MONARCHS IN PERIL

HERBICIDE-RESISTANT CROPS AND THE DECLINE OF MONARCH BUTTERFLIES IN NORTH AMERICA

CENTER FOR
FOOD SAFETY

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CENTER FOR FOOD SAFETY (CFS) is a non-profit public interest and environmental advocacy membership organization established in 1997 for the purpose of challenging harmful food production technologies and promoting sustainable alternatives. CFS combines multiple tools and strategies in pursuing its goals, including litigation and legal petitions for rulemaking, legal support for various sustainable agriculture and food safety constituencies, as well as public education, grassroots organizing and media outreach.

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THE MONARCH CRISIS

Monarch female nectaring on common milkweed, photo © Jeffrey E. Belth

The monarch butterfly is North America's best-known and most-loved insect, but its continued existence is threatened. Monarch numbers have plummeted with the destruction of milkweeds, its caterpillar's sole food source, by the herbicide used on genetically engineered crops. Without strong action to restore milkweed to Midwest crop fields, the spectacular migration of the monarch butterfly may be relegated to biological history.

"Aside from a possible sighting of monarchs migrating in eastern Mexico during one of Christopher Columbus's expeditions, D'Urban (1857) was apparently the first to report a migration of monarch butterflies. He described the butterflies appearing in the Mississippi Valley in 'such vast numbers as to darken the air by the clouds of them'. During September 1867 in southwestern Iowa, Allen described monarchs gathered in several groves of trees bordering the prairie 'in such vast numbers, on the lee sides of trees, and particularly on the lower branches, as almost to hide the foliage, and give to the trees their own peculiar color'". (Brower 1995, internal citations omitted)

"This year, for or the first time in memory, the monarch butterflies didn't come, at least not on the Day of the Dead [November 1st]. They began to straggle in a week later than usual, in record-low numbers. … Some experts fear that the spectacular migration could be near collapse." (Robbins 2013)

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THE MONARCH BUTTERFLY IS IN TROUBLE. Monarch numbers have plummeted over the past two decades. The butterfly's decline tracks the virtual eradication of common milkweed—its caterpillar's chief food source—from Midwestern cropland. The demise of milkweed is due to intensive spraying of glyphosate herbicide on Roundup Ready corn and soybeans that have been genetically engineered to withstand it. Without restoration of milkweed to Midwestern crop fields, the monarch's days in the heart of its range are numbered.

Few are unfamiliar with the striking orange and black monarch butterfly, renowned for its spectacular migration. From late summer through autumn, millions of monarchs from east of the Rocky Mountains stream south, flying over a thousand miles to converge, incredibly, on a few acres of forest in central Mexico. Monarchs that survive the perils of winter in Mexico begin flying north in the early spring. Whereas the journey south is made by a single generation, their return north spans several. The monarchs that overwintered in Mexico reach the southern U.S. in spring, where they breed. Their descendants continue north, after several generations fanning out to populate the Midwest and eastern U.S., progressing as far north as Canada. They then begin the migratory cycle anew in late summer.

The monarch population of 2013/2014 was by far the smallest ever recorded, capping a precipitous two-decade decline. Monarch numbers fell to just 10% of their average over the past 20 years. Entomologists fear that the spectacular migration of these iconic butterflies is coming to an abrupt end.

Although there are many factors at play, a critical driver of monarch decline is loss of larval host plants in their main breeding habitat, the Midwestern Corn Belt. Monarchs lay eggs exclusively on plants in the milkweed family, the only food their larvae will eat. Monarch caterpillars grow big consuming milkweed leaves, molting several times, and then form beautiful lime-green pupae suspended from leaves or stems. In as little as ten days, the metamorphosis from chrysalis to adult is complete, and the new butterflies emerge. However, milkweed has been largely eradicated from corn and soybean fields where it used to be common, depriving monarchs of the plant they require for food and reproduction.

Farming *per se* is not the problem. Monarch butterflies have coexisted with agriculture ever since the prairies and forests of the Midwest were converted to cropland in the late 1800s, thriving despite dramatic changes in farming practices over the 20th century. Monarchs have been able to thrive in a landscape dominated by agriculture because just one of the 130 or so North American milkweed species—*Asclepias syriaca*, or common milkweed—is remarkably well-adapted for life on disturbed ground, such as plowed fields, cleared woodlands, and roadsides. This one species has thus been able to largely replace the other kinds of milkweeds that hosted monarchs before prairies were plowed under and forests cut down.

How was common milkweed able to survive in 20th century agriculture? The short answer is tough, regenerative roots. Common milkweed is a perennial plant with a deep, extensive root system. The aboveground shoots die back in the winter, but re-sprout from buds on roots in the spring. Milkweed similarly regrows when the plants are mowed or treated with most herbicides, since the roots remain largely unaffected. Even when tillage dismembers roots, the larger sections can regenerate new plants. Thus, throughout the 20th century, common milkweed within and around corn and soybean fields has supported a large population of monarch butterflies. In fact, in the late 1990s roughly half of the monarchs in Mexican winter roosts had developed on common milkweed plants in the Corn Belt, making this far and away the most important habitat for maintaining the monarch population as a whole.

Recently, though, a dramatic change in farming practices—the widespread cultivation of genetically engineered, glyphosate-resistant Roundup Ready corn and soybeans—has triggered a precipitous decline of common milkweed, and thus of monarchs. Glyphosate, sold by Monsanto under the name of Roundup, is one of the very few herbicides that is effective on milkweed. Unlike many other weedkillers, once absorbed it is translocated (moved internally) to root tissue, where it kills milkweed at the root and so prevents regeneration.

Glyphosate is particularly lethal to milkweed when used in conjunction with Roundup Ready crops. It is applied more frequently, at higher rates, and later in the season—during milkweed's most vulnerable flowering stage of growth—than when used with traditional crops. The increasingly common practice of growing Roundup Ready crops continuously on the same fields means that milkweed is exposed to glyphosate every year, with no opportunity to recover.

Thus, it is not surprising that milkweed has declined dramatically. Two comprehensive surveys in Iowa—in 1999 and 2009—demonstrate this clearly. In 1999, common milkweed was found in half of corn and soybean fields, but only 8% of them a decade later. Where milkweed was found, it was nearly five times less abundant. It is estimated that just 1% of the common milkweed present in corn and soybean fields in 1999 remained by 2013. Milkweed surveys in Minnesota reveal a similar picture, as do reports of milkweed loss in Kansas, Nebraska, and other Midwestern states where Roundup Ready crops are intensively grown.

Numbers tell the story of the dramatically increasing range and intensity of glyphosate use responsible for milkweed loss. Between 1995, the year before the first Roundup Ready crop was introduced, and 2013, the following changes have occurred:

1. **Area treated expanding:** Nine-fold increase in combined corn and soybean acreage treated with glyphosate, from 17 to 157 million acres;
2. **Application rate rising:** Average glyphosate application rate increased by 58% on soybeans (0.60 to 0.95 lbs/acre) and 43% on corn (0.61 to 0.87 lbs/acre);
3. **More frequent applications:** Average number of glyphosate applications per year increased by 64% on soybeans (1.0 to 1.64) and 16% on corn (1.1 to 1.27);
4. **Total use:** Total glyphosate use on corn and soybeans rose 20-fold, from 10 million to 205 million lbs/year.

The expanding acreage treated with glyphosate reflects the massive adoption of Roundup Ready crops, which in 2013 comprised roughly 90% of soybeans and over 80% of all corn grown in the U.S. The rising intensity of glyphosate use (application rate times frequency) reflects farmers' response to the epidemic emergence of glyphosate-resistant weeds. There has also been a dramatic rise in acres treated every year with glyphosate, as farmers who once grew Roundup Ready soybeans in rotation with conventional corn have now transitioned to Roundup Ready corn as well. Finally, glyphosate is applied to Roundup Ready crops two weeks to a month or more later in the season than when used with traditional crops, a period when milkweed is in its most glyphosate-sensitive reproductive phases. Is it any wonder that common milkweed in corn and soybean fields has been unable to survive the Roundup Ready "revolution"?

Milkweed does grow outside of cropland, but there is too little habitat to support a viable monarch population, for two reasons. First, corn and soybeans dominate the Midwest landscape, leaving too little area in roadsides, pastures, and other land where milkweed grows. Second, monarchs produce almost four times more progeny per plant on milkweed in corn and soybean fields than on milkweed growing elsewhere. Thus, milkweed in these marginal areas cannot begin to compensate for habitat lost to glyphosate use on Roundup Ready crops.

In fact, milkweed is declining across the landscape. Data collected in several Midwest states show that milkweed density on retired farmland and pastures has declined by half from 1999 to 2013. In addition, more and more of this land is being converted to agriculture, which in most cases means Roundup Ready crops. This conversion of grasslands, retired farmland and pasture to crops, especially corn, is driven by federal subsidies and quotas for production of biofuels. As a result, what little monarch breeding habitat exists outside of cropland is shrinking. All told, in 2012 the Midwest produced 88% fewer monarchs than it did in 1999.

Can it get worse for milkweed? Unfortunately, yes. Pesticide companies are poised to introduce a host of "next-generation" GE crops resistant to both glyphosate and one or more other herbicides as well. These crops are being hyped as a "fix" to glyphosate-resistant weeds generated by Roundup Ready crop systems, but they will rapidly foster still more intractable weeds resistant to multiple herbicides. For instance, Dow AgroSciences has developed corn, soybeans and cotton resistant to 2,4-D; and Monsanto has soybeans and cotton resistant to dicamba. USDA recently approved Dow's 2,4-D corn and soybeans, which it projects will drive an astounding 200% to 600% increase in agricultural use of 2,4-D, while glyphosate will continue to be applied at current high rates. Monsanto's crops would have a similar effect on dicamba use.

2,4-D and dicamba cause considerable damage to milkweed, and in combination with glyphosate are about as toxic to milkweed as glyphosate alone. Because glyphosate will often be used together with 2,4-D or dicamba on crops resistant to them, remnant milkweed will continue to be eradicated from crop fields at undiminished rates, and will have no chance to reestablish, either.

These next-generation GE crops may also harm monarch adults. 2,4-D and dicamba are especially prone to drift—they move beyond the fields to which they are applied as spray droplets and vapor. Unlike caterpillars, which feed on milkweed leaves, adult butterflies require abundant nectar to sustain themselves during breeding and especially their strenuous migratory journey. Nectar plants will dwindle as herbicides used on resistant crops drift into areas where wildflowers abound. Herbicide use on crops has been connected with fewer and different kinds of flowering plants in hedges, along field edges, and within fields themselves in agricultural areas. Flowers may also bloom later and over a shorter span of time where weedkillers are routinely sprayed. Because herbicides are used more frequently, at higher rates, and later in the season with resistant crops, they will be even more likely to harm sensitive nectar plants. The resulting reduction in nectar resources may lead to poorly nourished monarchs that lay fewer eggs, or do not survive migration and overwintering.

This panoply of threats—milkweed eradication in herbicide-resistant crop fields, conversion of non-agricultural habitat to cropland, and commercialization of new herbicide-resistant crops—imperil the very existence of monarch butterflies in North America. As their population declines, other threats have greater impacts, and the butterflies are less likely to bounce back from adversity. Climate change exacerbates these threats by increasing the frequency of damaging weather extremes.

Monarchs are particularly vulnerable during winter roosting, when almost the entire population is concentrated in a few acres of unique forest habitat in the mountains of Central Mexico. Winter storms in this area have reduced overwintering populations by up to 75% in the past, and are expected to occur more frequently with climate change. Other threats include predation, illegal logging and habitat disruption by tourism.

The monarch's predicament is so dire that urgent action is required. To initiate much-needed action by the federal government, Center for Food Safety and Center for Biological Diversity, joined by the Xerces Society and renowned monarch scientist Dr. Lincoln Brower, filed a legal petition with the U.S. Fish and Wildlife Service to protect monarchs as threatened under the Endangered Species Act (ESA). In December 2014, the Service responded to this petition and announced that ESA listing may be warranted, an important first step towards securing stronger protections for monarch butterflies.

In order for monarchs to rebound, agriculture and common milkweed must coexist, as they did in the past. Too much land in prime monarch breeding territory is planted to corn and soybeans to write it off as habitat. And non-agricultural milkweed habitat is itself shrinking from conversion to Roundup Ready crops, and will be threatened by herbicide drift injury if new herbicide-resistant crops are approved and adopted.

In this report, we draw upon the work of milkweed and monarch biologists, weed scientists and other researchers to provide a detailed analysis of how herbicide use triggered by genetically engineered, herbicide-resistant crops has been a major driver in the dramatic decline of milkweeds and monarchs. Our immediate goal is to inform policies that reconcile agriculture and monarchs in the heart of North America.

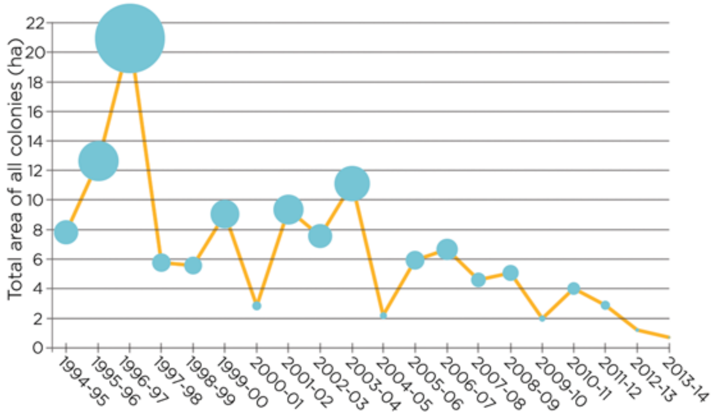
However, the same pernicious agricultural practices that threaten monarchs also imperil many other species, including our own. Modern industrial agriculture is a major contributor to both the ongoing extinction crisis and climate change. It is our hope that efforts to address monarch decline also serve the larger goal of transforming our food production system into one that is compatible with the well-being of future generations—of humans and other species as well.

1. INTRODUCTION: MONARCHS IN PERIL

Throughout North America, people know and love the orange and black monarch butterfly, long celebrated for its beauty. Countless children have learned the marvel of metamorphosis by watching a monarch emerge from its lime-green, gold-studded chrysalis. And perhaps nothing engenders respect for nature more than the monarch's amazing annual migration. That a creature so fragile could journey across half a continent in just a month or two is already cause for wonder. That monarchs scattered across a vast swath of the U.S. and southern Canada east of the Rocky Mountains could so precisely direct their millions of separate flights as to converge on just a few acres of Mexican forest is awe-inspiring. These monarchs overwinter in Mexico, then begin flying north in the early spring. Whereas the trip south is accomplished by one generation, the journey north is a multigenerational odyssey. The overwintering monarchs reach the southern U.S. in the spring, where they breed. Succeeding generations push on, some progressing as far north as Canada, before they begin the migratory cycle anew in late summer. The Midwestern Corn Belt states are their primary summer breeding ground.

In the winter of 2013-14, the monarch population east of the Rockies was by far the smallest ever recorded, capping a precipitous two-decade decline. Counts showed monarch numbers at just 10% of the 20-year average, in line with the overall trend of decline (Figure 1, discussed in Section 4). Entomologists fear that the spectacular migration of these iconic butterflies is coming to an abrupt end.

Figure 1. Area of monarch overwintering habitat in Mexico: 1994-95 to 2013-2014.



20-year average is 6.4 ha. Adapted and extended from Brower et al. (2011). See Section 4 for details.

A major factor driving this sharp decline is the loss of larval host plants in the monarch's main breeding habitat, the Midwestern Corn Belt. Monarchs rely completely on plants in the milkweed family for both reproduction and larval food. Female monarchs lay eggs on milkweed, and their caterpillars grow big consuming milkweed leaves. After several molts, the larvae form pupae suspended from leaves or stems. In as little as ten days the metamorphosis is complete, and new butterflies emerge from their chrysalises.

