Restoring Monarch Butterfly Habitat in the Midwestern U.S.: “All Hands on Deck”

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Running Title: Societal contributions to monarch restoration

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**Abstract**

The eastern migratory population of monarch butterflies (*Danaus plexippus plexippus*) is imperiled largely as a consequence of the loss of ≥1.3 billion milkweed stems (*Asclepias* spp.), the plants required by this species for reproduction. In an effort to restore monarchs to a population goal established by the U.S. Fish and Wildlife Service and adopted by Mexico, Canada, and the U.S., we developed scenarios for amending the Midwestern U.S. landscape with milkweed. Scenarios for milkweed restoration were developed for protected area grasslands, Conservation Reserve Program land, powerline, rail and roadside rights of way, urban/suburban lands, and land in agricultural production. Agricultural land was further divided into productive and marginal cropland. We elicited expert opinion as to the biological potential (in stems per acre) for lands in these individual sectors to support milkweed restoration and the likely adoption (probability) of management practices necessary for affecting restoration. Sixteen of 218 scenarios we developed for restoring milkweed to the Midwestern U.S. were at levels (>1.3 billion new stems) necessary to reach the monarch population goal. One of these scenarios would convert all marginal agriculture to conserved status. The other 15 scenarios converted half of marginal agriculture (730 million stems), with remaining stems contributed by other societal sectors. Scenarios without substantive agricultural participation were insufficient for attaining the population goal. Agricultural lands are essential to reaching restoration targets because they occupy 77% of all potential monarch habitat. Barring fundamental changes to policy, innovative application of economic tools such as habitat exchanges may provide sufficient resources to tip the balance of the agro-ecological landscape toward a setting conducive to both robust agricultural production and reduced imperilment of the migratory monarch butterfly.

**Key words**: agriculture, *Asclepias syriaca*, conservation design, *Danaus plexippus*, glyphosate, milkweed, strategic habitat conservation

**Introduction**

Global populations of many invertebrates are in decline (Collen *et al*. 2012); lepidopterans, for instance, have declined by 40% over the past 40 years (Dirzo *et al*. 2014). The eastern migratory population of monarch butterflies (*Danaus plexippus plexippus*), a species which breeds in the U.S. and Canada but migrates to central Mexico to overwinter, decreased by 84% between the winters of 1996–1997 and 2014–2015 (Semmens *et al*. 2016). The extent of the area occupied by this species as it overwinters in the high-elevation Oyamel fir (*Abies religiosa*) forests of central Mexico is used as a proxy for population size; the population was at its lowest level (0.67 ha) ever recorded in winter 2013–2014 (WWF 2016). Partly in response to this decline and small population size, on 20 June 2014, the Obama administration issued a presidential memorandum calling for the restoration of pollinator and monarch habitat with the planting of milkweed (*Asclepias* spp.) and nectar plants (Pollinator Health Task Force 2015). In August 2014, a coalition of nongovernmental organizations and citizens petitioned the U.S. Fish and Wildlife Service (USFWS) to list the monarch butterfly as a threatened species (Center for Biological Diversity *et al*. 2014), and in December 2014 the USFWS initiated a review of the status of the species (Federal Register 2014) with a listing decision to be rendered by June 2019 (Center for Food Safety *et al*. v. S.M.R. Jewell, 2016, No. 1:16-cv-01008-EGS). While the petition is under consideration, the USFWS announced a short-term goal of restoring by 2020 sufficient habitat in the U.S. to support a monarch population of 6-ha in overwintering habitat in Mexico (Pollinator Health Task Force 2015). This 6-ha indicator was adopted by Canada and Mexico as a trinational goal for this species (Trudeau *et al.* 2016).

*Asclepias* species (and a few closely-related genera) are the sole host plants for monarchs but common milkweed (*A. syriaca*) is the species used by >90% of monarchs in the summer breeding range within eastern North America (Malcolm *et al.* 1993). Pleasants and Oberhauser (2013) and Pleasants (2015, 2016) documented a strong relationship between the amount of milkweed in the Midwestern U.S. and forest area occupied by overwintering monarchs in Mexico; thus, it is not surprising that recent demographic analyses have indicated that reintroducing milkweed into landscapes in the Midwestern U.S., relative to other areas of the northern breeding range, would be most important for recovery of the population (Oberhauser *et al*.,2016; Flockhart *et al*. 2015). Less clear, however, is the identity of Midwestern habitats that should be restored with milkweed. A number of different land-use types have been proposed for monarch habitat restoration, including governmentally protected grasslands, rights-of-way along roadsides, powerlines and rail lines, areas in and adjacent to agricultural fields and, given the widespread enthusiasm across the country for planting milkweed and nectar plants in cities and towns, areas in schoolyards, backyards, and parks (National Pollinator Garden Network 2015, EPIC 2016, ERC 2016, NWF 2016, Pleasants 2016).

