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LETTER

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Supplementary material for this article is available online

Abstract

The eastern migratory population of monarch butterflies (*Danaus plexippus plexippus*) has declined by >80% within the last two decades. One possible cause of this decline is the loss of ≥1.3 billion stems of milkweed (*Asclepias* spp.), which monarchs require for reproduction. In an effort to restore monarchs to a population goal established by the US Fish and Wildlife Service and adopted by Mexico, Canada, and the US, we developed scenarios for amending the Midwestern US 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 US 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.

Introduction

Global populations of many invertebrates are in decline [1]; lepidopterans, for instance, have declined by 40% over the past 40 years [2]. The eastern migratory population of monarch butterflies (*Danaus plexippus plexippus*), a species which breeds in the US and Canada but migrates to central Mexico to overwinter, decreased by 84% between the winters of 1996–1997 and 2014–2015 [3]. The population was at its lowest level ever recorded in winter 2013–2014 [4]. In August 2014, a coalition of nongovernmental organizations and citizens petitioned the US Fish and Wildlife Service (USFWS) to list the monarch butterfly as a threatened species [5], and in December 2014 the USFWS initiated a review of the status of the species [6] 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 c v-01008 E GS).

One potential cause of the decline identified in the petition for listing is loss of milkweed (*Asclepias* species). *Asclepias* species are the sole host plant for monarchs [7], with common milkweed (*A. syriaca*) being used by >90% of monarchs in the summer breeding range within eastern North America [8]. For much of the twentieth century, a large majority of monarchs produced in the eastern US likely originated from milkweed growing in agricultural fields [9]. However, since the introduction of herbicide-tolerant corn and soybeans, milkweed has largely disappeared from these fields [10–13]. More than 861 million milkweed stems have disappeared in the Midwestern US since 1999 [13]. Approximately 98% of this loss of milkweed is attributed to loss of milkweed in corn and soy (850.3 million stem; SE = 194.2 million stems) [13]. Because a milkweed stem in corn and soy agricultural fields averages 3.9 times more monarch eggs than a milkweed stem in non-agricultural habitat [14], the effect on the potential size of the monarch population of losing milkweed from corn and soy is compounded.

A strong relationship between the amount of milkweed in the Midwestern US and forest area occupied by overwintering monarchs in Mexico has been proposed [12, 13, 15], suggesting that milkweed loss in the Midwestern US was a principal driver of the observed population decline; thus, it is not surprising that recent demographic analyses have indicated reintroducing milkweed into landscapes in the Midwestern US, relative to other areas of the northern breeding range, would be important for recovery of the population [9,16]. Despite this evidence, however, whether the species is indeed declining and the extent to which milkweed loss is contributing to this decline are controversial [17–25]. Alternative hypotheses for the decline include degradation of overwintering habitat [18], processes affecting migration success [19, 20, 22], pesticide use, and increasing incidence of disease in adult monarchs. Nevertheless, in response to the small population size and decline as measured in Mexico, on 20 June 2014, the Obama administration issued a presidential memorandum calling for the restoration of pollinator and monarch habitat, including the planting of milkweed [26]. Subsequently, while the petition for listing as threatened is under consideration, the USFWS announced a short-term goal of restoring by 2020 sufficient habitat in the US to support a monarch population occupying 6 ha of overwintering habitat in Mexico [26]. This 6 ha indicator was subsequently adopted by Canada and Mexico as a tri-national goal for this species [27].

A 6 ha population size mitigates risk of extinction [3]. Unclear, however, is the identity of Midwestern habitats where milkweed should be restored to return this population to a 6 ha level of abundance. A number of different land-use types have been proposed for monarch habitat restoration, including governmentally protected grasslands, rights of way along roadsides, powerline 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 [13, 28–31].

The current amount of milkweed in the northern US (~1.3 billion stems) is sufficient, in a year with

