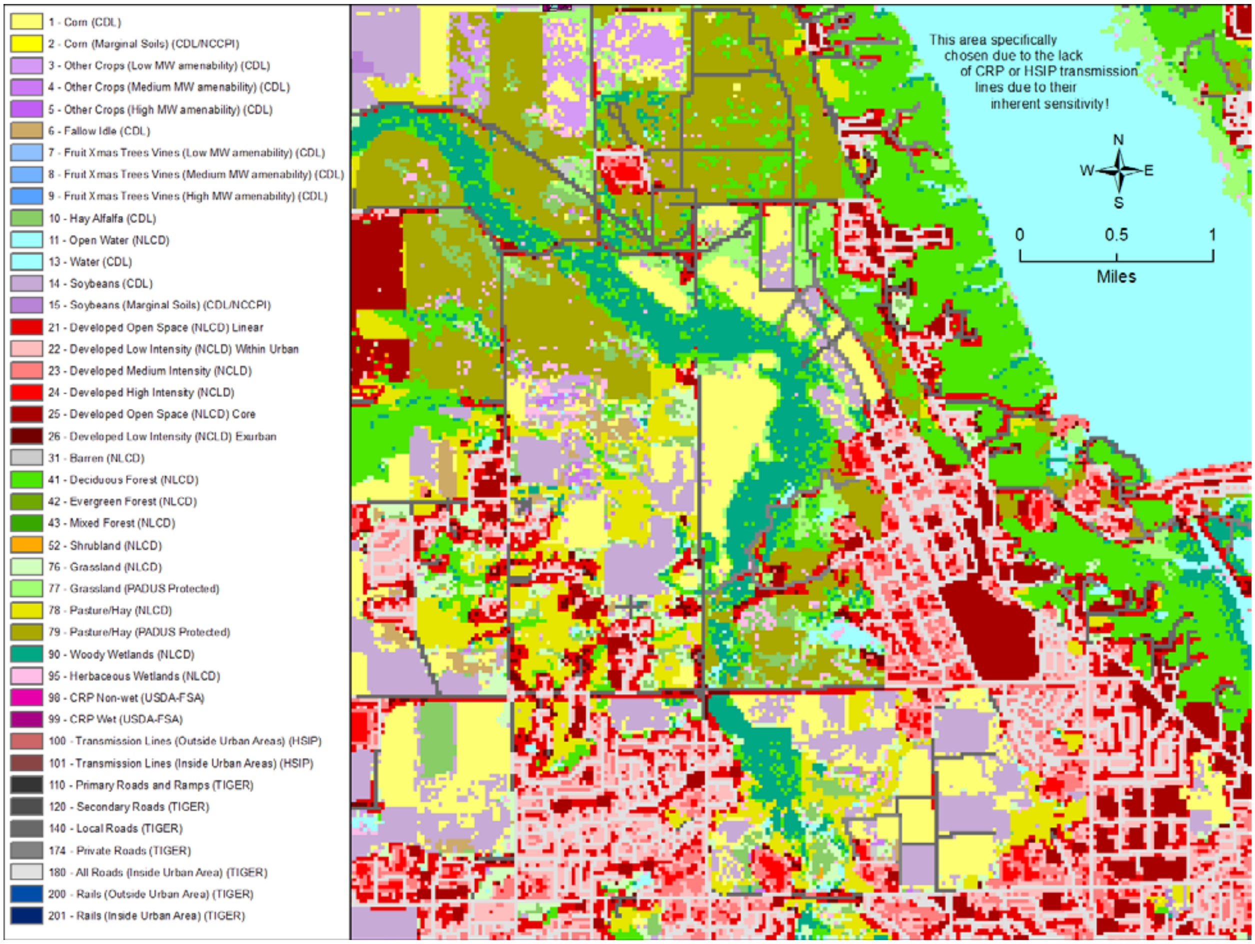
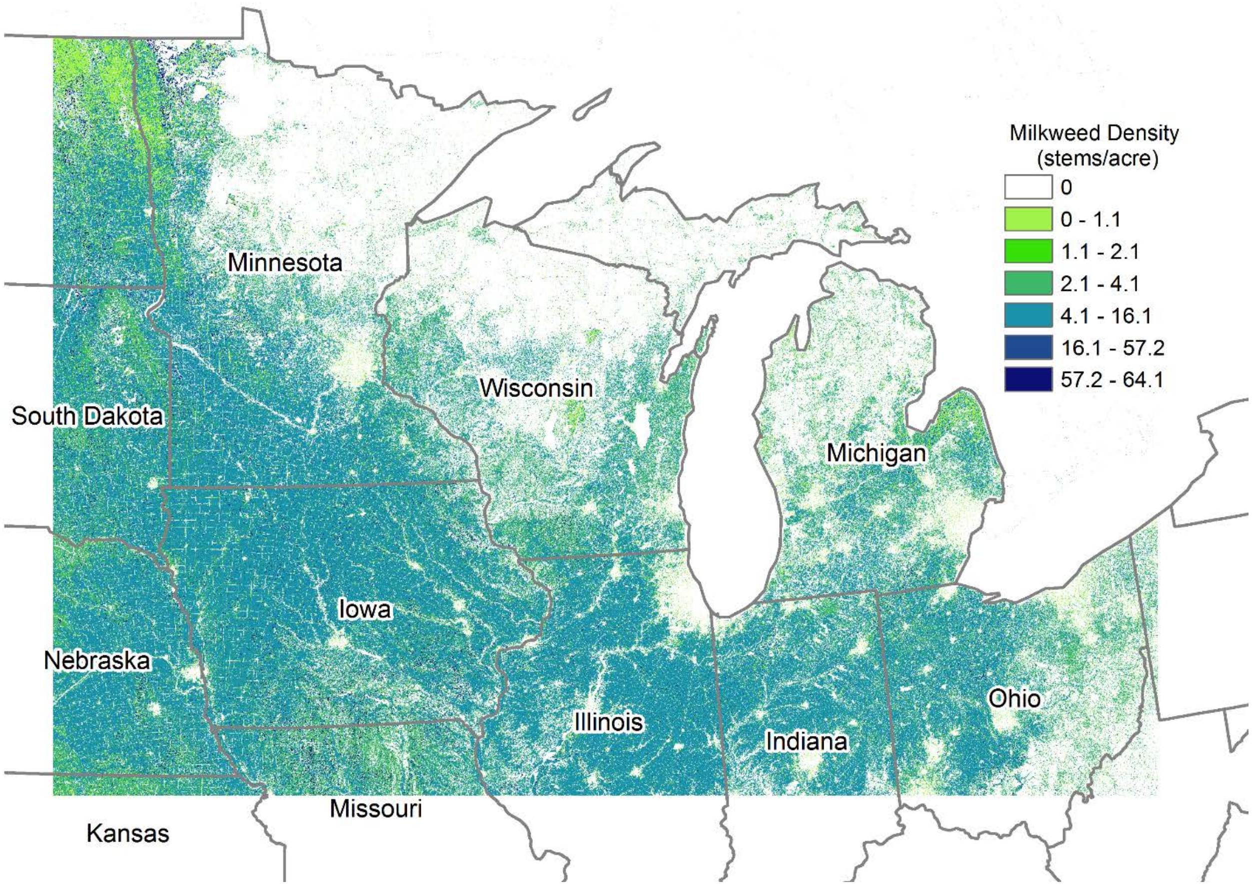