A first step in determining where to restore monarch habitat is to understand where monarch habitat has been lost. Milkweeds are the monarch butterfly’s primary food source during the larval stage (Brower 1984). Pleasants (2016) estimated that more than 861 million milkweed stems disappeared in the Midwest since 1999, primarily from agricultural and grassland habitat (Pleasants and Oberhauser 2013, Pleasants 2015). Approximately 98% of this change is attributed to loss of milkweed in plantings of corn and soy that has been genetically modified to withstand herbicide application (850.3 million stem; SE = 194.2 million stems); the remaining 2% of milkweed loss is attributed to conversion of grassland habitat to less suitable habitat such as human development (Pleasants 2016) and cropland expansion in the Midwestern U.S. (Lark *et al*. 2015) (11.3 million stem; SE = 8.9 million stems). Because milkweed in corn and soy agricultural fields averages 3.9 times more monarch eggs than a milkweed stem in non-agricultural habitat, the loss of milkweed from corn and soy is compounded.

According to calculations by Pleasants (2016), the current amount of milkweed in the northern U.S. (~1.3 billion stems) is sufficient, in a year with average weather conditions, to support an average of 3.2 ha of overwintering monarch butterflies in Mexico. Thus, a near doubling of average abundance (i.e., 6-ha overwintering goal) would require roughly a doubling of the number of stems; Pleasants (2016) calculated this number as 1.6 billion additional stems needed in the Midwest. Therefore, the goal for restoring monarchs to 6-ha of occupied habitat overwintering in the mountains of central Mexico requires restoration of at least 1.3 billion and possibly as much as 1.6 billion additional stems of milkweed.

Here we evaluated five land-cover sectors in terms of their present and potential ability to support milkweed: perennial herbaceous vegetation on protected lands, land enrolled in Conservation Reserve Program (CRP), lands in rights-of-way status, land associated with agricultural practices, and urban/suburban lands. To determine the habitat needed for achieving the 6-ha population goal for monarchs, we asked the following question: Could a 6-ha population be achieved by reintroducing milkweed in a given land cover sector alone, and if not, what combinations of these different sectors would be sufficient for reaching this goal?

**Methods**

*Study Area*

We considered opportunities for milkweed reintroduction for the Midwestern United States (1.1 million km2), encompassing the area north of ~39°N and between ~98°W and ~80°W (Fig. 1). This included the states of Minnesota, Iowa, Wisconsin, and Michigan in their entirety, most of Ohio, northern Indiana, Illinois, and Missouri, and eastern portions of Nebraska and North and South Dakota, but did not include West Virginia. Prior to loss of milkweed, this region constituted what was once ≥85% of the breeding population of monarch butterflies (Flockhart *et al*. 2013; O. Taylor, unpublished data). Current land cover in this area consists of corn and soy agriculture (42%), followed by forest (18%), grassland (13%), human habitation (~5%) and human infrastructure (i.e., transportation and powerline rights of way, ~6%). Other agriculture, including orchards, vineyards, alfalfa, and vegetable crops, constituted another ~5% of the landscape. Miscellaneous land cover (e.g., lakes and wetlands) comprised the remainder of the landscape. The region transitions from a largely forested north to row crop agriculture (historically tallgrass prairie) in the south.

*Where and how many milkweed plants are currently in Midwestern landscapes?*

We used the Cropland Data Layer 2014 as well as additional spatially explicit information to develop a land-cover map for the Midwestern U.S. pertinent to the mapping of milkweed habitat (Supplement S1). Additional sources of information included 2014 CRP enrollment locations; railroad, power line, and road rights-of-way; marginal versus productive farmland as determined by the 2012 National Commodity Cropland Productivity Index; and a characterization of exurban versus urban environs (Supplemental S1). As we defined it, marginal cropland devoted to corn and soy production comprises <5% of the overall landscape and 14% of total land in production.

To populate the monarch-relevant land-cover map with milkweed, we conducted a systematic review of the literature to obtain empirical common milkweed (*A. 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 1). Details of this literature review are provided in Supplemental S2; the most important empirical assessment of milkweed stem density in the Midwest region of the U.S. was conducted by Hartzler and Buhler (2000), followed by 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 occurrence 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 m2 ha-1, waterways and terraces had 169 m2 ha-1, roadsides had 102 m2 ha-1, other crops, railroad rights-of-way, wood lots and grassed field corners had 61 m2 ha-1, and corn and soybean had 30 and 16 m2 ha-1, respectively. Following Pleasants (2016), we converted m2 per hectare into stems per hectare with a conversion factor of 1.95 stems m-2 as reported by Flockhart *et al.* (2015).

*The potential of milkweed restoration in five sectors, individually and in combination*

Using geospatial tools developed for this analysis (Rohweder and Thogmartin 2016), we evaluated potential milkweed restorations in five sectors, individually and in combination. The protected area grassland sector included any herbaceous perennial vegetation (often grass-dominated, but containing nectar-producing forbs and plants in the *Asclepias* genus) or pasture/hayland occurring within lands identified as protected in the 2012 Protected Areas Database US. CRP lands included only wet- and non-wet reserve program lands capable of supporting milkweed, excluding those relating to tree plantings (Table S2.1).