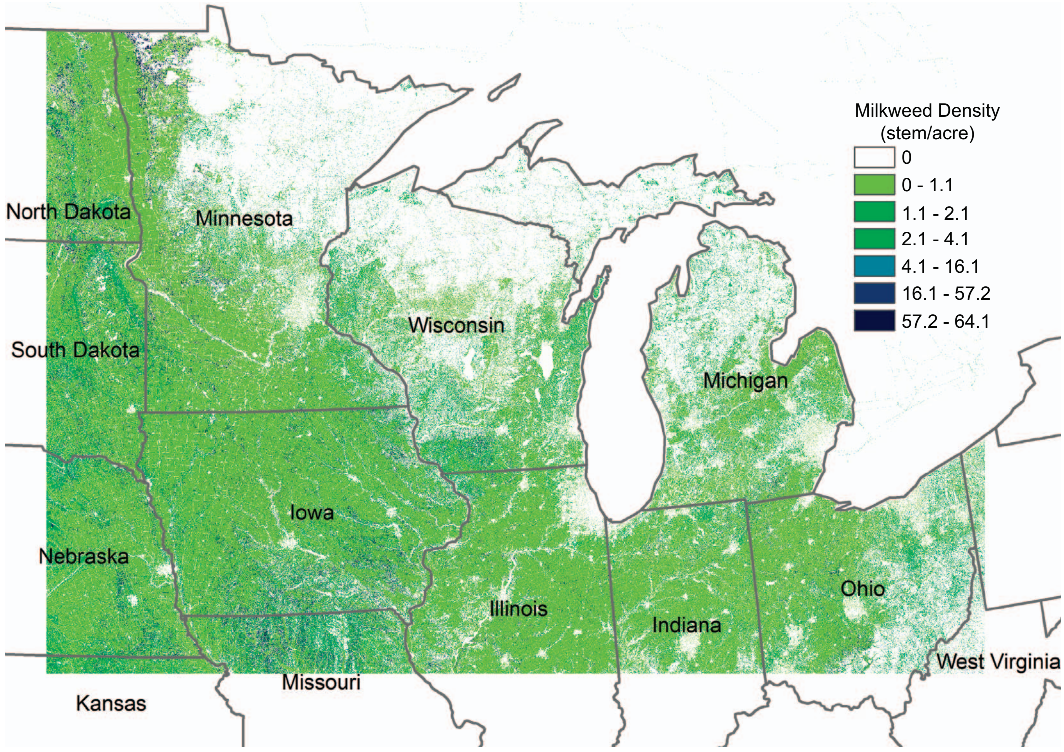

Figure 1. Map of current predicted density of milkweed across the Midwestern United States (see figure S2.3 for pre-glyphosate depiction).

average weather conditions, to support an overwintering population occupying 3.2 ha of habitat in Mexico [13]. Thus, a near doubling of average abundance (i.e. 6 ha overwintering goal) would require roughly a doubling of the number of stems; Pleasants [13] calculated this number as 1.6 billion additional stems needed in the Midwest. Therefore, we assume 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 a urban/suburban sector. 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 km^2), encompassing the area north of ~39°N and between ~98°W and ~80°W (figure 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 [32] (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 area in the 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 US pertinent to the mapping of milkweed habitat (supplement S1 available at stacks.iop.org/ERL/12/074005/mmedia). Additional sources of information included 2014 CRP enrollment locations; railroad, power line, and road rights of way; marginal versus productive farmland as

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 US 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).

Agriculture	Corn and Soy	Corn and Soy (Marginal)	Other Crops/ Orchard (Low)[a]	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
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	**Transmisstion 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	

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

determined by the 2012 National Commodity Cropland Productivity Index; and a characterization of exurban versus urban environs (supplement 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 [10,11] (supplement S2). We assigned these empirical density estimates to cover classes in our map of land cover (table 1). The most important empirical assessment of milkweed stem density in the Midwest region of the US was conducted by Hartzler and Buhler [10] and Hartzler [11]. 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. We converted m^2 per hectare into stems per hectare with a conversion factor of 1.95 stems m^{-2} [13,16].

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

Using geospatial tools developed for this analysis [33], 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 split the 22 authors of this study into two independent panels, from which we elicited 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 (supplement S5).

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

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 landowners and their willingness to implement milkweed amendment 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's contributions were identified, we examined every 2-, 3-, 4-, and 5-sector combinations, 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. Sensitivity of overall milkweed gains to cover-specific gains was indicated by its standardized regression coefficient [34], calculated from the best fit of a multiple linear regression model, $\mu = \delta + \delta_1 x_1 + \ldots + \delta_{30} x_{30}$, 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 four scenarios provided >1.4 billion new milkweed stems (figure 2, supplement S5). Conversion of all marginal cropland in corn and soy agriculture (i.e. 50 329 km^2, table S4.2) to cover practices equal in