However, milkweed has been largely eradicated from Midwestern corn and soybean fields where it used to be common, depriving monarchs of the plant they require for food and reproduction, due to massive use of the herbicide glyphosate on genetically engineered soybeans and corn.

Urgent action is required to stop further monarch decline and restore populations to viable levels. For this reason, Center for Food Safety and Center for Biological Diversity, joined by the Xerces Society for Invertebrate Conservation and renowned monarch scientist Dr. Lincoln Brower, have petitioned the U.S. Fish and Wildlife Service to protect migratory monarchs (*Danaus plexippus plexippus*) as threatened under the Endangered Species Act (Monarch ESA Petition 2014).

In this report, we first discuss common milkweed's distribution and prevalence in Midwestern crop fields of the 20th century, the factors responsible for its past success as an agricultural weed, and its near elimination from corn and soybean fields in the 21st century. In Section 3, we describe how glyphosate was unleashed by the rise of Roundup Ready crops to become a potent killer of milkweed. In Section 4, we show that milkweed loss in the monarch's Midwest breeding grounds is a major factor driving a 20-year decline in the monarch population, and explain why common milkweed in non-agricultural habitats is insufficient to save the monarch as a migratory species. The final section addresses the further threat to milkweeds and monarchs posed by the new generation of herbicide-resistant crops. We conclude with policy recommendations that, if implemented, could halt and reverse the trend of monarch decline.

2. THE DECLINE OF COMMON MILKWEED IN CROPLAND

2.1 COMMON MILKWEED PREVALENT IN 20TH CENTURY MIDWEST CROP FIELDS

MONARCH SURVIVAL DEPENDS CRITICALLY on the abundance of its primary host plant, common milkweed, in its Midwest breeding grounds. Common milkweed (*Asclepias syriaca* L.) is found from southern Canada to Virginia in the east, throughout the Midwest, and west to Kansas and the Dakotas (Woods et al. 2012, Woodson 1954). More recently, it has begun to colonize southern states such as Georgia, the Carolinas and Louisiana (Wyatt et al. 1993, Wyatt 1996). Common milkweed inhabits places that have experienced soil disturbance, such as some cultivated fields, abandoned or fallowed cropland, pastures, logged-over land, riparian zones, suburban and urban vacant lots and waste areas, and along trails, railroad tracks, and roadways. It is also sometimes intentionally planted in gardens.

Common milkweed has long inhabited cropland in the Midwest breeding grounds of the monarch. Although widely distributed, it has for the most part not been regarded by farmers as a problematic weed (Hartzler 2010; Doll 2001), which explains the relatively little attention it has received from weed scientists. Below we discuss the limited available information on common milkweed distribution and abundance.

In the 1940s, a survey was carried out in northern Michigan where milkweed was known to be particularly prevalent (Timmons 1946). The author found that "the rather delicate seedlings" become established best in disturbed habitats, for instance "during the transition period between cultivated crop and grassland," or in regularly cultivated fields that are not subject to intensive tillage. Timmons further reported that established milkweed stands tended to become thicker in cropland under ordinary cultivation practices, and to become thinner in unmowed grassland. Milkweed fared most poorly in "grass or legume hay meadows" such as alfalfa, which are subject to regular mowing. Timmons found that milkweed occupied 10% of the cropland of one carefully surveyed county, at an average density of 10,956 stems/acre.

In eastern and south central Nebraska, common milkweed became more prevalent in crop fields in the 1970s (Martin and Burnside 1977/84, Cramer and Burnside 1982). In a 1976-1979 survey, milkweed was found more frequently in fields of row crops like soybeans (73% of fields), sorghum (70%) and corn (36%) than in wheat (28%) or alfalfa (6%). In the parts of those fields where milkweed was present, densities ranged from 11,100 to 45,200 plants/hectare (4,500 to 18,300 plants/acre), which is comparable to the densities found in northern Michigan in the 1940s. Roughly 5 million acres harbored milkweed in Nebraska in the 1970s (Cramer and Burnside 1982).

In 1980, common milkweed was found in "at least 26 million acres in the 13 north central states" (Cramer and Burnside 1980). The two crops harboring the most milkweed were corn (12 million acres) and soybeans (6 million acres), although given the common practice of rotating these two crops the difference in reported acreage may not be very significant. Milkweed was also found to a much lesser extent in small grains, pastures, roadsides and sorghum (Bhowmik 1994). Iowa had the most land with milkweed, followed by Nebraska and Wisconsin (Cramer and Burnside 1980).

Common milkweed continued to be a common inhabitant of Midwestern cropland throughout the 1980s and 1990s, for instance in Iowa (Hartzler and Buhler 2000), Minnesota and Wisconsin (Oberhauser et al. 2001), and southwestern Ontario (Frick et al. 1990). Milkweed was even expanding into the late 1990s in parts of North Dakota (Zollinger 1998), Wisconsin (Doll 1998) and perhaps other states.

2.2 COMMON MILKWEED ONCE WELL-ADAPTED TO AGRICULTURE

COMMON MILKWEED'S SUCCESS in corn and soybean fields of the 20th century is attributable in large part to biological features of the plant that allowed it to survive under commonly used weed control practices of the period.

2.2.1 REPRODUCTIVE PROWESS

Most weeds are annual plants that are completely killed during the winter and reproduce exclusively from seed left in the soil during previous years. As a deciduous perennial plant, milkweed has a distinct advantage. Only its aboveground parts are killed in winter, leaving a reproductive root system intact. In the spring, buds sprout from the base of the stem and along lateral roots near the soil surface. These buds grow into new shoots two to six feet in height during the summer.

Milkweed's root system can be extensive. A top layer of lateral roots extends 4-8" below the soil surface; one or more additional root layers may be found at depth intervals of 6-12" below the roots above. Taproots descend from the lateral roots at intervals of several feet (Timmons 1946). Roots typically penetrate 3-4 feet below the soil surface (Bhowmik 1994). Because of its ability to vegetatively reproduce from lateral roots, milkweed is often found in patches, with groups of genetically identical shoots (ramets) growing from a common root system. Under favorable conditions, milkweed patches can occupy an area of from 10 to 50 feet in diameter (Timmons 1946). However, it is more common to find smaller patches and single-stem plants in cropland (Pleasants and Oberhauser

2012). For instance, average milkweed patch size in Iowa corn and soybean fields was just 3.3 square meters in 1999 (Hartzler and Buhler 2000, Table 1).

Removal of stems, as by mowing, foraging or herbicide use, stimulates buds on roots to sprout new shoots. Shoots can arise from lateral roots lying up to 3 ½ feet below the soil surface, though typically they sprout from roots in the top foot of soil (Evetts and Burnside 1974). Root fragments resulting from tillage operations are also capable of generating new shoots, with larger root segments having greater viability than small ones. Seedlings develop roots capable of reproduction as early as three weeks after sprouting (Bhowmik 1994).

Milkweed also reproduces from seed. Milkweed plants form two to six seedpods (Wilbur 1976, Bhowmik and Bandeen 1976) that in the fall crack open to release seeds with silky floss that are carried on the wind. Pods typically contain 150-425 seeds each (Bhowmik and Bandeen 1976). Most wind-borne seeds land within 30 meters of the parent plant, but some float distances of over 150 meters (Morse and Schmitt 1985). Seeds can also be carried by runoff water or irrigation canals, and remain viable in the soil for up to three years (Martin and Burnside 1977/84).

These two modes of reproduction help account for milkweed's success as an agricultural weed in the 20th century. Production of wind-borne seeds gives milkweed the ability to spread to cropland from field edges, roadsides, waste areas and fallowed or abandoned fields, and is thought to be one reason for the plant's presence in 20th century agricultural fields (Bhowmik and Bandeen 1976, Doll 1998). Milkweed's reproductive root system facilitates its persistence, once established.

2.2.2 VARIABLE EFFECTS OF TILLAGE

Tillage has variable effects on milkweed, depending on its timing and intensity as well as the stage of milkweed growth. By clearing a field of weeds, tillage provides delicate milkweed seedlings a good opportunity to become established from seed. However, young seedlings are killed by a single tillage operation if it occurs before they have become established (Martin and Burnside 1977/84).

Once milkweed has developed a mature root system, tillage operations dismember the roots and spread root sections, with larger segments capable of generating new plants. On the other hand, frequent tillage operations reduce milkweed populations. The repeated disruption of milkweed growth from roots or root fragments, with aborted generation of new shoots accompanying each tillage event, saps the roots of the carbohydrate reserves required for further regeneration. In addition, deep tillage in the fall exposes milkweed roots to winterkill (Bhowmik 1994).

Some blamed the trend to lesser use of tillage for expansion of milkweed populations in certain areas from the 1970s to late 1990s (e.g., Zollinger 1998; Martin and Burnside 1977/84). While reduced tillage is known to favor many perennial weeds, there has been little research on this question with common milkweed (Bhowmik 1994). Buhler et al. (1994) followed perennial weed populations over 14 years in corn and soybeans under various tillage regimes. While reduced tillage fostered some perennials, tillage regime had no effect on common milkweed populations. Yenish et al. (1997) tracked the fate of milkweed seedlings in corn, soybeans and wheat with use of different cropping practices; averaged over crops, seedling density did not differ significantly in fields under conservation versus conventional[1] tillage from 70 to 115 days after emergence in three of four site years (*Ibid*, Fig. 4).

In short, tillage creates a favorable environment for establishment of milkweed from seed, but kills young seedlings with undeveloped roots. Ordinary use of tillage may spread mature milkweed, while more intensive (more frequent, deeper) tillage reduces populations.

2.2.3 HERBICIDES GENERALLY NOT EFFECTIVE

Like many perennials, common milkweed tolerates most herbicides, which generally kill the above-ground plant while leaving the reproductive root system intact to regenerate new plants.

In the 1970s and 1980s, weed scientists in Nebraska advised farmers that "the widely used herbicides of the day often do not harm milkweed, but remove annual weeds that would otherwise compete with it" (Martin and Burnside 1977/84). North Dakota agronomists agree that "[c]ommon milkweed appears tolerant to most all labeled herbicides currently registered" (Zollinger 1998). Iowa weed scientist Bob Hartzler concurs: "….common milkweed emerging from vegetative rootstocks is not significantly affected by pre-emergence herbicides[2] used in corn and soybean" (Hartzler 2010).

Controlled studies examining the effect of tillage regime and herbicide use on milkweed support these assessments. Buhler et al. (1994) found that small milkweed populations in corn and soybean fields were not reduced by annual use of common herbicides of the 1970s and 1980s, including atrazine, alachlor, cyanazine and metribuzin, over a 10-year period. A five-year study in which soybeans were grown every year in a conservation tillage system showed slightly increasing milkweed prevalence with annual use of the herbicides bentazon and imazethapyr, as well as one interrow cultivation and pre-emergence or post-harvest application of glyphosate each year (Colbach et al. 2000). Dicamba and 2,4-D exhibit variable effectiveness on milkweed, and are discussed further in Section 5.

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[1] Conservation tillage refers to a collection of practices, including no-till, that leave 30% or more or more of a field covered with crop residues and thereby reduce soil erosion. In this study, neither conventional nor conservation tillage involved cultivation for weeds after crop emergence.

[2] As discussed further below, "pre-emergence" means early-season application prior to "emergence" or sprouting of the crop seed. Pre-emergence herbicides are those used primarily or exclusively in this manner.

Pleasants (in press) closely observed common milkweed in Iowa corn and soybean fields before and after treatment with herbicides, classified as glyphosate or non-glyphosate. Leaves turned yellow within a few days of treatment, and fell off within a week, regardless of the herbicide used. With non-glyphosate herbicides, some plants did not recover, but many sprouted new branches from leaf axils and new stems from the root, and appeared to be fully recovered in 2-3 weeks. In contrast, with glyphosate treatment "most plants were killed and those that were not had little if any resprouting from leaf axils."

Seedlings are more susceptible to herbicides than mature plants. Martin and Burnside (1977/84) report that milkweed seedlings are killed by pre-emergence use of atrazine or metribuzin,[3] but that neither atrazine nor 2,4-D gives satisfactory control when applied post-emergence. A two-year study of common milkweed prevalence in corn, soybeans and wheat found that milkweed seedlings were little affected by cyanazine (corn), diclofop (wheat), or imazethapyr (soybeans), although alachlor (corn and soybeans) and bromoxynil (wheat) were found to have limited effectiveness (Yenish et al. 1997).

Although most herbicides are not very effective at killing milkweed, the defoliation they cause prevents development of monarch eggs laid prior to treatment. Pleasants (in press) showed that just 1.9% of eggs present before herbicide spraying subsequently developed into larvae, versus 17.4% in a control group without herbicide treatment.

2.2.4 OTHER FACTORS

In drier areas such as North Dakota, common milkweed populations tend to expand in wetter and decline during drier periods. Plant scientist Rodney Lym reports that expanding milkweed populations in parts of North Dakota in the mid to late 1990s were attributable to wetter than normal conditions (NDSU 1999).

In the 20th century, row crops (e.g., corn, soybeans) were generally more favorable habitat for milkweed than small grains (e.g., wheat), forage or grasslands, for several reasons. Heavy use of milkweed-ineffective herbicides on corn and soybeans removes competing weed growth. Intensive fertilizer applications to corn, and irrigation in drier areas like eastern Nebraska and Kansas, also promote milkweed growth (Martin and Burnside 1977/84).

In contrast, crops and plants that grow more densely than corn and soybeans tend to suppress milkweed. For instance, farmers are urged to include winter wheat in their rotations as a milkweed control measure. Alfalfa competes strongly with milkweed, and virtually eliminates it over three years;

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[3] The authors use trade names: Aatrex = atrazine; both Sencor and Lexone have metribuzin as the active ingredient.

besides the competition effects, regular cutting depletes milkweed's root system, and hence its capacity to regenerate. Milkweed populations tend to decline in unmowed pastures as well (Martin and Burnside 1977/84; Timmons 1946).

2.2.5 PREVALENT BUT LOW-IMPACT WEED

Despite its wide distribution and ability to survive in row crops, common milkweed has rarely posed a threat to crop yields. An Iowa agronomist reports that: "Although common, [common milkweed] rarely reaches population densities that impact crop yield and typically does not drive weed management decisions" (Hartzler 2010). Wisconsin agronomist Jerry R. Doll surveyed perennial weeds in Wisconsin from 1977 to 1994, and found that "milkweeds were rated as only a slight problem in the majority of both tilled and no-till fields" and "[i]n my more than 20 years as an extension weed scientist, rarely has anyone described a situation where milkweeds were an economic problem and sought advice on how to control them. Travels around the state during this period confirm that milkweeds are commonly found but seldom reduce crop yields" (Doll 2001).

One good measure of a weed's importance is the attention it receives from weed scientists, whose research tends to focus on agriculturally damaging weeds. Table 1 shows that common milkweed has generated very little research interest in the weed science community relative to other weeds, indicative of its low impact.

SPECIES	COMMON NAME	CITATIONS	
		1950-1995	1996-2013
Asclepias syriaca	Common milkweed	7	7
Chenopodium album	Lambsquarters	55	205
Cyperus esculentus	Yellow nutsedge	67	159
Sorghum halepense	Johnsongrass	113	123
Abutilon theophrasti	Velvetleaf	124	243
Amaranthus palmeri	Palmer amaranth	12	148
Setaria glauca	Yellow foxtail	5	19

Table 1. Research interest in common milkweed versus more damaging weeds.
Results of Web of Science searches for the cited date ranges in the journals Weed Science, its predecessor Weeds, and Weed Technology on June 26, 2014. Topic: "*Asclepius syriaca*" – Publication: "Weed Science OR Weeds OR Weed Technology." Similar searches conducted for other named weeds.