We elicited from two independent panels of experts the biologically reasonable amounts of new milkweed stems restorable in a given land-cover sector, and the likelihood that milkweed amendment practices could be adopted by landowners and land managers in the sector (Table 1, Supplement S4). The panels included monarch biologists, grassland restoration and management experts, policy analysts, and ecologists.

For the protected area grasslands, CRP, and land in utility rights-of-way sectors, the panels’ sector-specific adoption rates represent a mean expectation of restoration success among the variety of conservation approaches that could reasonably be employed in these sectors (Table 2). For the agricultural land cover and urban/suburban sector, panelists envisioned a broad array of possible rates of adoption of conservation practices largely depending upon financial support provided to and willingness of landowners within those sectors. Accordingly, the panels developed scenarios with low, medium, and high restoration adoption rates. Further, because the experts believed GMO corn and soy agriculture has little potential for milkweed restoration as well as little opportunity for adoption of non-GMO crops, the agricultural sector scenarios reflect modest, moderate, and vigorous *conversion* of land currently in corn and soy production to cover types amenable to milkweed restoration, such as CRP-like grasslands.

For each sector, we calculated the gain in milkweed stems. Once individual sector contributions were identified, we examined every 2-, 3-, 4-, and 5-sector combination, for a total of 218 unique combinations. The 5-sector combination – requiring engagement in milkweed restoration from all land uses – was termed ‘All Hands on Deck.”

We used regression analysis to determine sensitivity of scenario-specific overall gains in milkweed to land cover-specific differences in milkweed. Following methods of Lonsdorf *et al.* (2009, 2016), the sensitivity of overall milkweed gains to cover-specific gains was indicated by its standardized regression coefficient, calculated from the best fit of a multiple linear regression model, , where *x* is one of the 30 land cover categories and δ is a regression coefficient for each predictor. The standardized regression coefficient was calculated as the *t* value, i.e., the regression coefficient divided by its standard error (δ/SE). The *t* value is a unitless quantity allowing for direct comparison of the sensitivity among parameters, with the largest *t* value indicating greatest sensitivity of milkweed gain to gains in specific land cover classes.

**Results**

To support the USFWS 6-ha population goal for monarchs, 16 of 218 scenarios provided >1.3 billion new milkweed stems in the Midwest region whereas only 4 scenarios provided >1.4 billion new milkweed stems (Fig. 2, Supplement S5). Conversion of all marginal cropland in corn and soy agriculture (i.e., 50,329 km2, Table S4.2) to cover practices equal in milkweed density to that supported by CRP land (i.e., “CRP-like”) could provide the requisite amount of milkweed. However, all of the other scenarios providing >1.3 billion new stems, including the 3 other scenarios providing >1.4 billion stems, required converting approximately half of the marginal cropland to this CRP-like state. Because the calculus we conducted was a function of adoption rate and biological gain, reductions in one would require increases in the other (Fig. 3). Conversion of half of marginal cropland contributed 730 million stems, or ~½ of the milkweed needed to reach the 6-ha population target. Individual sectors provided from 3.2 million (in railroad rights of way) to 275.5 million additional stems (in protected area grasslands), and as a result, contributions from no less than three sectors were needed in addition to that provided by marginal cropland.

Expert-suggested adoption rates for the planting of milkweed ranged from 0% in corn and soy agriculture to as much as 20% in lands in CRP and along powerline rights-of-way. Outside of converting corn and soy agriculture to land cover amenable to milkweed restoration, the greatest potential for gains in mean milkweed stem density occurred in the protected grassland and roadside rights of way sectors (Fig. 4). Moderate contributions could be made by CRP lands and with strong participation within the urban/suburban sector. Potential gain in milkweed stems is relatively small for the powerline sector and when participation from the urban/suburban sector is low or medium. Potential gain along railroad rights-of-way is insignificant, despite there being at least 1,790 km2 of railroad rights-of-way across the Midwestern landscape outside of urban areas.

Scenario-specific milkweed gains were most sensitive to expected changes in milkweed density, in order, in marginal cropland (*t* = 255.3, p < 0.0001), protected area grasslands (*t* = 119.2, *p* < 0.0001), non-wet CRP (*t* = 50.7, *p* < 0.0001), and secondary roadsides (*t* = 17.1, *p* < 0.0001). The overall gain in milkweed was insensitive to gains expected in linear developed open spaces in urban environs (*t* = -0.6, *p* = 0.58) and only marginally sensitive to gains in railroad rights of way (*t* = 1.92, *p* = 0.06). These sensitivities reflect interaction of the biological potential of a land use to support milkweed amendment with the footprint of the land use; thus, milkweed gains in productive corn and soy, with its large footprint but small biological potential outside of organic corn, was roughly equivalent to gains expected in transmission line rights of way where the biological potential was equivalent to roadsides but operating over a considerably smaller footprint (*t*’s ≈ 4.8, *p*’s < 0.0001).