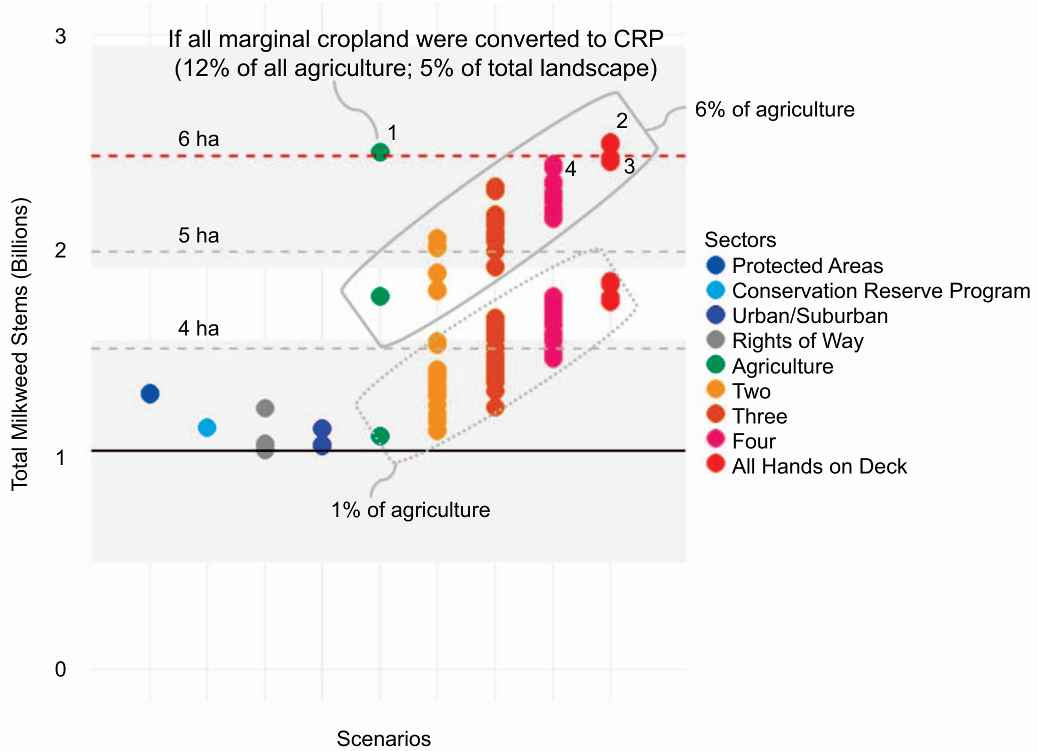

Figure 2. Individual and combined scenarios (circles) contributing number of milkweed stems in the Midwestern US and the overwinter population size supported. The current or baseline amount of milkweed is denoted by the black line (1.034 billion stems). Milkweed stems needed to maintain 4-, 5-, and 6-ha average overwintering monarch butterfly population sizes are denoted by dashed lines. Scenarios closest to the 6 h a 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 (2017)[22 23 24 25].

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 three 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 (figure 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.

[22] Agricultural contribution of all marginal cropland in corn and soy production; 50 329 km^2.
[23] 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.
[24] This scenario differs from 2 only in the assumptions relating to the contribution of powerline rights of way.
[25] 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.

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 (figure 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 km^2 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