2.3 THE DEMISE OF COMMON MILKWEED IN CROP FIELDS OF THE 21ST CENTURY

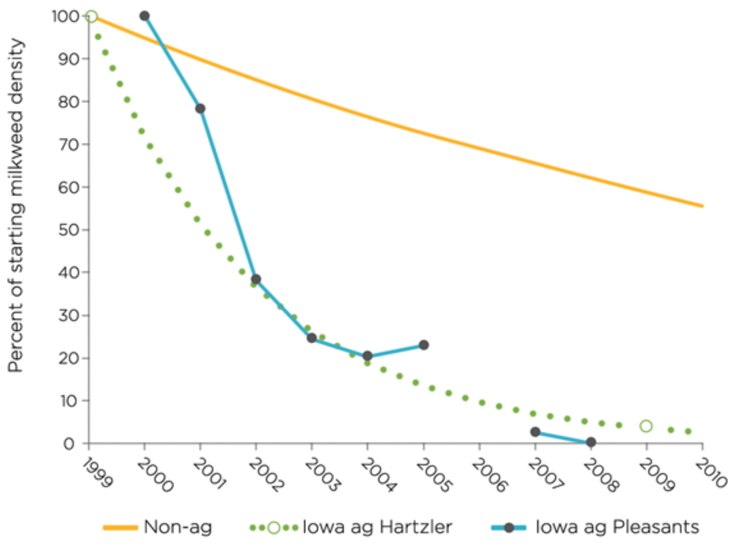
FROM A SUCCESSFUL INHABITANT of Midwestern crop fields throughout the 20th century, common milkweed populations have plummeted in the 21st, threatening the monarch's very survival. The best evidence comes from rigorous weed surveys conducted in Iowa and Minnesota, though similar land-use patterns in other states as well as anecdotal evidence make it clear that milkweed is disappearing from cropland throughout the Midwest.

2.3.1 MILKWEED DISAPPEARING FROM CROP FIELDS IN IOWA

Iowa is the state where common milkweed was once most abundant, occupying over five million acres in 1980 (see Section 2.1). In 1999 and again in 2009, Iowa State University scientists conducted comprehensive surveys that established the prevalence and distribution of common milkweed in both crop fields and non-agricultural land throughout the state (Hartzler and Buhler 2000, Hartzler 2010). Both surveys were conducted with the goal of determining whether genetically engineered crops were impacting milkweed populations. Both surveys utilized a similar, randomized site selection protocol to prevent sampling bias; and the surveys were conducted at the same time each year: June and July. Iowa State University plant scientist Bob Hartzler was involved in both surveys, helping to ensure that comparable methodologies were used. An adequate number of sites were surveyed in each year (859 in 1999, 432 in 2009) to achieve statewide representative samples. The results for milkweed prevalence in corn and soybean fields are discussed here, while milkweed in other habitats is discussed in Section 4.5.

In 1999, common milkweed was detected in half (51%) of Iowa corn and soybean fields, but by 2009 in just 8%, a more than six-fold reduction in the number of fields that harbored it. Equally dramatic, the average milkweed density in fields where it ***was*** present declined by nearly five-fold, from 23 to just 5 square meters per hectare. The declining number of fields with milkweed,

Figure 2. Change in milkweed density in Iowa: agricultural and non-agricultural habitats.



Updated from Pleasants and Oberhauser (2012), Figure 1, supplied by authors.

and the reduced density where it was found, translate to a 96.5% decline in agricultural milkweed from 1999 to 2009 (Figure 2). It is estimated that 99% of the milkweed in corn and soybean fields in 1999 had been eliminated by 2013 (see Section 4.5).

These survey results are corroborated by a second, more limited survey conducted by entomologist John Pleasants from 2000 to 2008 in Iowa (Pleasants and Oberhauser 2012). Pleasants charted declining milkweed populations in seven fields that he carefully surveyed over this nine-year period. Interestingly, his count of milkweed stems yielded a trend of milkweed decline quite similar to that of Hartzler's more extensive surveys (Figure 2). Of roughly 1,000 milkweed stems at the start of his survey in 2000, none remained by 2009 (Pleasants, in press).

2.3.2 MILKWEED LOSS IN MINNESOTA CROP FIELDS

Extensive milkweed surveys were also conducted from 2003 to 2005 in Minnesota crop fields (Koch 2005). Surveyors used a methodology similar to that of Hartzler and Buhler (2000) and Hartzler (2010) in Iowa, selecting fields at random, without regard to level of weed infestation or other characteristics. The survey covered the 72 Minnesota counties (of 87 total) with appreciable acreage planted to corn and soybeans, with an average of six to seven fields surveyed per county. An average of 453 fields were surveyed each year, equally divided between soybeans and corn.[4] Averaged over the three years, milkweed was detected in just 3.4% of surveyed fields; and those fields harbored just 0.084 milkweed plants/m^2 (or 1 plant per 10 square meters). Averaged over ***all*** fields (including those with no milkweed), milkweed density came to just 30 plants per hectare.

Although comparison to the survey results from Iowa is hindered by the use of different units for milkweed presence, a few things can be said. First, roughly half as many Minnesota fields (3.4%) harbored milkweed in 2003-2005 as did Iowa fields in 2009 (8%). Second, the density of milkweed in Minnesota from 2003-2005 (30 plants/ha) was likely similar to that of Iowa in 1999 (12 m^2/ha), if one assumes two milkweed plants per square meter.[5] This suggests that milkweed prevalence in Minnesota is similar to that in Iowa.

Milkweed plants were much more numerous in this area just three to five years before these surveys. In the year 2000, Oberhauser et al. (2001) studied milkweed in five cornfields in east central Minnesota/west central Wisconsin, finding on average 2,850 milkweed plants per hectare, roughly two orders of magnitude (100-fold) higher than the level found in the 2003-2005 surveys discussed above.

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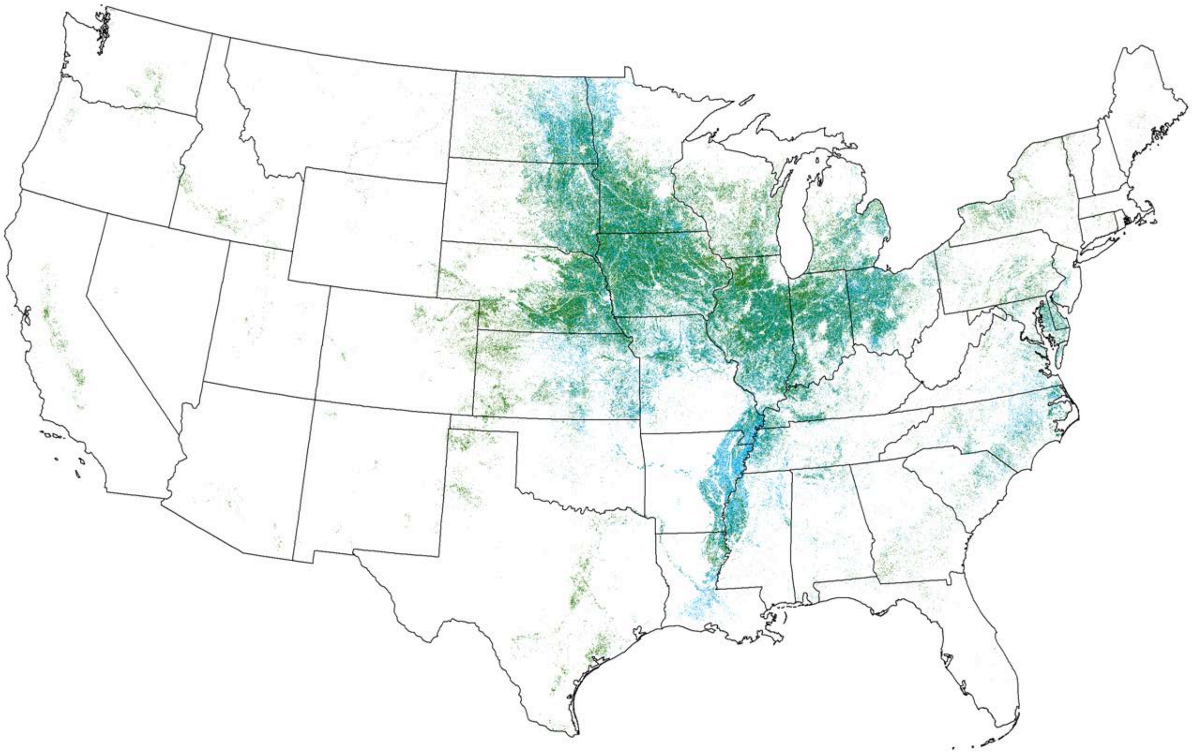
[4] In one year, 2003, five of the fields surveyed were growing crops other than corn or soybeans (four sunflower and one alfalfa field).

[5] Flockhart et al. Supplemental (2014) found on average 1.95 milkweed plants per square meter in surveys conducted in Illinois and Ontario, Canada in June and July of 2012 (pp. 22-23).

Although these sites were not necessarily representative of landscape milkweed prevalence,[6] most of the fields the authors visited during their site selection process had some milkweed (Personal communication from Dr. Karen Oberhauser to Bill Freese, 3/20/14), versus just 3.4% in the Minnesota surveys. Dr. Oberhauser also reported that their study fields in 2000 had never been planted to herbicide-resistant soybeans or corn, and attributed the big drop in milkweed numbers by 2003-2005 to the widespread planting of glyphosate-resistant soybeans (*Ibid*).

2.3.3 SIMILAR LOSS OF MILKWEED OCCURRING THROUGHOUT MIDWEST

The Iowa and Minnesota surveys exemplify the broader picture of milkweed decline throughout the historical monarch breeding range in the Midwest (Section 4.3), based on similarity of land use and climate (Becker 2000). As illustrated in Figure 3, the Midwest breeding range is dominated by corn and soybean fields. In fact, the twelve states of this range—Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin—have been home to 81-83% of combined corn and soybean acres in the U.S. since 2007 (USDA NASS 2014).



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[6] Candidate fields with less than 10 milkweed stems/ha were excluded.

Figure 3. Corn and soybean production in the U.S.: 2013.
Source: USDA CropScape (2013). Green represents corn, blue represents soybeans. Depth of color signifies intensity of cultivation.

to

Roundup Ready varieties. Figure 4A shows that similar proportions of the soybeans in the 12 Midwestern states are herbicide-resistant; and that the adoption trends in each state have been quite similar, converging to a narrow range of 89-97% adoption by 2013. Figure 4B shows herbicide-resistant corn adoption, which occurred 5-10 years after herbicide-resistant soybeans. As with herbicide-resistant soybeans, the trends in each state are similar, converging to 79-94% adoption by 2013.[7]

Farmers who grow Roundup Ready crops employ similar weed control practices; they rely primarily and often exclusively on post-emergence applications of glyphosate to control weeds. As discussed further below, it is the massive increase in glyphosate use with sharply rising cultivation of Roundup Ready crops that is responsible for the demise of common milkweed in Midwest crop fields.

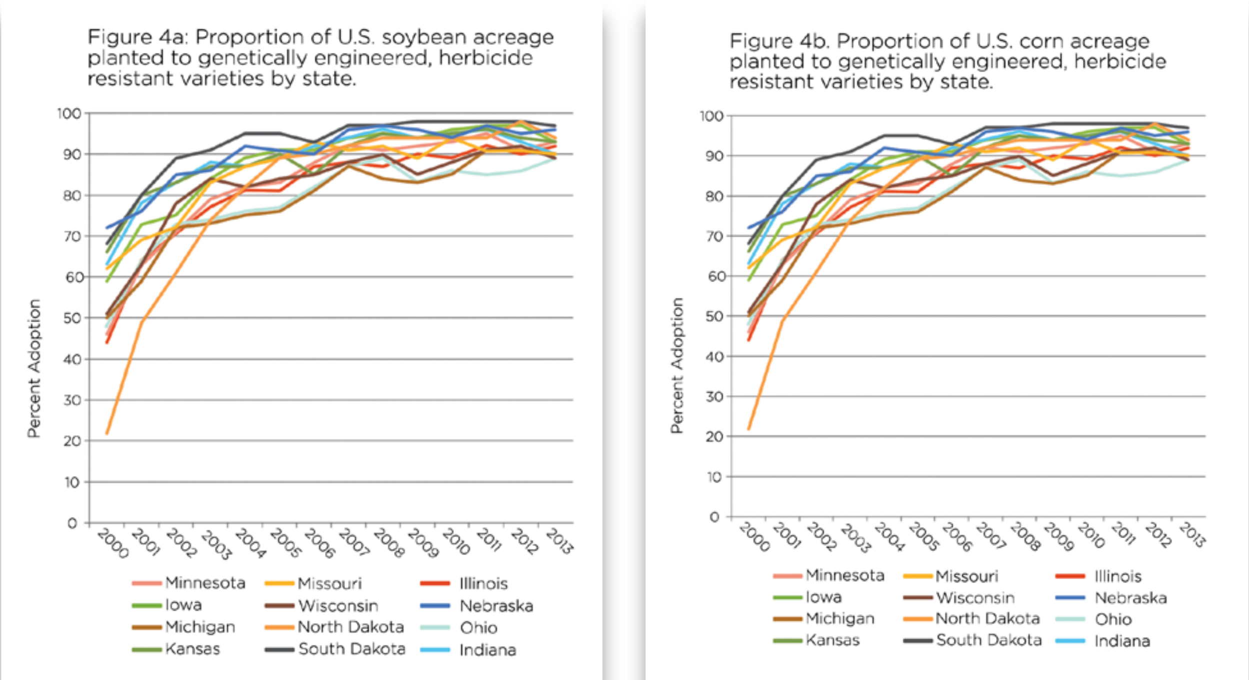

Figure 4. Proportion of U.S. soybean (A) and corn (B) acreage planted to genetically engineered, herbicide-resistant varieties by state.
Source: USDA ERS (2014a).

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[7] While Roundup Ready varieties are dominant, a few percent of U.S. corn and soybean acreage are planted to varieties resistant to glufosinate herbicide. See footnote to Figure 6 below.

2.3.3.1 Climate and land-use patterns similar throughout Midwest breeding grounds

Figure 5. Average annual precipitation in the U.S.: 1961-1990.
Source: http://mapsof.net/map/us-average-precipitation-map

Climate is broadly similar in the Midwestern monarch breeding grounds. Annual precipitation ranges from 30” to 50” in Iowa, Minnesota and the relevant portions of the other nine states, except for western Minnesota and eastern Nebraska and South Dakota, where it dips to the 20”-30” range (Figure 5).

2.3.3.2 Evidence of milkweed loss from other Midwest states

Personal observations by credible witnesses provide additional support for the Midwest-wide eradication of common milkweed in corn and soybean fields. According to David A. Wurdeman, a grain farmer in the northeast Nebraska town of Leigh:

> As someone who has raised crops, I can personally attest to scarcity of the milkweed plant today compared to, for example, 20 years ago. Milkweed used to be a common weed in this part of Nebraska. Roundup is particularly effective in eliminating milkweed, since it works on the rootstock of milkweed. Although I have always considered milkweed a rather troublesome ‘weed,’ and have appreciated how modern herbicides have controlled it, I am concerned about the effect this might have on the monarch butterfly population. I consider the monarch a very beautiful insect, and have noticed that they appear to be scarcer than in years past.... (as quoted in Taylor 2004).

The “scarcity” of milkweed observed by Mr. Wurdeman in 2004 is particularly striking in view of its past prevalence in Nebraska, the state that circa 1980 had more land occupied by common milkweed than any other except Iowa (Section 2.1).