**Discussion**

Restoring sufficient milkweed to support a 6-ha population goal for monarchs is likely to be an immense task but, when evaluated by sector, may be attainable. The contribution of any particular sector is insufficient to make substantial individual progress towards the goal, with the exception of the agricultural scenarios of medium and high conservation adoption rates in marginally productive land. The multi-sector participation approach under the ‘All-Hands-on-Deck’ scenarios would, however, provide sufficient milkweed to reach the goal, but would depend on half of marginal agricultural land being converted to CRP-like habitat. It appears that, without this substantial contribution from the agricultural sector, the opportunities for milkweed restoration are simply insufficient to reach the goal. This result is driven principally by the footprint of each sector. The agricultural sector is the largest by area in the region (365,359 km2 in corn and soy, 29,397 km2 in other cropping practices), followed far behind by land in urban and suburban areas (45,313 km2), lands along rights-of-way (43,148 km2), lands enrolled in CRP (15,535 km2), and protected grassland areas of mixed herbaceous perennial vegetation (8,804 km2). In total, the non-agricultural sectors combined could provide up to 800 million additional stems of milkweed, >500 million stems short of what is necessary to support the 6-ha goal, prompting the need for possible modification or conversion of marginal agricultural land, or changes in agricultural practices that may allow persistence of milkweed.

There are, however, considerable sources of uncertainty in the amount of milkweed needed to attain the 6-ha population goal. For instance, the relationship between monarchs and milkweed is known imprecisely; based upon Pleasants (2016), the 6-ha goal is known within ±300 million milkweed stems. Further, variability in milkweed density among sectors and across the region is largely unknown. Recently, Kasten *et al.* (2016) described mean and variation in milkweed density along Upper Midwestern U.S. roadsides; this study suggested our expert-based estimates may have been only two-thirds of the actual amount, which could translate to an additional 265 million milkweed stems over the region. Our expert estimates of milkweed density in urban and suburban areas (excluding natural areas), however, seem reasonable based upon early analyses of data from the Ecological Places in Cities project (K. Voorhies, U.S. Fish and Wildlife Service, personal communication). Clearly, given the role milkweed density has in addressing whether target attainment is possible, additional information on sector-specific milkweed density is essential. Probably the largest source of uncertainty, however, relates to sector-specific adoption rates; voluntary participation in conservation action is influenced by a slew of factors which are only partly understood (e.g., Nelson *et al.* 2007, Reimer and Prokopy 2013, Diffendorfer *et al.* 2014). Given the footprint of agriculture in the Midwestern U.S., understanding the socioeconomic constraints to the adoption of conservation practices in this sector seems clear.

Various sectors of society are responding to the U.S. President’s call for action in support of monarchs and other pollinators. In cities and towns, for instance, programs such as Milkweeds for Monarchs (EPIC 2016), Monarch Waystation (Landis 2014), Million Pollinator Garden Challenge (National Pollinator Garden Network 2015), and the Mayor’s Monarch Pledge (NWF 2016) are underway. The Rights-of-Way as Habitat Working Group (ERC 2016) has convened the relevant management authorities, including state departments of transportation and energy companies, to develop and share best management practices capable of delivering milkweed and nectar resources to roadsides, rail sidings, and powerline corridors (Hopwood *et al*. 2016).

Governments have been quick to act in support of monarch habitat management and restoration. In the year following release of the President’s Pollinator Health Strategy (Pollinator Health Task Force 2015), the USFWS, for example, took a number of steps to protect monarchs and support creation of monarch-friendly habitat, including curtailing use of both neonicotinoid pesticides and genetically modified crops on National Wildlife Refuge System lands (Kurth 2014), creating or restoring nearly 113,000 hectares on USFWS and private lands (Monarch Headquarters Team 2016), and distributing pollinator guidance for grassland management activities (USFWS 2015).

Because of the large footprint of agriculture, however, this sector will clearly need substantive involvement in monarch habitat restoration in the Midwest to reach the 6-ha goal. Given current agricultural practices and subsidy policies, it is unreasonable to expect that milkweed will ever be prevalent in corn and soy fields at pre-glyphosate levels. However, it may be possible to establish mixed herbaceous plants in perennial cover-crop fields amidst robust agricultural production (Stull *et al*. 2004, Dosskey *et al*. 2005), such as prairie strips, if issues with pesticides can be overcome. Increasing the footprint of CRP-like plantings by 2.6 times over that which currently exists in the Midwest is one means of affecting the medium agriculture scenario – no small task. With precision farming and associated removal from production of poor-producing portions of fields, farmers may increase yield, decrease cost, and return marginal areas to wildlife habitat (Bongiovanni and Lowenberg-Deboer 2004, Brandes *et al*. 2016).