Figure S1.3. Map of predicted density of milkweed across the Midwestern United States prior to application of glyphosate to genetically modified corn and soy fields (see Fig. 1 for current predicted density).



Supplemental S2. Review of literature for published estimates of milkweed density.

To populate the monarch-relevant land-cover map with milkweed, we conducted a systematic review of the literature to obtain empirical common milkweed (*Asclepias syriaca*) stem density estimates (Sauer and Feir 1974, Bhowmik and Bandeen 1976, Cramer and Burnside 1982, Hartzler and Buhler 2000, Taylor and Shields 2000, Hartzler 2010, Smith et al. 2012). We assigned these empirical density estimates to cover classes in our map of land cover (Table S2.1).

Average maximum densities of field-scale common milkweed infestation have been reported to be between 5.0 (Sauer and Feir 1974) and 8.8 stems m^{-2} in abandoned agricultural fields and agricultural field margins (Bhowmik and Bandeen 1976, Cramer and Burnside 1982). Durgan and Wyse (1988) reported 12 shoots m^{-2} (equivalent, presumably to ~4 stems m^{-2}) in hard red spring wheat in Nebraska. Smith et al. (2012) reported 0.24–0.63 stems m^{-2} in fallow fields bordering onion and potato crops in New York.

Groh and Dore (1945) reported surveys along Ontario roadsides, finding 75 stalks km^{-1} in Lennox county, 100 stalks km^{-1} in Lincoln county, 1,863 stalks km^{-1} in Essex county, and 10,954 stalks km^{-1} in Renfrew county; they reported densities of 11,819–88,226 stalks ha^{-1}, where stalks are presumed to equal stems.