Dr. Orley (Chip) Taylor, an entomologist who runs the non-profit Monarch Watch from University of Kansas in Lawrence, KS, has not seen milkweed in Kansas cornfields for years:

> Nobody has the time or resources to survey for milkweeds throughout the cb [Corn Belt] but I can tell you this—I haven't seen any in corn in KS in years and years and I can't get people to send contemporary images of mws [milkweeds] in corn—probably because, like me, they can't find it. (Personal communication to authors, 9/19/13)

As noted above, in the 1940s milkweed was more prevalent in northern Michigan than perhaps anywhere else in the country (Timmons 1946). Today, Dr. Mark Hunter, professor of ecology and evolution at Michigan State University, has observed a loss of milkweed in the same area that Timmons surveyed. Although most of his observations have to do with field margins (see Section 4.5.3), he has not seen milkweed in cornfields either, and would have surely noticed if milkweed was still at significant levels (Personal communication to Dr. M.L. Crouch, 8/22/13).

Common milkweed has also declined steeply in North Dakota cropland. According to plant scientist Dr. Rodney Lym of North Dakota State University: "Milkweed in cropland is down a lot, similar to Iowa I would think and for the same reason, lots of Roundup Ready cropping." (Personal communication to Bill Freese, 10/10/13)

Dr. Lym is based in Fargo, North Dakota, at the northeastern edge of the major monarch breeding range (Section 4.3). Interestingly, Dr. Lym also reports that milkweed is more abundant in north-central North Dakota, outside of the major breeding range, "where quite a few non-glyphosate tolerant crops are grown" (*Ibid*).

2.3.4 SUMMARY OF MILKWEED DISAPPEARANCE FROM MIDWEST CROP FIELDS

Rigorous weed surveys in Iowa and Minnesota establish that common milkweed—prevalent through the turn of the century—has been virtually eradicated from the states' corn and soybean fields in the 21st century. Iowa and Minnesota are typical of Midwest corn and soybean country in terms of climate, land use patterns and glyphosate-resistant crop adoption. Thus, it is not surprising that common milkweed is in dramatic decline throughout the region, as evidenced by personal observations of common milkweed's absence from or rarity in the crop fields of Nebraska, Kansas, Michigan and North Dakota—all states where it was once quite prevalent.

3. ROUNDUP READY CROPS UNLEASH GLYPHOSATE

IDEALLY, WE WOULD LIKE TO OBTAIN 90 to 100% control of common milkweed, but this is not feasible with our present weed-control methods against this tenacious perennial. Thus, production practices that decrease common milkweed populations are important, but they must be continued over a number of years to have a significant impact on the demise of this weed. (Cramer and Burnside 1981)

3.1 GLYPHOSATE: HERBICIDE PAR EXCELLENCE FOR CONTROL OF PERENNIAL WEEDS

GLYPHOSATE IS AN EXTREMELY EFFECTIVE HERBICIDE, killing a broader range of plants than most weedkillers (Duke and Powles 2008). This is because glyphosate inhibits a critical enzyme—5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS)—that is found in virtually all green plants, and which helps the plant synthesize various compounds it requires for growth and survival. Glyphosate is thought to kill plants by inducing shortages of these essential compounds (Henderson et al. 2010), though other potentially complementary mechanisms have been proposed. These include structural damage to the plant's vascular tissue (Lorentz et al. 2011); rendering the plant more susceptible to plant disease (Johal and Rahe 1984, Duke et al. 2007); and diverting carbon from other essential metabolic pathways (Duke and Powles 2008).

Glyphosate is particularly prized for its efficacy on perennial weeds, such as common milkweed, that most other herbicides fail to kill (Franz et al. 1997). When glyphosate is sprayed on a weed, it is absorbed by the leaves and stems and then translocated inside the plant to concentrate in actively growing meristematic tissues, including the plant's roots and developing buds (Duke and Powles 2008). By killing common milkweed at the root, regrowth the following year is largely prevented (Bhowmik 1994).

3.2 LIMITATIONS ON GLYPHOSATE USE BEFORE ROUNDUP READY CROPS

GLYPHOSATE WAS INTRODUCED IN 1974, but for two decades it was used very little in field crops like corn and soybeans. The chief factor inhibiting broader use was crop injury: glyphosate kills crops as well as weeds. Farmers had to apply it "pre-emergence"—that is, in the early spring before the crop was planted, or shortly after planting but before the crop seeds had "emerged" or sprouted—to avoid injuring their crop (Duke and Powles 2008). Thus, with a few exceptions (discussed in Section 3.5.4), it could only be used to control early-season weeds, not those that emerged later amidst the growing crop.[8]

Many other herbicides are not limited in this way. Because certain crops have a tolerance to them, these "selective herbicides" can be sprayed directly on crops (post-emergence) to kill weeds that emerge later in the growing season. These so-called post-emergence herbicides had become increasingly popular in the 1980s and 1990s, especially for use on soybeans (Carpenter and Gianessi 1999). Despite its efficacy, the fact that glyphosate was limited to less popular pre-emergence use helps explain how little it was used in the five years prior to Roundup Ready crop introduction.[9] From 1990 to 1995, glyphosate was applied to only 5-20% of soybean acres and 1-6% of corn acres each year (USDA NASS 1991-2008).

3.3 GENETICALLY ENGINEERED ROUNDUP READY CROPS

Roundup Ready (RR) crops are genetically engineered to survive direct broadcast application of glyphosate, sold by the Monsanto Company under the brand name of Roundup, but also in many generic versions produced by other firms. Resistance to glyphosate is achieved by inserting into the crop plant genome a variant of the EPSPS gene that encodes a glyphosate-insensitive EPSPS enzyme. The first and most widely deployed glyphosate-resistance gene was derived from a soil bacterium (*Agrobacterium*) that had evolved resistance to glyphosate in the sludge around Monsanto's Louisiana glyphosate production plant (Adler 2011).

Roundup Ready crops enable glyphosate to be used post-emergence to kill weeds through much of the growing season without risk of crop injury. Monsanto introduced Roundup Ready soybeans in 1996 and Roundup Ready corn in 1998. Roundup Ready soybeans were adopted very rapidly, exceeding 50% of all soybeans planted in the U.S. just three years after they were introduced. They have comprised roughly 90% of soybean acres since 2007. Roundup Ready corn was slower to be adopted by farmers, exceeding 50% of total corn acres only in 2007, though by 2013 85% of all corn was herbicide-resistant (Figure 6).

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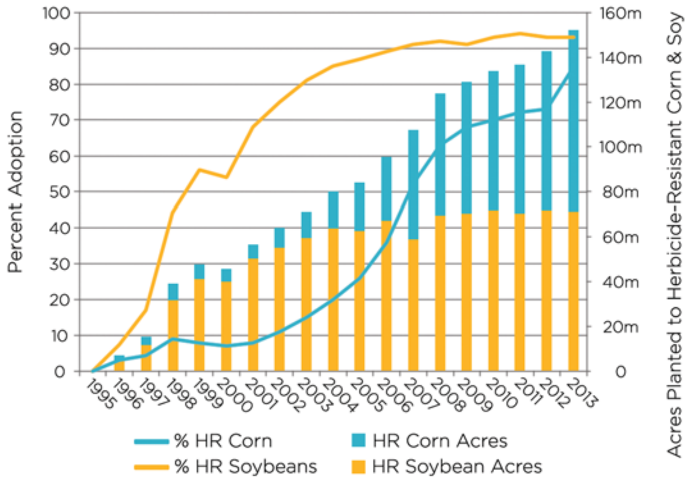
[8] A much less common practice was (and is) to apply glyphosate in the late summer or fall, when the crop is mature and thus crop injury is not a concern. These "pre-harvest" applications are made a few weeks before harvest, primarily to kill thick stands of late-season weeds that escape control earlier in the year in order to make the harvest "cleaner." Glyphosate could also be applied "post-harvest" to clear a field of weeds to prepare for the following year's planting. Except locally in some areas, these practices were and are uncommon because farmers prefer to control weeds earlier in the season, when yield loss due to weed competition can be prevented.

[9] Another factor inhibiting use was Roundup's high price, which Monsanto began to lower in 1994, two years before Roundup Ready crop introduction in 1996 (Barboza 2001).

Figure 6. Adoption of genetically engineered, herbicide resistant corn and soybeans in the U.S.



Sources: USDA ERS (2014b) for percent of corn and soybean acres that are herbicide-resistant, and USDA NASS (2014) for "acres planted" of corn and soybeans, for respective years.[10]

Roundup Ready soybean acreage skyrocketed from just under 5 million acres in 1996 to over 60 million acres by 2004, increasing slowly thereafter to stabilize at 68-71 million acres since 2008. Roundup Ready corn has accounted for most of the increase since 2005, and today is planted on roughly 80 million acres, for combined acreage of RR soybeans and RR corn of approximately 150 million acres in 2013. As discussed below, this extremely rapid and massive conversion to Roundup Ready crops has "unleashed" glyphosate and thereby had a profoundly negative impact on milkweed populations and the monarchs that depend upon them.

3.4 EARLY WARNINGS THAT ROUNDUP READY CROPS WOULD HARM MONARCHS

IN 1998, TWO CANADIAN SCIENTISTS published a groundbreaking paper (Wassenaar and Hobson 1998) demonstrating that 50% of migratory monarchs originated in a relatively narrow "swath of the Midwest just a few hundred kilometers from Nebraska to Ohio" (Science 1999). The authors immediately realized the implications. Conceding that "milkweed host plants are persistent there despite pesticide and weed control measures" (Wassenaar and Hobson 1998), they clearly foresaw that "new herbicide-resistant corn and soy crops—which allow farmers to kill milkweed after plants have sprouted—could devastate monarch food supplies" (Science 1999).

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[10] Note that all GE herbicide-resistant (HR) soybeans were Roundup Ready until 2010. According to Dow AgroSciences, LibertyLink, glufosinate-resistant soybeans comprised 1.1%, 1.3% and 3.9% of U.S. soybeans from 2010 to 2012, respectively (Dow 2013). Herbicide-resistant corn is almost entirely glyphosate-resistant. Though some corn varieties (e.g., SmartStax) have dual resistance to glufosinate and glyphosate (Nielsen 2010), growers make little use of glufosinate, which was applied to only 2-5% of corn acres from 1998 to 2010 (USDA NASS 2011, 1991-2008).

Responding to the same research on natal origins, Orley "Chip" Taylor also understood that Roundup Ready crops would have a devastating impact on monarchs:

> The bad news is that Mexico is not the only country with a monarch-conservation problem, says Orley R. Taylor of the University of Kansas in Lawrence. At least half of the winter migration stems from the U.S. agricultural heartland, between eastern Nebraska and western Pennsylvania. Open fields of corn and soybeans are popular spots for milkweed, but the plant may soon be wiped out as crops are bio-engineered to survive pesticides designed to kill all weeds, says Taylor. Loss of the milkweed would threaten the monarch's survival (Simpson 1999).

Writing in the year 2000, Iowa agronomists Robert Hartzler and Douglas Buhler also warned of the impact Roundup Ready crops would have:

> The importance of the Midwest in the monarch butterfly life cycle raises concerns over common milkweed populations in corn and soybean fields as the use of glyphosate-resistant crops increase. Glyphosate provides an additional herbicide for the control of common milkweed in the growing crop (Owen and Hartzler 1999) and may reduce common milkweed occurrence in crop fields (Hartzler and Buhler 2000).

Entomologist Lincoln Brower has studied monarchs since 1954 and is widely regarded as the world's leading expert on the butterfly. He sounded an alarm about increasing use of herbicides in general in 1995, concerned about loss of milkweed both as food for larvae and as nectar plants to feed adults (Brower 1995). In an article from 2001, he underscores the broad-spectrum efficacy of Roundup in killing off milkweed as well as "nearly all native flora" in America's crop fields:

> Genetic engineering also led to the development of numerous crop strains resistant to herbicides. It is now possible, for example, for farmers to plant "Roundup Ready" seeds of several crops—seeds that produce seedlings unaffected by Roundup spray. Roundup eliminates competing weeds, as well as nearly all native flora—including milkweeds, upon which the monarch depends. .... The result of such extensive use of herbicide-resistant crops is the destruction of biodiversity throughout North America and elsewhere, as millions of acres of land are converted to monoculture deserts of potatoes, soybeans, cotton, or corn (Brower 2001).

In 2002, a National Academy of Sciences committee produced a comprehensive report examining the environmental impacts and regulation of transgenic plants. The authors, who pointed to serious deficiencies in USDA oversight of these crops, also predicted problems for monarchs:

> In the upper Midwest, herbicide-tolerant soybeans might cause indirect reductions of monarch populations because their milkweed host plants are killed by the herbicides (NAS 2002, p. 71).

These early warnings on the devastating impact Roundup Ready crop systems would have on milkweeds and monarchs went completely unheeded. Absolutely no attempt was made to regulate in any way either the planting of Roundup Ready crops or the associated use of glyphosate with them.

3.5 GLYPHOSATE “UNLEASHED”

Roundup Ready crops triggered a radical shift in weed control practices. In less than two decades, American farmers of the country’s two leading crops went from employing a variety of weed management tactics to unprecedented reliance on a single herbicide—glyphosate—for weed control.[11] This transformation has several components:

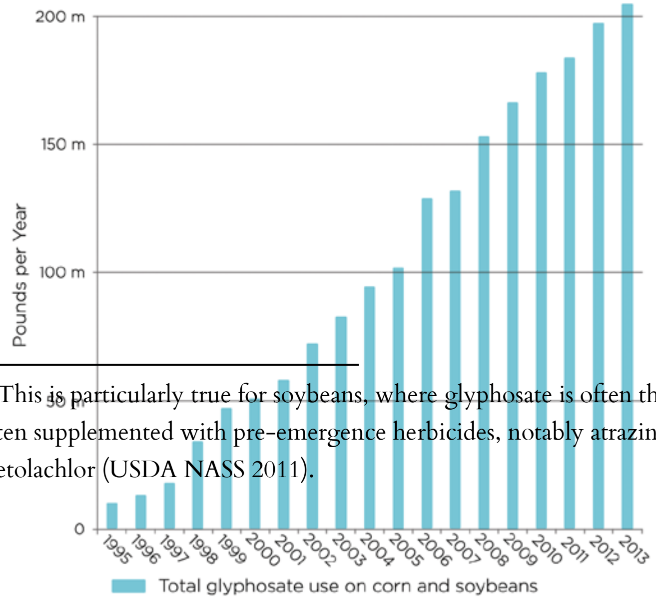
1. Vastly increased acreage sprayed with glyphosate;
2. Dramatically increasing intensity of use; and
3. Shift in application period from early spring to late spring and summer.

Each of these factors and its relevance to common milkweed is described below.

3.5.1 OVERALL INCREASE IN GLYPHOSATE USE

Glyphosate use on corn and soybeans rose from just 10 million lbs in 1995, the year before Roundup Ready soybeans were introduced, to 205 million lbs in 2013 (Figure 7). This represents an extraordinary 20-fold increase over just 18 years. To give an idea of how heavily this herbicide is used, glyphosate comprises (by weight) 82% of the 58 herbicide active ingredients applied to soybeans in 2012 and 35% of the 72 herbicide active ingredients applied to corn in 2010 (USDA NASS 2013, 2011). Glyphosate is by far the most heavily used pesticide in the U.S.; the 250 million lbs applied in all of agriculture in 2011 exceeds by nearly four-fold the usage of the second-leading pesticide, atrazine (USGS 2011; US EPA 2011, Ta-

Figure 7. Glyphosate use on corn and soybeans in the U.S.: 1995-2013.



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[11] This is particularly true for soybeans, where glyphosate is often the only herbicide employed. In corn, glyphosate is still often supplemented with pre-emergence herbicides, notably atrazine and/or chloracetamides such as acetochlor and S-metolachlor (USDA NASS 2011).

ble 3.6).

The overall increase in glyphosate use is the product of two factors: increase in area sprayed; and rising intensity on those acres that are treated.

Sources: USDA NASS (2014, 2013, 2011, 1991-2008). See Supplemental Materials on our website for methodology.