Milkweed availability is a limiting factor for monarchs, and milkweed stems throughout the Midwest landscape serve as a useful metric to evaluate conservation targets; however, milkweed is rarely planted in isolation. By incorporating milkweed into grassland land cover comprised of diverse nectar resources, conservation activities for monarchs can provide many additional benefits for bees and other pollinators, grassland birds, upland-nesting waterfowl, game species, water quality, and carbon sequestration (Steffan-Dewenter and Tscharntke 1999, Santelmann *et al*. 2004, Robertson *et al*. 2007, Asbjornsen *et al*. 2014). These benefits can provide economic value to farmers on-site, as well as to municipal water providers and fisheries downstream (Kremen and Miles 2012, Huang *et al*. 2015).

Federal policies such as the Ethanol Fuel Standards (Renewable Fuel Standard) (Wright 2015), crop insurance (Faber *et al*. 2012, Lark *et al*. 2015), and waning Farm Bill support for CRP (Wright and Wimberly 2013, Stubbs 2014) reduce support for integrated agro-ecological landscapes capable of sustaining both food production and monarch habitat, principally because these policies promote row crops over mixed, herbaceous perennial vegetation. Thus, in the absence of changes to Farm Bill policy, economic tools such as habitat exchanges, market-based compensatory mitigation programs, and payments for ecosystem services (Pindilli and Casey 2015) may offer the most promising means of restoring monarch habitat. In habitat exchanges, for instance, landowners earn credits by restoring and maintaining habitat on their land, which can then be sold to industry to compensate elsewhere for development, such as roads, power lines, and wind turbines (EDF 2016). Pleasants (2015) identified fully one-quarter of lost milkweed in the northern U.S. was due to land conversion. These market-based solutions for financing conservation offer a potential mechanism for offsetting on-going declines and, ideally, restoring new habitat (Pindilli and Casey 2015).

**Conclusion**

Restoring >1.3 billion stems of milkweed to the Midwestern U.S. will require participation from all sectors of society, but most importantly from the agricultural sector where the majority of milkweed stems have been lost over the last two decades. Restoring marginal cropland to CRP-like grassland cover has the greatest potential for supporting attainment of the population goal for monarchs, however an “all hands on deck” cross-sector strategy will likely be necessary. Conservation efforts that incorporate milkweed along with grassland cover and diverse nectar resources can help to ensure a stable monarch population while also providing important habitat for other species and additional ecosystem services. Combinations of policy changes and innovative economic tools have the potential to tip the balance of the agro-ecological landscape toward one allowing robust populations of the iconic migratory monarch butterfly.

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**Figure Legend**

**Figure 1**. Map of current predicted density of milkweed across the Midwestern United States (see Figure S2.3 for pre-glyphosate depiction).

**Figure 2**. Number of milkweed stems predicted in the study area contributed by individual and combined scenarios and the overwinter population size supported. The current or baseline amount of milkweed estimated for the North Central region of the U.S. is denoted by the black line (1.034 billions stems). Milkweed stems needed to maintain 4-, 5-, and 6-ha average overwintering monarch butterfly population sizes are denoted by dashed lines. Scenarios closest to the 6-ha goal are labeled with footnotes 1-4. The areas in gray denote uncertainty in the milkweed estimate and 6-ha goal as inferred from Pleasants (2016).

1 Agricultural contribution of all marginal cropland in corn and soy production; 50,329 km2.

2 Two overlapping scenarios, each comprised of contributions from all sectors (including high urban/suburban and medium agriculture contributions); scenarios differ solely in panel assumptions for biotic potential of protected area grasslands.

3 This scenario differs from 2 only in the assumptions relating to the contribution of powerline rights of way.

4 The four-sector scenarios closest to the goal are comprised of medium agriculture, protected area grasslands, and rights of way contributions, and either high urban/suburban or Conservation Reserve Program contributions.

**Figure 3**. As adoption rate increases, the expected density of milkweed needed to reach the 6-ha goal declines. Converting half of marginal cropland (light green circle) to a milkweed density equal to that found in Conservation Reserve Program (CRP) land (125 stems/acre, dashed blue line) is equivalent to converting all marginal cropland to a milkweed density half that of CRP (open square). For the high agriculture scenario (dark green square), receiving less than 100% adoption on marginal croplands would require higher densities of milkweed than that seen currently in CRP (blue dashed line); below an adoption rate of 50% (i.e., half of all marginal cropland), milkweed densities would be at levels not biologically feasible over regional scales (i.e., >180 stems/acre). Enhanced CRP (i.e., milkweed amendments on 10% of CRP) is included for reference (blue diamond).

**Figure 4**. Gain in mean density (stems/ac) of milkweed relative to the baseline condition for individual sectors. Bar labels are the proportional increase in milkweed provided by the sector relative to the baseline (e.g., the medium agriculture scenario increases the amount of milkweed by an additional 62% over the baseline whereas railroads only increase it by 0.5%). Labels with ‘A’ and ‘B’ refer to results from the two independent expert panels.