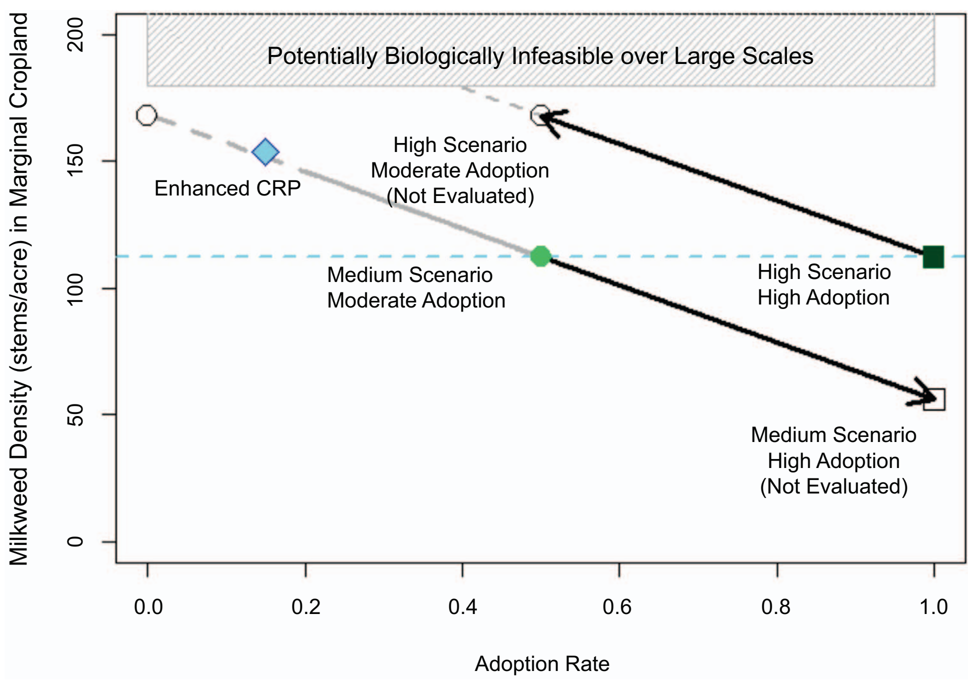

Figure 3. As adoption rate increases, the expected density of milkweed needed to reach the 6-ha goal declines. Converting half of marginal cropland (light green circle) to a milkweed density equal to that found in Conservation Reserve Program (CRP) land (125 stems/acre, dashed blue line) is equivalent 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).

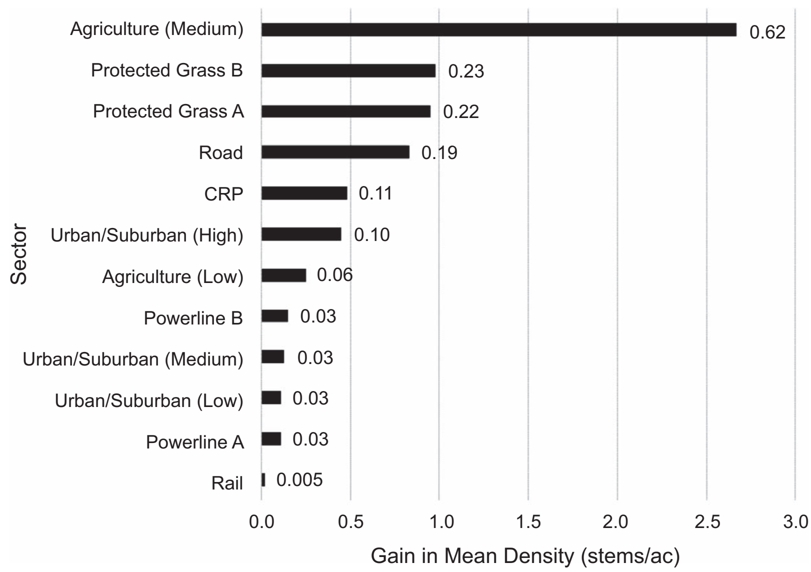

Figure 4. Gain in mean density (stems/ac) of milkweed relative to the baseline condition for individual sectors. Bar labels are the proportional increase in milkweed provided by the sector relative to the baseline (e.g. the medium agriculture scenario increases the amount of milkweed by an additional 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.

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 ($t \approx 4.8$, $p < 0.0001$).

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. 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 km^2 in corn and soy, 29 397 km^2 in other cropping practices), followed far behind by land in urban and suburban areas (45 313 km^2), lands along rights of way (43 148 km^2), lands enrolled in CRP (15 535 km^2), and protected grassland areas of mixed herbaceous perennial vegetation (8804 km^2). 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 [13], 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.* [35] described mean and variation in milkweed density along Upper Midwestern US 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, US 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 [36–38]. Given the footprint of agriculture in the Midwestern US, understanding the socioeconomic constraints to the adoption of conservation practices in this sector seems clear.

Various sectors of society are responding to the former US President's call for action in support of monarchs and other pollinators. In cities and towns, for instance, programs such as Milkweeds for Monarchs [29], Monarch Waystation [39], Million Pollinator Garden Challenge [28], and the Mayor's Monarch Pledge [31] are underway. The Rights of Way as Habitat Working Group [30] 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 [40].

Governments have been quick to act in support of monarch habitat management and restoration. In the year following release of President Obama's Pollinator Health Strategy [26], 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 [41], creating or restoring nearly 113,000 hectares on USFWS and private lands [42], and distributing pollinator guidance for grassland management activities [43].

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 [44, 45], 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 [46, 47].

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 [48, 49]. These benefits can provide economic value to farmers on-site, as well as to municipal water providers and fisheries downstream [50, 51].

Federal policies such as the Ethanol Fuel Standards (Renewable Fuel Standard) [52], crop insurance [53, 54], and waning Farm Bill support for CRP [55] 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 [56] 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 [57]. These market-based solutions for financing conservation offer a potential mechanism for offsetting on-going declines and, ideally, restoring new habitat [56].

Conclusion

Restoring >1.3 billion stems of milkweed to the Midwestern US 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 both strong agricultural production and robust populations of the iconic migratory monarch butterfly.

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