3.5.2 EXPANSION IN AREA TREATED WITH GLYPHOSATE

Prior to the 1996 introduction of Roundup Ready soybeans, common milkweed in Midwest crop fields was able to survive because most of it escaped any exposure to glyphosate. USDA pesticide usage data bear this out, showing that only 13% of total cropland planted to corn and soybeans was sprayed with glyphosate in 1995, or just one of every eight acres. The rapidly increasing share of soybean and corn acres treated with glyphosate since then (Figure 8) closely tracks Roundup Ready crop adoption (Figure 6), and coincides with common milkweed's eradication in the years after 1999, when the first comprehensive milkweed survey took place (Section 2.3.1). The rising use of glyphosate may well have begun impacting milkweed populations from the very start of the Roundup Ready era (1996), but data are lacking to confirm this.

Today, nearly all corn and soybeans (91%), and what little common milkweed remains there, are sprayed with glyphosate. For perspective, these 157 million glyphosate-treated corn and soybean acres represent half of all harvested cropland in the entire country in 2012 (315 million acres) (USDA Census 2012, Table 8), an area nearly the size of Texas.

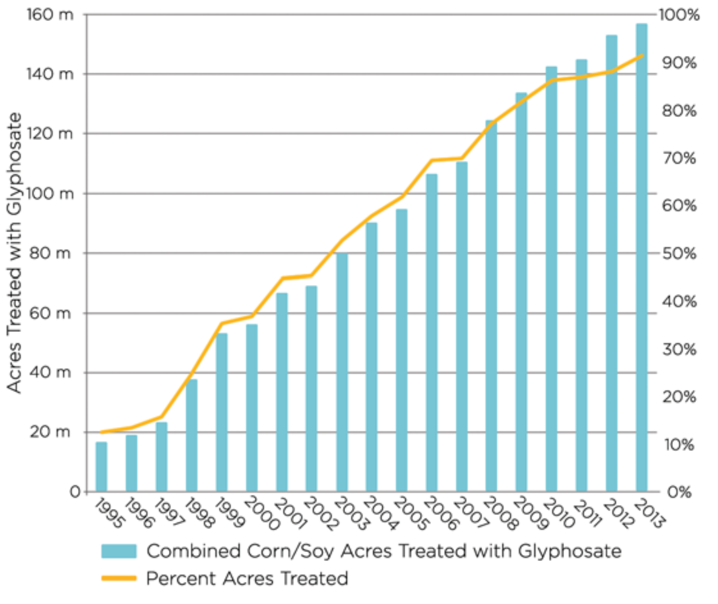
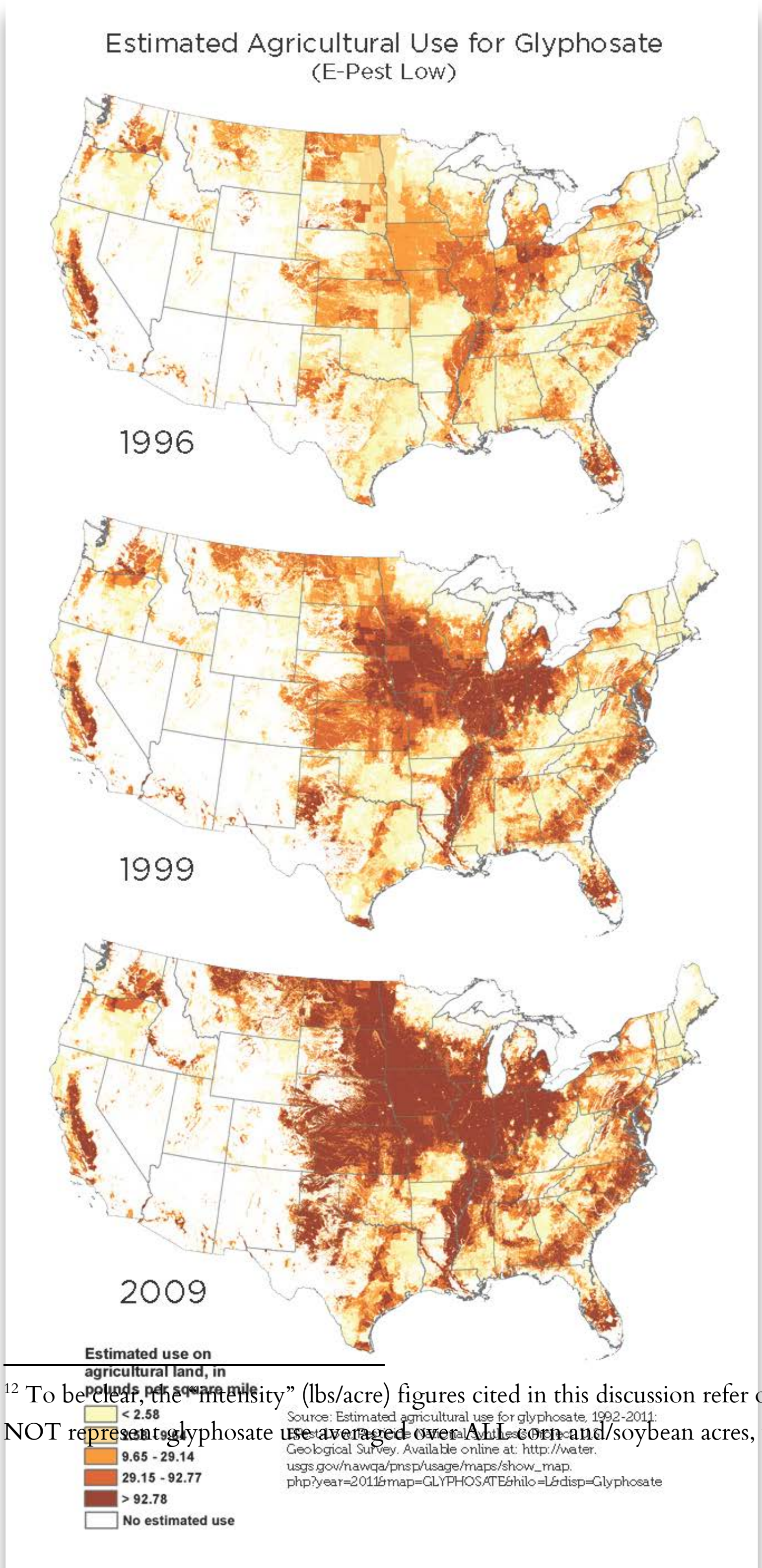


Figure 8. U.S. corn and soybean acres treated with glyphosate: 1995-2013

Sources: USDA NASS (2014, 2013, 2011, 1991-2008). See Supplemental Materials on our website for methodology.



Source: Estimated agricultural use for glyphosate, 1992-2011: [illegible] National Synthesis Project, U.S. Geological Survey. Available online at: http://water.usgs.gov/nawqa/pnsp/usage/maps/show_map.php?year=2011&map=GLYPHOSATE&hilo=L&disp=Glyphosate

Figure 9: Glyphosate use before and after significant adoption of Roundup Ready crops. Source: USGS (2011).

Figure 9 shows that the increase in glyphosate use from 1996 to 2009 has been largely concentrated in the Midwestern states.

3.5.3 INCREASING INTENSITY OF GLYPHOSATE USE

Glyphosate is not only being applied to vastly more acres than ever before, it is being applied much more intensively to those acres treated with it.[12] Figure 10 shows that the average amount of glyphosate applied to soybeans per acre per year climbed from 0.61 lbs in 1995 to 1.53 lbs in 2013. This represents a 150% or 2½-fold increase in glyphosate intensity over just 18 years. A similar though less pronounced trend is evident in corn over the same years: from 0.64 to 1.10 lbs/acre per year, for a 72% increase in glyphosate intensity.

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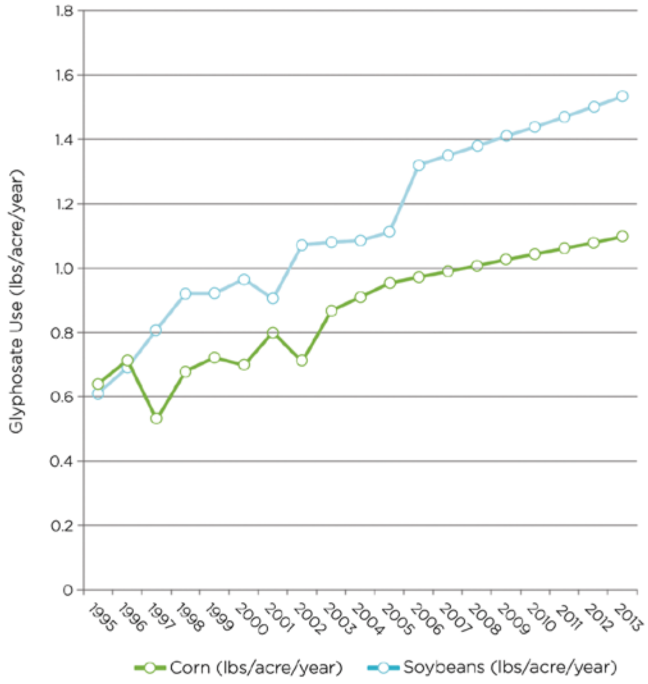
[12] To be clear, the "intensity" (lbs/acre) figures cited in this discussion refer only to treated acres. In other words, they do NOT represent glyphosate use averaged over ALL corn and/soybean acres, whether treated or untreated.

Intensity is the product of two components: the amount applied in a single application, and the number of applications per year.

Figure 10. Intensity of glyphosate use on U.S. corn and soybeans: 1995-2013.



Sources: USDA NASS (2013, 2011, 1991-2008). See Supplemental Materials on our website for methodology.

3.5.3.1 Application rate rising

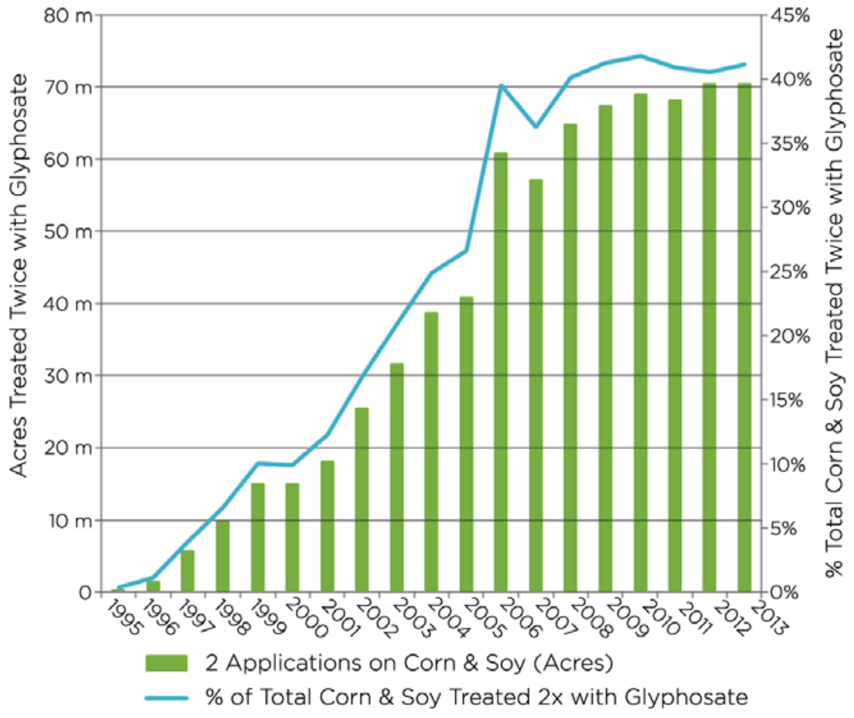
From 1995 to 2013, the average single application rate of glyphosate increased by more than half (58%) in soybeans, from 0.60 to 0.95 lbs/acre, and by 43% in corn, from 0.61 to 0.87 lbs/acre (for following discussion, see sources for Figure 10). Higher application rates generally result in more consistent killing of weeds in different environments. Because higher rates of glyphosate are recommended for more effective control of perennial weeds like common milkweed (Monsanto 2009, 12.7 and 12.8), this rising intensity of use in the Roundup Ready era is one factor in common milkweed's demise in cropland.

3.5.3.2 More acres receive multiple applications within season

Even more significant is the increasing ***frequency*** of glyphosate use, both within season and over years. From 1995 to 2013, the average number of annual glyphosate applications rose from 1.0 to 1.64 in soybeans, and from 1.1 to 1.27 in corn. This indicates that virtually all corn and soybean farmers who used glyphosate made just one application in 1995, with rapidly increasing acreage receiving two or more applications since then.

One simplified but fairly accurate way to portray this development is to assume that all glyphosate-using corn/soybean farmers make either one or two applications per season, but not three or more. Figure 11 shows that under this scenario, corn/soybean acreage twice-treated with glyphosate increases on average 3.9 million acres each year from 1995 to 2013, with 70.6 million acres sprayed twice by 2013. In that year, fully 41% of combined U.S. corn and soybeans were not only treated with glyphosate, but treated twice with it. Because perennial weeds like common milkweed that regenerate from roots are more effectively killed by "repeat treatments" of glyphosate than by just one (Monsanto 2009, 15.0), increased application frequency is another factor in common milkweed's disappearance from cropland.

Figure 11. Estimated U.S. corn+soybean acres receiving two glyphosate applications



Source: USDA NASS (2014, 2013, 2011, 1991-2008). See Supplemental Materials on our website for methodology.

3.5.3.3 More acres treated every year without respite

Over three decades ago, weed scientists in Nebraska recommended glyphosate to control common milkweed, but noted that: "…production practices that decrease common milkweed … must be continued over a number of years to have a significant impact on the demise of this weed" (Cramer and Burnside 1981). Roundup Ready crops have greatly facilitated continual use of such milkweed-killing practices.

One can make a semi-quantitative estimate of the acreage of corn and soybean fields sprayed every year with glyphosate based on herbicide-resistant corn and soybean adoption rates (Figure 6) and data on cropping sequences. Herbicide-resistant crop adoption rates represent within a few percent adoption of Roundup Ready varieties (see caption to Figure 12). USDA crop rotation data (USDA ERS 2012, Figure 3.4.2; USDA ERS 2013) show that roughly:[13]

1. **10%** of soybean acres are followed by soybeans the next year (continuous soybeans);

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[13] We have used the rough average of crop rotation data presented in the two USDA sources cited. One reason for disparities in crop rotation data is differing definitions. For instance, "continuous corn" might be defined as at least two or at least three successive three years of corn; the former definition would yield a higher figure for continuous corn.

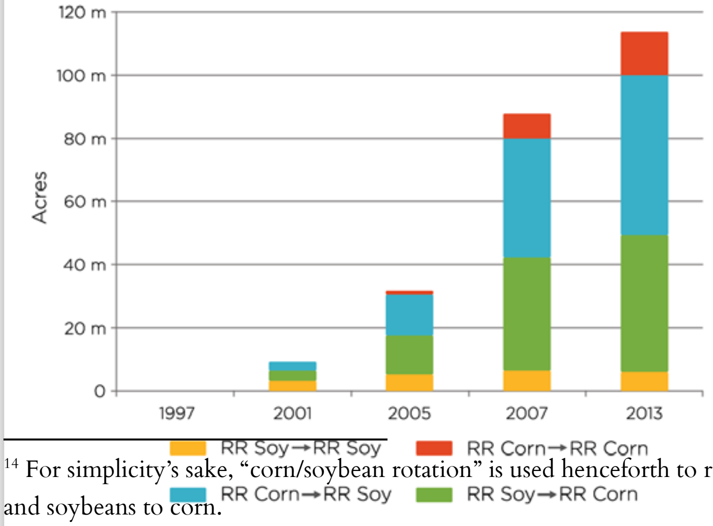
2. **75%** of soybean acres are followed by corn the next year (soybeans/corn);
3. **70%** of corn acres are followed by soybeans the next year (corn/soybeans); and
4. **20%** of corn acres are followed by corn the next year (continuous corn).