**Table 1**. Milkweed stems per acre (1 ac = 0.405 ha) by cover class for current and amended scenarios of milkweed addition. Current is the expected density of milkweed in the current Midwestern U.S. landscape. Low, Medium, and High scenarios require increasing amounts of milkweed stems per unit area. Current values are based upon empirical estimates (Supplement S3) whereas restoration scenarios are estimates provided by two expert panels (Supplement 4).

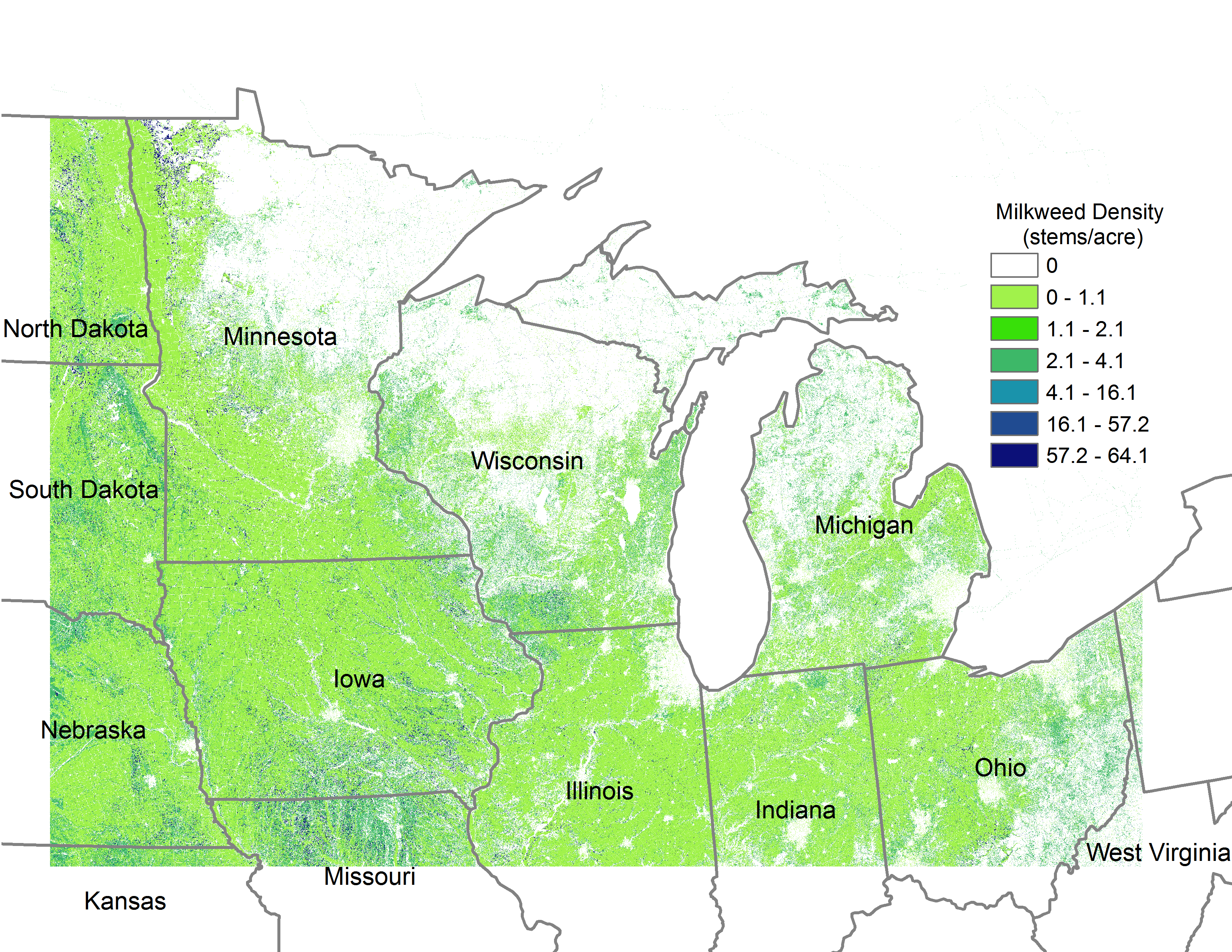
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| --- | --- | --- | --- | --- | --- |
| Agriculture | Corn and Soy | Corn and Soy (Marginal) | Other Crops/Orchard  (Low)1 | Other Crops/Orchard (Medium) | Other Crops/Orchard (High) |
| Current | 0.05 | 0.05 | 3.09 | 5.3 | 7.5 |
| Low | 0.06 | 4.05 | 5.56 | 7.74 | 9.93 |
| Medium | 0.06 | 56.07 | 5.56 | 7.74 | 9.93 |
| High | 0.06 | 112.14 | 5.56 | 7.74 | 9.93 |
|  |  |  |  |  |  |  |
| Urban/  Suburban | Developed Open Space Linear | Developed Low Intensity, Within Urban | Developed Medium Intensity | Developed High Intensity | Developed Open Space Core | Developed Low Intensity, Exurban |
| Current | 0 | 0 | 0 | 0 | 0 | 1.00 |
| Low | 3.09 | 1.49 | 0.75 | 0.20 | 3.09 | 3.09 |
| Medium | 3.09 | 3.09 | 1.50 | 0.40 | 3.09 | 3.09 |
| High | 16.31 | 6.18 | 3.09 | 0.40 | 3.09 | 3.09 |