The most important empirical assessment of milkweed stem density in the Midwest region of the U.S. was conducted by Hartzler and Buhler (2000) and Hartzler (2010). They used randomly chosen locations on roads and extended a 100 × 50 m transect into the surrounding vegetation. Within this transect they identified patches of common milkweed and measured the area covered by each patch. Their studies were limited to Iowa, but included a variety of land-cover types (*n* =

7), including non-agricultural cover. They reported infestation rates as high as 67% and 71% in Conservation Reserve Program (CRP) and along roadsides, respectively, and as low as 28% in pasture. CRP land had densities of 212 m^2 ha^{-1}, waterways and terraces had 169 m^2 ha^{-1}, roadsides had 102 m^2 ha^{-1}, other crops, railroad rights-of-way, wood lots and grassed field corners had 61 m^2 ha^{-1}, and corn and soybean had 30 and 16 m^2 ha^{-1}, respectively. Following Pleasants (2016), we converted m^2 per hectare into stems per hectare with a conversion factor of 1.95 stems/m^2 as reported by Flockhart et al. (2015).

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Table S2.1. Milkweed density estimates as reported by Hartzler and Buhler (2000) and Hartzler (2010).

	Area covered[1]	Stem density within milkweed patches	Stem density
	m^2/ha	stems/m^2	stems/ha
CRP suitable, non-wet	142.04	1.95[2]	276.98
Waterways and terraces	77.74	1.95	151.59
Grassland/Pasture/Range	3.92	1.95	7.64
Roadside	72.42	1.95	141.22
Other	25.01	1.95	48.77
Corn and soybeans, 1999	11.46	1.62[3]	18.57
Corn and soybeans, 2009	0.40	1.62	0.65

[1] Data from Hartzler and Buhler (2000), except for corn and soybeans 2009 from Hartzler (2010)

[2] Data from Flockhart et al. (2015)

[3] See Pleasants (2016)

Supplemental S3. Results of expert elicitation of the potential and willingness of different societal sectors to restore milkweed.

Protected grassland, land enrolled in non-wet Conservation Reserve Program, and roadside rights of way have the greatest biological potential for milkweed restoration. Conversely, because genetically modified corn and soy is now grown in >90% of all corn and soy fields, the biological potential for milkweed in this habitat is lowest among the types of habitats we examined. The potential for milkweed restoration in hayland is also low, given the potential deleterious consequences of milkweed to livestock. Rates of adoption of practices amenable to the restoration of milkweed ranged from 0% in corn and soy agriculture and 1% in other cropping practices up to 50% within protected area grasslands.

Our two expert panels came to similar conclusions on the biological potential for milkweed restoration across the different land-cover sectors. For instance, the difference between panels in the biological potential for milkweed stem restoration on protected area grasslands was 6.9 million stems, or 2.5%. However, the two panels of experts differed in the assessment of potential adoption rates in the powerline rights-of-way sector, in particular, citing different potential for engagement and investment; the difference between panels' expectation for milkweed restoration was an 8.5 million stem difference, or 25%. As such, we evaluated both estimates in our assessment of how the rights-of-way land-cover sector might contribute to reaching the USFWS 6-ha population target.

Table S3.1. Expert elicited adoption rates and biological potential of different land covers in the North Central region of the United States. Experts were divided into two panels, A and B. The difference and mean of their panel estimates are provided, as well as the mean density (in acres and hectares) of milkweed stems expected (adoption rate × biologically reasonable density of milkweed).