Figure 12 portrays estimated acreage planted to a Roundup Ready (RR) crop in consecutive years. The stacked bars show (from bottom to top): continuous RR soybeans, RR soybeans to RR corn, RR corn to RR soybeans and continuous RR corn.[14] Because of the predominance of the corn/soybean rotation over continuous corn or soybeans, most of the consecutive RR crop acres are RR corn in alternation with RR soybeans. Because RR corn adoption lagged RR soybean adoption by roughly a decade (see Figure 6), through the mid-2000s most farmers grew RR soybeans in rotation with non-RR corn, meaning an every other year break from post-emergence glyphosate applications. The growing adoption of RR corn is the main factor driving up acres in an all-RR crop rotation since that time, meaning glyphosate sprayed every year without respite. Overall, it is estimated that RR crops were grown in successive years on 6%, 21%, 54% and 66% of combined corn and soybean acreage in 2001, 2005, 2009 and 2013. Thus, today, two-thirds of America's corn and soybean fields receive one or more applications of glyphosate every year.

This estimate of rapidly growing acreage planted to Roundup Ready crops and sprayed with glyphosate every year is consistent with survey data. In 2005, when we estimate 54% of corn/soybean acreage was in continuous RR crops, Shaw et al. (2009) found that from two-thirds to three-fourths of surveyed farmers in Iowa, Illinois, Indiana and Nebraska were growing Roundup Ready crops continuously on at least some of their fields.[15]

When milkweed in corn and soybean fields receives two rather than one application of glyphosate, and is treated with it every year instead of every other, it has little opportunity to regenerate. Clearly, the sharply rising frequency of glyphosate application has played an important role in the decimation of common milkweed in Midwest farmland.

Figure 12. Estimated area planted to Roundup Ready corn and/or soybeans in successive years: 1997 to 2013



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[14] For simplicity's sake, "corn/soybean rotation" is used henceforth to refer to the two cropping sequences corn to soybeans and soybeans to corn.

[15] Calculated from Table 2 of Shaw et al. (2009).

Sources: USDA ERS (2014b, 2013, 2012), USDA NASS (2014). The herbicide-resistant (HR) crop adoption rates in USDA ERS (2014b) are corrected to account for non-RR varieties. See Supplemental Materials on our website for methodology.

Figure 13. Common milkweed growing between rows of Roundup Ready soybeans in Iowa field. Left: 8 days after post-emergence glyphosate treatment. Right: 18 days after glyphosate treatment. (Photos courtesy of John Pleasants).

3.5.4 LATER APPLICATION MORE HARMFUL

Roundup Ready crops have not only increased the extent, intensity and frequency of glyphosate use, they have also shifted the application period later into the growing season, when common milkweed is going through its reproductive stages and is more susceptible to glyphosate.

It is well-known that "[t]he application timing of herbicides in relation to plant growth plays an important role in herbicide effectiveness" (Bhowmik 1994). Bhowmik (1982) found that glyphosate applied at the early bud or late bud/flowering stages more effectively reduced milkweed stands in the year after application than it did when applied at the post-flowering stage (Bhowmik 1982).

Weed scientists in Nebraska advised farmers in the 1970s and 1980s to apply glyphosate to milkweed "from flower bud through flowering growth stages," corresponding in Nebraska and much of the Midwest to "approximately the month of June…" (Martin and Burnside 1977/84). In Ohio, agronomists similarly advised farmers that: "[l]ate post applications, when plants are in the bloom stage, will provide the most complete control of underground plant parts" (Loux et al. 2001). With regard to common milkweed, the Roundup WeatherMAX label states: "Apply when most plants have reached the late bud to flower stage of growth" (Monsanto 2009, 15.0).

Figure 14 shows that pre-emergence application of glyphosate to conventional corn would generally occur before common milkweed buds or flowers, while application to conventional soybeans would overlap only the early stages of milkweed reproduction. In contrast, milkweed growing in Roundup

Ready corn and soybeans would receive one or two post-emergence applications when it is most vulnerable.

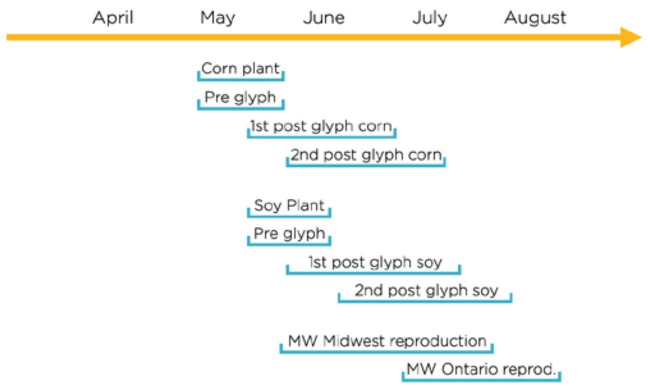

Figure 14. Glyphosate timing and common milkweed reproductive stages

Sources: Corn and soybean planting dates, "most active" period for Iowa (USDA NASS 2010); PRE glyph: pre-emergence glyphosate to conventional corn and soy occurs around planting time; 1st POST glyph corn: 1st post-emergence application to Roundup Ready (RR) corn 2-4 weeks after planting before V2 to V3 corn growth stages (Johnson and Leer 2006); 2nd POST glyph corn: 2nd POST application to RR corn 10-14 days after 1st POST (Monsanto 2009, 12.0) as late as V8 corn growth stage (ISU undated; Monsanto 2009, 12.4); 1st POST glyph soy: 1st POST application to RR soy 2-5 weeks after planting (Monsanto 2009, 12.7 and 12.8); 2nd POST glyph soy: 10-14 days after 1st POST up to R2 soy growth stage (Monsanto 2009, 12.0, 12.7, 12.8; Endres undated; Hardman and Gunsolus undated); MW Midwest Reproduction: Milkweed budding/flowering period in St. Louis and Nebraska (Sauer and Feir 1974; Martin and Burnside 1977/1984); MW Ontario Repro: Later milkweed reproductive period in Ontario, Canada (Bhowmik 1982).

In contrast, a study of weed abundance in a field of no-till conventional soybeans showed that a weed control regime that included either a pre-plant or post-harvest application of glyphosate[16] (specifically to control perennial weeds) did not prevent common milkweed from becoming established and steadily increasing in density over a period of four years (Colbach et al. 2000). Likewise, Monsanto's Roundup label does not claim efficacy against common milkweed when the herbicide is applied pre-emergence or post-harvest to conventional soybeans or corn (Monsanto 2009, 9.2 and 9.8).

The greater efficacy of mid-season glyphosate use is also suggested by the rather unwieldy equipment that was deployed to permit post-emergence applications to common milkweed (and other tenacious weeds) without damaging the crop prior to the introduction of RR soybeans.

These devices, which include wiper applicators and sponge bars, exploit the difference in height between the low-growing crop and the tall weed. The herbicide-bearing wiper or sponge, held aloft on the arms of a tractor-drawn rig, was dragged across the top of the tall weed (e.g., common milkweed) without contacting the crop. Similarly, glyphosate was applied with spray wands wielded by workers sitting in "bean buggies" mounted on the front of the tractor. Such devices were used especially in soybean production, prior to the introduction of Roundup Ready crops (Carlson and Burnside 1981; Buhler et al. 1994; personal communication from Bob Hartzler to Bill Freese, 6/23/14). There would have been no need for such unwieldy and time-consuming weed control practices if

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[16] Other weed control tactics used were a post-emergence application of bentazon and imazethapyr followed after two weeks by an interrow cultivation.

either pre-emergence or post-harvest application of glyphosate had been effective in controlling common milkweed.

Thus, the later application of glyphosate with Roundup Ready crops represents still another reason this crop system has led to decimation of common milkweed in Midwest agricultural fields.

4. MONARCH DECLINE LINKED TO GLYPHOSATE USE WITH ROUNDUP READY CROPS

THE ABUNDANCE OF MONARCHS across a landscape level will be determined by factors that influence immature and adult survival and oviposition. While many factors may be important, climate and the distribution and abundance of host plants will be key factors for any insect herbivore. (Zalucki and Rochester 2004, p. 223)

Figure 15. Monarch caterpillar feeding on common milkweed, *Asclepias syriaca*
(photo © Jeffrey E. Belth)

Monarch butterflies have been in steep decline since the mid-1990s. Although population size fluctuates considerably from year to year, influenced by weather, predation, diseases, and other factors, the precipitous two-decade decline in monarchs reflects more fundamental changes. One of the most important factors is the near-eradication of the monarch's common milkweed host plant by glyphosate use with Roundup Ready corn and soybeans.

4.1 MONARCH MIGRATION

DURING THE SPRING AND SUMMER breeding season, monarchs are dispersed throughout the continent, from the west to east coasts. However, monarchs cannot survive the freezing temperatures of winter in most of North America. The falling temperatures and shorter days of late summer and early autumn trigger a series of physiological changes in monarchs that result in suspension of breeding, accumulation of fats, and directional migration to the south and west in search of warmer climes (Solensky 2004, Merlin et al. 2012). In their epic journey south, which takes one to two months, monarchs fly about 50 miles a day[17] and can cover up to 2,500 miles. Most butterflies east of the Rockies converge on oyamel fir and pine forests in the mountains of central Mexico, where they pack tightly together in roosts that blanket the trees. These forests offer ideal temperature conditions for overwintering: warm enough to prevent freezing, yet cool enough to keep monarchs in a state of minimal activity, which preserves the energy stores they will require for their return journey (Brower et al. 2008, 2009).

Monarchs west of the Rockies end up in a series of roosting sites centered along coastal areas of south-central California (Jepsen et al. 2010), although some are thought to migrate to the same Mexican roosts used by eastern monarchs (Brower and Pyle 2004).

Recent research provides strong evidence that almost all of the monarchs in North America belong to one interbreeding population of the subspecies *Danaus plexippus plexippus* (Lyons et al. 2012). This includes the monarchs in the Western U.S., as well as the much larger number of monarchs east of the Rocky Mountains.[18] Some researchers suggest that the western monarchs depend on occasional interbreeding with eastern butterflies for long-term resilience (Brower and Pyle 2004). Western monarchs represent less than 1% of the U.S. population, on average, and are subject to different specific stresses than the main part of the population in the Midwest and East.[18] Some researchers suggest that the western monarchs depend on occasional interbreeding with eastern butterflies for long-term resilience (Brower and Pyle 2004). Western monarchs represent less than 1% of the U.S. population, on average, and are subject to different specific stresses than the main part of the population in the Midwest and East.[19]

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[17] Monarch Watch. Frequently Asked Questions: 3. How fast does the migration advance?. http://www.monarchwatch.org/read/faq2.htm#3.

[18] There are small populations of non-migrating monarchs in Florida and California whose relationships to the larger population are still unclear (Monarch ESA Petition 2014).

[19] We do not consider the western monarchs or non-migrating populations further in this report.

Some mating occurs at Mexican winter roosts before spring dispersal (Brower et al. 2007). As early spring arrives, monarchs begin the journey north, mating and laying eggs on milkweeds along the way. Migration tracks the availability of milkweeds, which emerge progressively later the further north they travel. Most individuals of the overwintering generation go on to colonize northern Mexico and the southern tier of states in the U.S., although a few migrate directly to more northern areas (Miller et al. 2012, Flockhart et al. 2013). Breeding monarch adults typically live from two to five weeks. Thus, successive generations continue north and east as southern areas become too hot and milkweeds decline in number and quality there (Cockrell et al. 1993, Malcolm et al. 1993, Brower 1995). Monarchs begin colonizing the Midwest and points north in June, with 2 to 3 more generations being produced there before migration south begins in August, completing the yearly cycle.

While monarchs breed on a variety of milkweed species in the south, common milkweed (*Asclepius syriaca*) is dominant in the Midwest breeding grounds. The abundance, distribution and condition of common milkweed largely determines the resource base for the monarchs that will migrate to Mexico, since the generation of butterflies making the journey originate almost entirely within the range of this most-used milkweed species. In fact, historically more than 90% of the butterflies in Mexican winter roosts were raised on common milkweed, as established by a technique known as cardenolide fingerprinting, which can distinguish between consumption of many different milkweed species (Seiber et al. 1986, Malcolm et al. 1993).

4.2 ESTIMATES OF MONARCH POPULATION SIZE SHOW STEEP DECLINE

POPULATION SIZE BEFORE RELIABLE SURVEYS were instituted in the 1990s cannot be known with certainty. However, monarchs have been abundant in Midwestern and eastern North America since at least the mid-1800's (Brower 1995). D'Urban in 1857 described monarchs appearing in the Mississippi Valley in "such vast numbers as to darken the air by the clouds of them" (Brower 1995, p. 349). Scudder and Allen in 1869 described monarchs gathered in groves of trees bordering the prairie in Iowa "in such vast numbers, on the lee sides of trees, and particularly on the lower branches, as almost to hide the foliage, and give to the trees their own peculiar color" (Brower 1995, p. 306). In the 1870s, swarms of monarchs were reported in New England and the Great Lakes, with one observer estimating “millions” (Brower 1995, p. 308).

Were monarchs also abundant before historical reports? It is likely that the many different species of prairie milkweeds were plentiful then. The abundance of various milkweed species has been measured in some current prairie remnant habitats in Iowa and extrapolated to provide an estimate of pre-agricultural milkweed occurrence. Pleasants (in press) estimates that milkweeds occupied roughly 0.65% of Iowa’s former prairie land, compared to 1999 when common milkweed, the predominant species today, covered only 0.19% of the Iowa landscape. Thus, pre-agricultural milkweeds were likely able to support a very large number of monarchs.

Today, the size of the monarch population can be estimated with some precision.

The concentration of the majority of North American monarchs in just a few total hectares of forest in Mexico provides an opportunity to estimate total population size all at once (Brower et al. 2012). Aerial surveys have not discovered any previously unknown roosts in these mountains (Slayback et al. 2007). Each winter, the area of trees occupied by butterflies is measured by a team of scientists and trained monarch monitors, using various methods to survey butterflies in areas known as host roost sites, and then total area is used as a proxy for numbers.

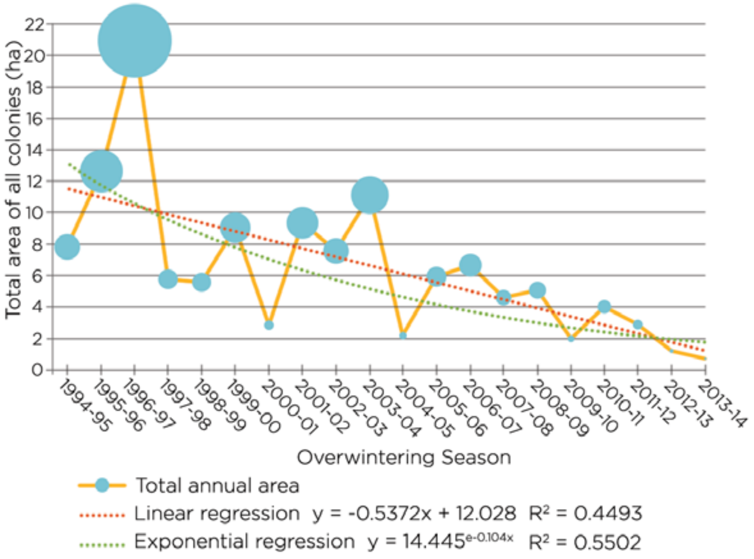
Translating hectares occupied into number of monarchs is not straightforward because monarch density changes over the winter, and perhaps also with the specific site. On-the-ground counts result in estimates of 10 to over 60 million butterflies per hectare (Solensky 2004). Monarch scientists now use a high-end conversion of 50 million monarchs in each hectare of occupied trees, since official measurements are taken at a time of year when butterflies are likely to be most tightly packed (Brower et al. 2004, Slayback et al. 2007).