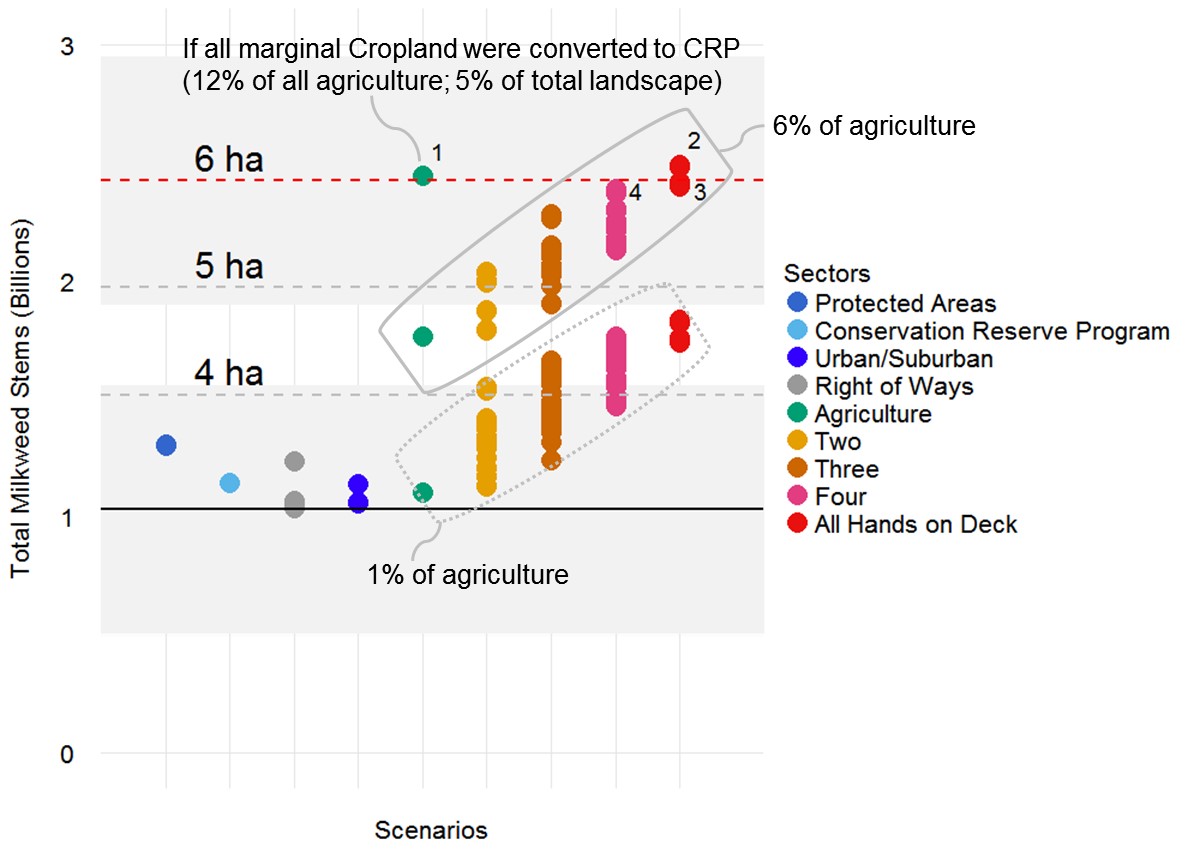
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|  |  |  |  |  |  |  |  |  |  |  |
| Grass and Conservation Reserve Program | Grass | Protected Grass | Pasture | Protected Pasture | CRP Non Wet | CRP Wet |  |  |  |  |
| Current | 3.09 | 3.09 | 3.09 | 3.09 | 112.14 | 61.37 |  |  |  |  |
| Amended | 3.09 | 126.55 | 3.09 | 126.55 | 153.5 | 65.46 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| Rights of Way | Transmission Line (Outside Urban Areas) | Primary Roads and Ramps | Secondary Roads | Local Roads | Rails (Outside Urban Areas) |  |  |  |  |  |
| Current | 3.09 | 57.15 | 57.15 | 57.15 | 3.09 |  |  |  |  |  |
| Amended | 32.63 | 100.02 | 78.59 | 78.59 | 10.44 |  |  |  |  |  |