Land Use / Land Cover	Milkweed stems/acre	Biologically Reasonable stems/acre (A)	Biologically Reasonable stems/acre (B)	Difference	Mean	Realistic Adoption Rates (A)	Realistic Adoption Rates (B)	Difference	Mean	Mean stems/ acre (A)	Mean stems/ acre (B)	Mean stems/ ha (A)	Mean stems/ ha (B)
Conservation Reserve Program - Non-wet	112.14	250.00	200.00	50.00	225.00	0.10	0.20	-0.10	0.15	125.93	129.71	311.16	320.51
Conservation Reserve Program - Wet	61.37	75.00	61.32	13.68	68.16	0.10	0.20	-0.10	0.15	62.73	61.36	155.01	151.62
Pasture / Hay	3.09	40.00	40.00	0.00	40.00	0.05	0.05	0.00	0.05	4.94	4.94	12.20	12.20
Grassland	3.09	40.00	40.00	0.00	40.00	0.10	0.05	0.05	0.08	6.78	4.94	16.76	12.20
Protected Grass	3.09	250.00	250.00	0.00	250.00	0.50	0.50	0.00	0.50	126.55	126.55	312.69	312.69
Roadside (secondary road)	57.17	200.00	150.00	50.00	175.00	0.07	0.05	0.02	0.06	67.17	61.81	165.97	152.73
Roadside (freeway/highway)	57.17	200.00	100.00	100.00	150.00	0.15	NA	0.15	0.08	78.59	57.17	194.20	141.27
Roadside (small road)	57.17	200.00	NA	200.00	100.00	0.07	0.03	0.04	0.05	67.17	55.45	165.97	137.03
Powerline Rights of Way	3.09	150.00	150.00	0.00	150.00	0.15	0.20	-0.05	0.18	25.13	32.47	62.09	80.24
Rail Rights of Way	3.09	200.00	200.00	0.00	200.00	0.05	0.05	0.00	0.05	12.94	12.94	31.96	31.96
Corn and Soy	0.05	8.00	0.08	7.92	4.04	0.00	0.00	0.00	0.00	0.06	0.05	0.15	0.12
Other Crops	7.50	250.00		250.00	125.00	0.01	0.00	0.01	0.01	9.93	7.50	24.52	18.53
Wetland	61.37	75.00	61.32	13.68	68.16	0.10	0.05	0.05	0.08	62.73	61.37	155.01	151.64
Exurban	19.74	89.00	80.00	9.00	84.50	0.05	0.02	0.03	0.04	23.20	20.95	57.33	51.75
Marginal Crop	0.05	200.00	NA	200.00	200.00	0.02	NA	0.02	0.02	4.05	0.05	10.00	0.12
Urban - Low Intensity	1.00	50.00	NA			0.01	NA			1.49	NA	3.68	NA
Urban - Medium Intensity	0.50	25.00	NA			0.01	NA			0.75	NA	1.84	NA
Urban - High Intensity	0.10	10.00	NA			0.01	NA			0.20	NA	0.49	NA

Table S3.2. Potential area (km^2) for milkweed restoration by sector in each state within the Midwest Region of the United States.

State Name	Marginal Corn and Soy	Other Crops	Suburban/ Urban	Rights-of-Way	Conservation Reserve Program	Protected Grassland	Sum
Illinois	1,692	495	6,599	3,454	884	366	13,491
Indiana	2,950	906	2,991	2,596	390	96	9,929
Iowa	1,814	411	5,621	6,552	4,625	706	19,729
Michigan	1,881	5,837	8,302	7,649	529	1,398	25,596
Minnesota	11,944	9,110	6,361	8,428	3,799	2,130	41,771
Missouri	205	114	474	886	1,152	117	2,949
Nebraska	2,606	372	1,615	2,398	960	518	8,469
North Dakota	9,075	6,430	706	1,182	782	1,162	19,336
Ohio	726	1,963	5,848	4,032	555	182	13,306
South Dakota	11,847	1,031	988	1,672	1,222	1,527	18,287
Wisconsin	5,589	2,728	5,808	6,857	637	604	22,223
Grand	50,329	29,397	45,313	45,708	15,535	8,804	195,087

Supplement S4. Scenarios (*n* = 218) depicting combinations of approaches for restoring milkweed to the Midwestern U.S. landscape.

See Scenario_Results.xlsx

Supplement S5. Expert set providing insight into the biological potential and willingness of different sectors of society to restore milkweed for monarch butterfly conservation.

Expert		Principal Expertise
Scott	Black	insect ecology and conservation, habitat restoration
Iris	Caldwell	rights-of-way as habitat, restoration science
Donita	Cotter	tri-national policy
Jay	Diffendorfer*	landscape and wildlife ecology
Pauline	Drobney	prairie/grassland restoration
Ryan	Drum	landscape and wildlife ecology
Michael	Gale	national and international policy
Doug	Helmers	prairie/grassland restoration
Steve	Hilburger	national and international policy
Elizabeth	Howard	monarch migration ecology, citizen science
Laura	Jackson	prairie/grassland restoration
Laura	López-Hoffman	transboundary governance, political ecology
Karen	Oberhauser	monarch and milkweed ecology, citizen science
John	Pleasants	monarch and milkweed ecology
Jason	Rohweder	geospatial analyses
Brice	Semmens	quantitative ecology
Darius	Semmens	natural resource economics, spatial subsidies
Orley	Taylor	monarch and milkweed ecology, citizen science
Wayne	Thogmartin*	quantitative and spatial ecology
Patrick	Ward	monitoring
Jake	Weltzin	phenology, monitoring
Ruscena	Wiederholt	quantitative ecology

*Led group elicitation of biological potential and willingness to adopt conservation