There are now 20 years of reliable data on area occupied by all overwintering monarchs in Mexico. Brower and colleagues graphed and analyzed total monarch colony area from 1994-1995 through 2010-2011 (Brower et al. 2011, Fig. 1):

> Reliable information on colony sizes and locations is available since the 1994-1995 overwintering season; earlier information was gathered on increasing numbers of colonies as they were discovered by diverse groups of investigators with variable expertise. Even though the data span only 17 years, the decline is statistically significant. The regressions remain significant when either extreme measurement (high in 1996-1997 or low in 2009-2010) is removed (linear model, P = 0.032 or 0.042; exponential model, P = 0.040 or 0.049). We believe that all the measurements we have analyzed are reasonably reliable. Continued monitoring will, of course, strengthen conclusions about trends in monarch abundance. (Brower et al. 2011, p. 2)

Continued monitoring has indeed strengthened these conclusions. We have extended Brower's graph to include results of the three most recent surveys, with a new regression analysis, and unfortunately find a continuation of the downward trend (Figure 16). There has been a 90% decline in overwintering monarchs in the 20 years surveyed. The 2013-2014 population is by far the smallest yet, estimated at about 33 million individuals (Rendón-Salinas and Tavera-Alonso 2014). In addition, some of the locations with colonies in past years have been empty of monarchs recently (Rendón-Salinas and Tavera-Alonso 2014, Table 1.) This dramatic fall in numbers and colonies puts the migrating monarch's continued existence at grave risk (Monarch ESA Petition 2014).

Figure 16. Decline in area of monarch overwintering habitat in Mexico: 1994-95 to 2013-14



Source: Brower et al (2011, Fig. 1) updated through 2014. The two trend lines portray linear (straight line) and exponential regression analyses.

As the population declines, monarchs become more vulnerable to severe shocks, such as extreme weather events that are becoming ever more common with climate change. For example, a winter storm in 2002 killed an estimated 468-500 million monarchs (Brower et al. 2004, p. 162). A similar storm today could decimate today's much smaller population.

Monarch scientists blame much of the dramatic overall decline in monarch abundance on loss of milkweeds due to increasing use of glyphosate on Roundup Ready crops (Brower et al. 2011, Pleasants and Oberhauser 2012, Flockhart et al. 2014). They have reached this conclusion because the Midwest region where common milkweed has declined so sharply due to glyphosate use is also the major breeding grounds for migratory monarchs, to which we now turn.

4.3 NATAL ORIGIN STUDIES SHOW IMPORTANCE OF MIDWEST AS BREEDING GROUND FOR MIGRATORY MONARCHS

IN EARLY 1997 AND 2011, scientists conducted fine-grained surveys of where monarchs overwintering in Mexico were born in the preceding year (1996 and 2010, respectively) to determine specifically where the larvae developed and metamorphosed into migrating adults. Together with annual assessments of the size of Mexican winter roosts, these surveys provide important insights into the plight of monarchs, although they must be interpreted cautiously since the researchers sampled a limited number of butterflies, and migratory patterns will fluctuate from year to year in response to weather and other factors.

Wassenaar and Hobson's landmark study of monarchs overwintering in 1996/1997 provides useful data on the natal origins of butterflies before Roundup Ready crops and glyphosate were widely used (Wassenaar and Hobson 1998). The authors first established that stable hydrogen and carbon isotope profiles in butterfly wings were correlated with the latitude and host plants where they developed as larvae, and used this information to map natal origins.

The study showed that half of the approximately one billion overwintering monarchs that year were born in the Corn Belt of the Midwest (Figure 17), and raised on common milkweed:

> ... 50% of wintering monarchs originated from a fairly restricted geographic part of the breeding range, including the states of Kansas, Nebraska, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio. This corresponds to an area of intense corn, soybean, and dairy production in the Midwestern United States. Possibly, larger numbers of monarchs are produced in such areas of cultivation since milkweed host plants are persistent there despite pesticide and weed control measures. (Wassenaar and Hobson 1998, p. 15439)

They concluded that "…because the primary geographic production area for monarchs is centered in the American Midwest, that area should be focal for conservation efforts in North America."

Figure 17: Natal origins of monarch butterflies in Mexico from the 1996 breeding season

Researchers recently repeated the natal origins analysis, this time sampling the smaller population of approximately 200 million butterflies overwintering in 2010/2011; that is, monarchs that were born in the late summer and fall of 2010 (Flockhart et al. 2013; see Figure 18).[20] They determined that this overwintered generation had natal origins throughout much of the Midwest and East, but that most individuals came from a swath running from the northeastern states through the lower Midwest into northern Texas. In comparison to

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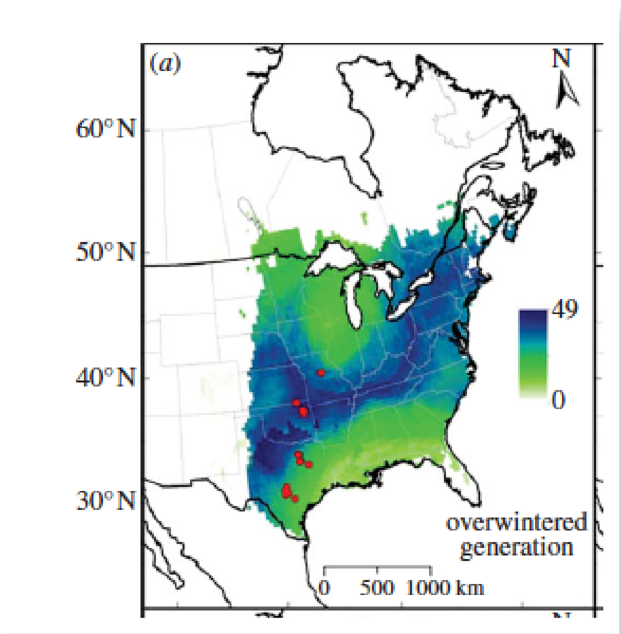
[20] The main difference is that while Wassenaar and Hobson (1998) sampled monarchs in Mexico, Flockhart et al. (2013) sampled monarchs in the southern U.S. in early spring 2011 as the butterflies that overwintered in 2010/2011 returned north.

Source: Wassenaar and Hobson (1998), Fig. 3, original caption omitted. The blue- and yellow-shaded areas show the natal origins of 50% and 95% of the one billion monarchs that overwintered in 1996/97. The Mexican monarch overwintering colonies are denoted



by the solid blue circle.

1996, a smaller proportion of overwintered butterflies originated in the heart of the Corn Belt: Illinois, Iowa, northern Indiana, Michigan, and the southern portions of Minnesota and Wisconsin (see Figures 17 and 18).

Figure 18. Probability distribution for natal origins of monarchs that overwintered in Mexico in 2010/2011. Source: Flockhart et al (2013), Fig. 2a, original caption omitted. Red dots represent monarch capture locations. The color gradient (light green to dark blue) represents the natal origins of the 115 butterflies analyzed, with increasing numbers of butterflies born in areas with progressively darker coloration, as indicated by the scaled bar to the right of the map.

4.4 MILKWEED LOSS IN CROPLAND HAS SIGNIFICANT IMPACTS ON MONARCH NUMBERS

LOSS OF COMMON MILKWEED in Midwest corn and soybean fields has had a huge impact on Monarch productivity. This is because cropland milkweeds tend to produce more monarchs per plant than those growing elsewhere, and because cropland dominates the Midwest landscape.

Figure 19: Monarch egg on common milkweed leaf
(photo © Jeffrey E. Belth)

Oberhauser et al. (2001) studied milkweed distribution and per plant monarch productivity in four areas: Iowa; Minnesota/Wisconsin; Ontario, Canada; and coastal Maryland. In all four areas, milkweed density was higher in non-cropland habitats, which included field edges, old fields and pastures, than in cropland, mainly corn. However, the number of eggs per milkweed plant was higher in the corn fields of Minnesota/Wisconsin, and the corn and soybeans fields of Iowa, than in the non-cropland habitats of those states.[21] Survival of eggs to adulthood was similar between habitats.

Pleasants and Oberhauser (2012) extended this analysis over four years (2000-2003) in Iowa, finding that per plant egg density on milkweed was on average 3.89 times greater when growing in corn or soybean fields versus non-crop habitats. These findings are consistent with Australian research, which found higher densities of monarch eggs and higher survivorship to adulthood on single plants more typical of cropland than on plants growing more densely in patches (Zalucki and Suzuki 1987, Pleasants in press).

Pleasants and Oberhauser (2012) conclude that "agricultural milkweeds are more heavily used than non-agricultural milkweeds,"[22] and present several possible explanations (see also Pleasants in press). Females may prefer cropland milkweed because their larvae are less subject to predation or parasitism; because their leaves have higher nitrogen content, potentially making them more nutritious for monarch larvae; and/or because the milkweed chemical signal that attracts monarch females may be more apparent against the monoculture background of crop fields, making it easier for females to find milkweed there.

Finally, a modeling study suggests that for insects like monarchs that are successful searchers, milkweeds distributed discontinuously in highly concentrated patches outside of crop fields are less productive of monarchs than a landscape with both patches and milkweed distributed at low density in cropland (Zalucki and Lammers 2010). The authors constructed this model in part to simulate the impact on monarchs of eradicating milkweed from cropland via heavy use of glyphosate with Roundup Ready crops, a situation they refer to as the "empty matrix":

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[21] There were no differences in egg densities between agricultural and non-agricultural habitats in Ontario or Maryland.

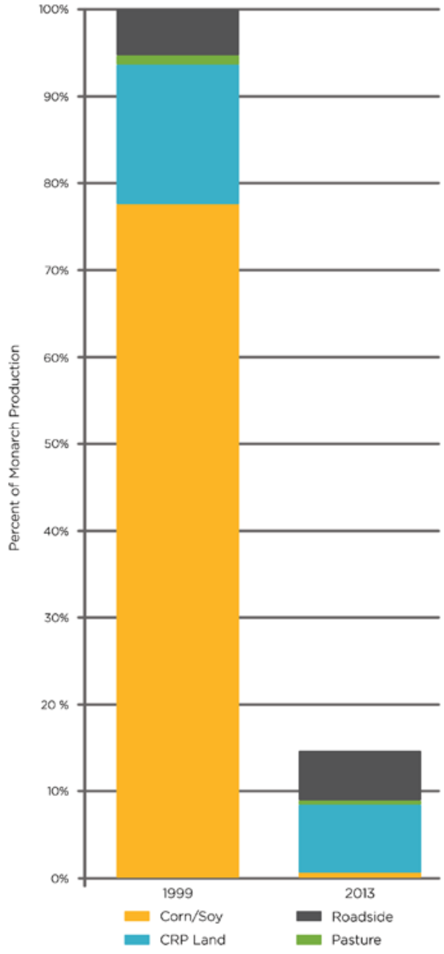
[22] In their nomenclature, "agricultural" denotes only corn and soybean fields, while "non-agricultural" encompasses pastures and temporarily retired farmland often regarded as agricultural land.

> Our results have implications for the cleaning up of agricultural landscapes, as crops genetically modified to be herbicide-resistant are increasingly planted. Since 1997 some 90% of American farmers have adopted Roundup Ready soybeans occupying some 40.5 million ha of row crop monarch habitat. .... Whereas before such fields contained some milkweeds sufficient for these plants to be considered weeds, the increasing use of herbicides is effectively creating an empty matrix. Even though conservation-minded consciences might be salved by leaving some fraction of the landscape with habitat, perhaps even a substantial area such as roadsides and the odd old field, an empty matrix may make a big difference for highly dispersive species with good searching capacity, like monarchs (Figs 3 and 4). (Zalucki and Lammers 2010, internal citations omitted)

How big a difference is illustrated by these startling figures? In just the 13 years from 1999 to 2012, corn and soybean fields in Iowa have lost 98.7% of their milkweed, driving a 64% decline in overall milkweed over this period (Pleasants in press). However, because a cropland milkweed produces nearly four times as many monarchs as plants in other settings, their loss has a *disproportionate* impact on monarch numbers. Pleasants (in press) estimates that in 2012, the Midwest produced 88% fewer monarchs than it did in 1999.

Does the decline in monarch productivity in Midwest corn and soybean fields affect monarch numbers in the population as a whole? Pleasants and Oberhauser correlated monarch egg production in the Midwest with overwintering population size in Mexico (Pleasants and Oberhauser 2012, Fig. 4; updated in Pleasants in press, Fig. 14.5). They found a significant correlation, showing that indeed more than half of the variation in the whole overwintering population size from 1994-2012 could be explained by declining monarch production in the Midwest.

Figure 20. Estimated production of monarchs in the Midwest by habitat type: 1999 and 2013



4.5 MONARCH PRODUCTION BY HABITAT TYPE

SCIENTISTS LONG CONCERNED by the monarch's plight have formed organizations and developed programs to conserve existing and plant new milkweed in hopes of saving the monarch. These important initiatives—led by groups such as Monarch Joint Venture, Monarch Watch and the Xerces Society for Invertebrate Conservation—have enlisted the services of citizen scientists, brought public attention to the monarch crisis, and spurred countless local efforts to plant pollinator gardens across the country.[23] Expanding habitat for milkweed and other pollinators outside of cropland may help to slow monarch decline and mitigate to some extent stressors that are depressing populations of pollinators in general. In our view, however, as valuable as such initiatives are, they cannot save the monarch without parallel efforts to reverse the decline in cropland milkweed.

Estimated proportion of monarchs produced on milkweed from different habitats, relative to monarch production in 1999.
Sources: Pleasants and Oberhauser (2012); Pleasants (in press); USDA NASS (2014) and USDA FSA (2014b).

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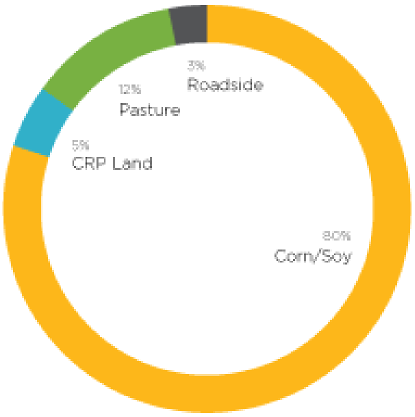
[23] For instance, see Monarch Watch, http://www.monarchwatch.org; the Monarch Larva Monitoring Project, http://www.mlmp.org; Monarchs in the Classroom, http://www.monarchlab.org; and the Xerces Society, http://www.xerces.org, among many other such initiatives.

Figure 20 portrays not only the overall decline in the number of monarchs from the Midwest from 1999 to 2013 (represented by relative height of stacked bars), but also the proportions raised on milkweed from different habitats in each year: corn/soybean fields, land enrolled in the Conservation Reserve Program, pastures and roadsides. Figure 21 displays the proportion of each habitat type in Iowa.

Sources: Pleasants and Oberhauser (2012), USDA NASS (2014), USDA FSA (2014b).

Figure 21. Area of different monarch habitats in Iowa: 2013



4.5.1 MONARCHS FROM CROPLAND HABITAT

The number of monarchs from milkweed in Midwest corn and soybean fields has declined by 99% since 1999 (compare blue bar segments for 1999 and 2013 in Figure 20). While cropland milkweed was responsible for 78% of Midwest monarchs in 1999, today it contributes only 5% of a much-reduced population (blue bar segments as proportion of total bars). These changes reflect the drastic reduction in cropland milkweed, the greater number of monarchs it produces plant for plant (Section 4.4), and the dominance of crop fields in the Iowa landscape.

4.5.2 MONARCHS FROM NON-CROPLAND HABITAT

Milkweed habitat outside of crop fields is found primarily in pastures, on retired farmland enrolled in the Conservation Reserve Program, and on roadsides (Hartzler and Buhler 2000, Hartzler 2010, Oberhauser et al. 2001, Pleasants and Oberhauser 2012, Pleasants in press). Milkweed may also be found in field edges that do not abut roads.