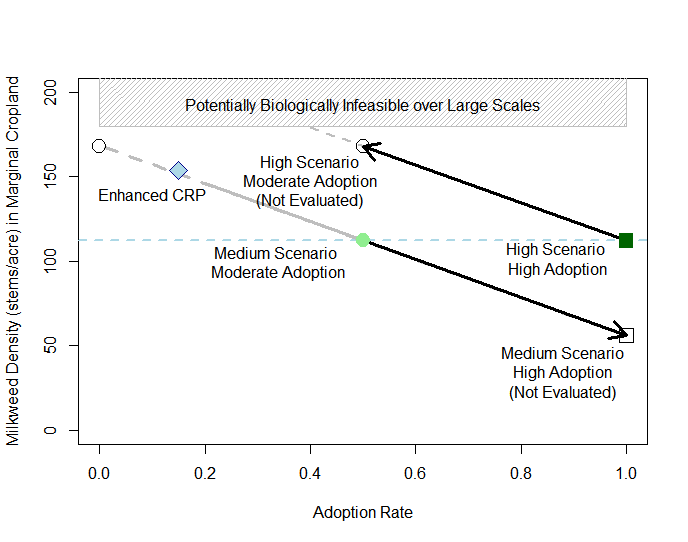
1 Other crops and orchards were differentiated into low, medium, and high categories by their amenability to support milkweed.

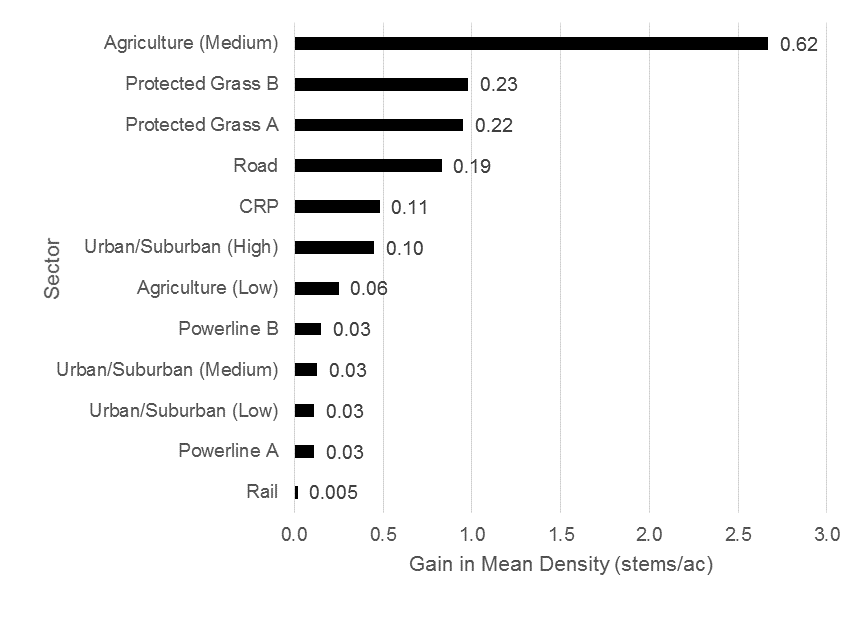
**Table 2**. Potential actions to increase milkweed and the nectar resources monarchs need. The current level of abundance of milkweeds in each sector is the product of two factors: availability of propagules in the regional species pool, and management regime. Increasing the abundance in any sector may require addition of plants, but will likely also require adjusting the disturbance regime (i.e. periodic management practices) for these new populations to persist. Adding seeds or plants to the sector may be a one-time-only event, but management practices will likely need to be adjusted in perpetuity.

|  |  |
| --- | --- |
| Sector | Possible Actions |
| Protected Area Grasslands | Cease use of neonicotinoid and other pesticides |
|  | Cease use of genetically modified cropping practices on refuge and wildlife areas |
|  | Pollinator-friendly mowing, haying, grazing and burning practices |
|  | Planting of source-identified and locally adapted seeds of milkweed and flowering nectar plants |
| Conservation Reserve Program | Including source-identified and locally adapted milkweed seeds in seed mixes used in initial plantings |
|  | Supplementing mid-cycle plantings with source-identified and locally adapted seeds of milkweed and flowering nectar plants |
|  |  |
| Urban/Suburban | Planting of source-identified and locally adapted seeds and nursery stock of milkweed and flowering nectar plants in homeowner yards |
|  | Conversion of homeowner lawns and corporate and city parks to prairie patches |
|  | Rewilding of urban spaces |
| Rights of Way | Pollinator-friendly mowing practices, especially on the backslope of roadside ditches and within powerline corridors |
|  | Planting of source-identified and locally adapted seeds of milkweed and flowering nectar plants in interchanges, medians, and powerline corridors |
| Agriculture | Expansion of organic farming |
|  | Cessation of the planting of genetically modified corn and soybean |
|  | Pollinator-friendly mowing, haying, grazing and burning practices |
|  | Retention of fencerows/hedgerows, or inclusion of patches in field design |
|  | Planting of source-identified and locally adapted seeds of milkweed and flowering nectar plants in edge-of-field practices to aid nutrient reduction |
|  | Expanded use of riparian buffer and prairie filter strips, or retention/restoration of vernal wetland as natural habitat |
|  | Conversion to Conservation Reserve Program-type cover |
|  | Fallowing of marginal cropland |

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