4.5.2.1 Pastures

Pastureland represents the most abundant habitat for milkweed outside of corn and soybean fields (Figure 21), but milkweed is very sparse in pastures (Hartzler and Buhler 2000). One possible explanation is that milkweed does not compete well with long-established grasses (Section 2.1). Another factor might be the common use of broadleaf herbicides (e.g., 2,4-D and dicamba) on pastures (Johnson and VanGessel 2012, USGS 2011). For instance, the largest single use of 2,4-D and one of the major uses of dicamba is on pasturelands (US EPA 2012; Monsanto 2010a, Table VIII-12, p. 199). While not as lethal to milkweed as glyphosate, 2,4-D and dicamba still cause considerable damage (Section 5.1.3.2), and also kill flowering plants that provide nectar to monarch adults (Sections 5.2.5 and 5.2.6). The already low milkweed density in pastures in 1999 declined by over 50% by 2013 (Pleasants and Oberhauser 2012). Thus, it is estimated that pastures account for just 3% of the Midwest's monarchs (Figure 20).

4.5.2.2 Land in the Conservation Reserve Program

The U.S. Department of Agriculture administers the Conservation Reserve Program (CRP), which compensates farmers for taking environmentally sensitive land out of crop production for 10-15 year periods and instead planting species that will improve environmental quality. The goals of the CRP are to reduce soil erosion, provide wildlife habitat and improve water quality (USDA FSA 2014a).

The number of monarchs from CRP lands has declined by roughly half since 1999, due primarily to an annual 5.2% decline in milkweed density over this period (Pleasants and Oberhauser 2012, Pleasants in press). Yet because of the much more precipitous decline in monarchs from corn and soybean fields, lands enrolled in CRP have emerged as their most important breeding habitat. While CRP lands accounted for only 16% of Midwest monarchs in 1999, today they provide more than half of the much-reduced population (Figure 20).

4.5.2.3 Roadsides

Milkweed density is relatively high on roadsides, and does not appear to have declined since 1999, at least in Iowa (Hartzler 2010). However, like milkweed in pastures and CRP land, each roadside plant produces only one-fourth the monarchs of milkweed in crop fields. Most importantly, roadsides comprise too small a habitat area to support viable monarch populations (Figure 21). When crop fields had more milkweed in 1999, roadside plants accounted for only 6% of monarchs. Because of the decimation of cropland milkweed, they now produce 39% of Midwest monarchs, second only to CRP lands (Figure 20).

Figure 32. Common milkweed growing on roadside next to a soybean field in Iowa
(photo © Robert Hartzler)

4.5.2.4 Field edges

Although in theory milkweeds could also grow on the margins of crop fields that do not abut roads, in fact there are not likely to be many milkweeds in these areas. According to Bob Hartzler, who conducted the Iowa milkweed surveys discussed above:

> When you get into the heart of Iowa, there are relatively few field edges other than what is on the roadside. Most of the state is laid out in sections of 1 square mile. Thirty or forty years ago the 640 acres of these sections would have been split into 10 to 15 separate fields with fencerows and perennial vegetation separating them. Now it isn't unusual to see sections with only two or three fields, with no fence line separating the fields (thus, there is no perennial vegetation between fields). (Personal communication to Dr. M.L. Crouch, 1/21/14)

Similar trends are evident in other Midwest states (Doll 1998). Of course, the farmland consolidation process that reduces field edge habitat for common milkweed also incorporates it into cropland planted primarily to Roundup Ready corn and soybeans, where it is eliminated through glyphosate use.

4.5.3 MILKWEED AND MONARCHS IN DECLINE ACROSS MIDWEST BREEDING GROUNDS

The preceding discussion of milkweed and monarch decline is based on data and observations from a number of Midwest states, though the precise numerical estimates rely heavily on Iowa data. Pleasants and Oberhauser (2012) argue persuasively that these largely Iowa-based trends are representative of the entire Midwest. In Section 2.3.3, we discussed how similar in agricultural land use and practices Iowa is to other states (or parts of states) that comprise the Midwest breeding grounds. The same holds for non-agricultural monarch habitats.

For instance, grasslands, permanent pasture, rangeland and cropland pastures comprise 9.2% of Iowa's total land, which is representative of the Corn Belt (12.2%) and Lake States (7.3%) (USDA ERS 2007, Summary Tables 1 and 2).[24] While the corresponding figure for the Northern Plains is 41%, much of this area is rangeland and grasslands that lie in the western two-thirds of these four states, outside of the major monarch breeding grounds. The eastern thirds are intensive corn/soybean growing regions (Figure 3), which would have roughly similar proportions of pasture as in the Corn Belt and Lake States. In any case, pasture milkweed accounts for very few monarchs, so any state-to-state differences in area of pastures have little importance for the broad applicability of the Iowa survey results.

Neither is there any reason to expect that roadside milkweed habitat in Iowa would be meaningfully different from that in other Midwest states. Each state would have a similar density of roads and thus

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[24] The sum of "grassland, pasture and range" and "cropland pasture" is divided by total land area.

area in roadsides. The only potential difference might be in roadside management practices. Iowa established an integrated roadside vegetation management program in 1988 that involves declining use of herbicides, which may contribute to the relative prevalence of milkweed in this habitat (Hartzler 2010). To the extent that herbicides are used more intensively on roadsides in other Midwestern states that have not established such programs, they would perhaps have smaller populations of milkweed. In this case, the Iowa results would overstate the roadside contribution of milkweed in the Midwest landscape as a whole.

Observations in Michigan provide evidence of disturbing recent losses of common milkweed in roadsides there, likely due to management changes. Mark Hunter, professor of ecology and evolutionary biology at University of Michigan, studies milkweeds and monarchs in northern Michigan, in the very region where milkweeds were so prevalent in the 1940s (Timmons 1946, see Section 2.1). Hunter says:

> In the eight years I have been doing research in Emmet County, I have seen common milkweed outside of my protected field sites decrease dramatically. There used to be a lot of it on the edges of the corn fields along county roads, and it was easy to find many monarchs for research and teaching by stopping at any field edge. Now there is very little milkweed along the field margins. I think farmers are actually spraying the field margins with herbicides to reduce weed seeds. In fact, Michigan State agricultural extension agents are advising farmers to remove common milkweed along field edges and around their farmsteads, using glyphosate, to prevent its spread into their fields.[25] Monarchs have become very rare in this part of the state, where they used to be so abundant. (Personal communication to Dr. M.L. Crouch, 8/22/13)

Iowa is also representative of the Midwest in terms of CRP lands (following discussion based on data at USDA FSA 2014b). In 2007, CRP lands comprised 7.4% of Iowa's total cropland, versus 5.9% in the Corn Belt as a whole.[26] This suggests that Iowa's CRP milkweed prevalence if anything overstates CRP milkweed in the core monarch breeding range represented by the five Corn Belt states of Iowa, Illinois, Ohio, Indiana and Missouri. Iowa is also representative of the entire Midwest, which includes seven additional states that lie only partially within the major monarch breeding habitat: Michigan, Minnesota, Wisconsin, Kansas, Nebraska, South and North Dakota. In 2007, CRP lands comprised 7.7% of the total cropland in these twelve states, virtually identical to Iowa's 7.4%. Thus, the monarch contribution of milkweed in Iowa CRP lands likely reflects, or perhaps overstates, that of milkweed in CRP lands of the entire Midwest.

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[25] For confirmation of this practice in Michigan's Upper Peninsula, which however is outside of the major Midwest breeding range, see Isleib (2012).

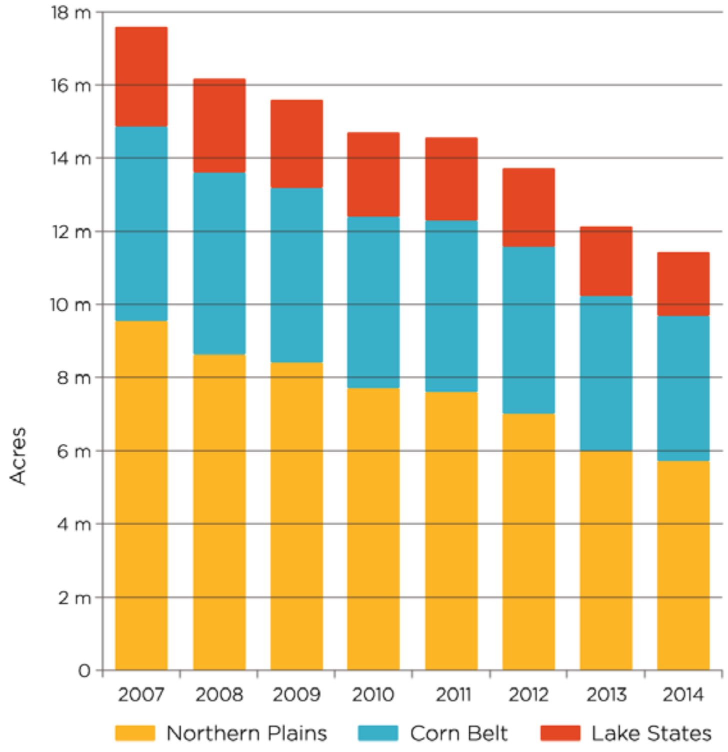
[26] Farmland enrolled in CRP is generally counted as a component of "total cropland" as defined by USDA. It falls into the subclass of "idle cropland."

4.5.4 TRENDS IN LOSS OF MILKWEED OUTSIDE OF CROP FIELDS

Two key trends are combining to degrade the remnant monarch breeding habitat outside of crop fields. As discussed above, data collected in several Midwestern states suggest that milkweed density in CRP lands and pastures has declined by roughly half from 1999 to 2013, or by 5.2% a year (Pleasants and Oberhauser 2012). While this decline is not as steep as that in cropland, which is losing milkweed at the astonishing rate of 50% every two years,[27] it is very troubling because remnant milkweed populations are already too sparse to ensure monarch survival, making any further losses unacceptable.[28]

The other worrying trend is sharply declining acreage enrolled in the CRP program. National CRP enrollment has shrunk by 11.2 million acres (30%) from its peak in 2007. Over half of this decline has taken place in the twelve Midwest states, which have lost 6.2 million CRP acres (Figure 23).

Figure 23. Decline in Midwest acreage enrolled in Conservation Reserve Program: 2007-2014



Source: USDA FAS CRP (2014). Midwest here defined as the 12 states of the Corn Belt (IA, IL, IN, MO, OH), the Lake States (MI, MN, WI) and the Northern Plains (KS, NE, ND, SD).

4.5.5 BIOFUELS POLICY DRIVING LOSS OF MONARCH HABITAT

The 2005 Energy Security Act and 2007 Energy Independence and Security Act established quotas and subsidies for biofuels production, chiefly ethanol from corn (Cassidy and Bruzelius 2014). New ethanol plants were constructed, increasing demand for corn. Farmers responded to the unprecedented rise in corn prices

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[27] Based on data underlying the trend described in Pleasants (in press), obtained from the author.

[28] Though based on considerable data, Pleasants and Oberhauser (2012) state that the decline they found may not be representative of milkweeds in non-agricultural habitats across the landscape; however, their estimate of overall loss of monarch production was only slightly lower when they re-ran their calculations without factoring in this milkweed decline in non-agricultural habitats.

triggered by this massive new demand by growing more corn—17 million acres more since just 2006 (USDA NASS 2014).

It is hard to overstate the impact of these biofuels mandates on U.S. agriculture. Corn prices that for decades had hovered around $2/bushel spiked to the $3 to $7/bushel range (USDA ERS 2014c). The share of the U.S. corn harvest processed for ethanol rose from 6% in the year 2000 and 14% in 2005 to a staggering 43% in the drought year 2012, and a still substantial 36% in 2013 (USDA ERS 2014d).[29] The area planted to corn exceeded 95 million acres in 2012 and 2013 for the first time since the 1940s (USDA ERS 2014c). Some of these new corn plantings have come at the expense of crops like wheat, cotton and hay (Wallander et al. 2011). But it is clear that many Midwest farmers are converting their CRP lands to corn, a major factor driving the decline in CRP enrollment.

A farmers' cooperative in Kansas anticipated this development in 2008: "With high commodity prices, expired Conservation Reserve Program (CRP) acres are likely to be planted to corn and soybean" (Beattie 2008). Wisconsin agronomists likewise found that: "With the increased interest in ethanol, more CRP land may be pressed into corn production… (U of WI 2007)." Pesticide/seed suppliers are also advising farmers on conversion of CRP land to corn (Dow undated). The ethanol-driven "corn rush" has contributed to declining CRP acreage in Iowa (Love 2012) and throughout the Midwest (Fargione et al. 2009, Cappiello and Apuzzo 2013).

While precise figures are lacking, the decline in CRP lands is strongly correlated with rising area planted to row crops. Nationally, combined corn and soybean acreage has risen by nearly 14 million acres since 2007, coinciding with the 11.2 million acre reduction in CRP lands. The same trend is seen in the Midwest, where an 8.5 million acre rise in corn and soybeans is matched by a 6.2 million acre reduction in CRP lands over the same period (USDA FSA 2014b, USDA NASS 2014). Wright and Wimberly (2013) estimate that 1.3 million acres of grassland in the western Corn Belt (much of it likely enrolled in the CRP program) was converted to corn and soybean production from 2006 to 2011. CRP enrollment in the Midwest has declined precipitously since 2011 (Figure 23), suggesting a continuation of this disturbing trend.

Congress has made matters worse by sharply reducing the maximum acreage that can be enrolled in the program, which stood at 39.2 million acres from 2002 to 2009. The 2014 Farm Bill will reduce this "CRP cap" by 39% by 2017 and 2018, to just 24 million acres (Figure 24). Thus, lands enrolled in the CRP program are sure to decline further in the future.

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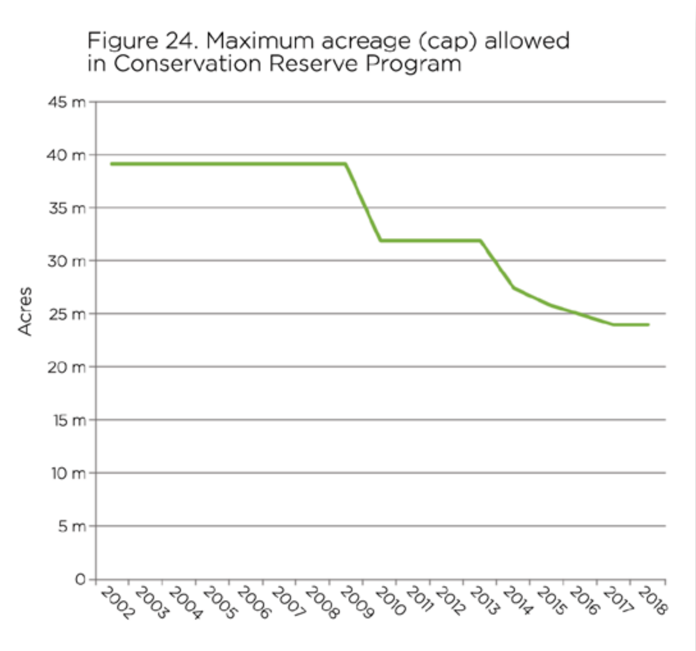
[29] Each bushel of corn processed for ethanol generates byproducts (distillers' grain) that can substitute for 0.38 bushels of corn that would otherwise be fed to livestock (Hoffman and Baker 2011). Thus, for example, while 43% of corn was processed for ethanol in 2012, the actual percentage of corn involved in ethanol production in that year was somewhat lower (27%), assuming that byproducts from all corn processed for ethanol were in fact deployed as animal feed.



Sources: NSAC (undated), NCFC (2014).

Continuing conversion of CRP acres to corn and soybeans will have devastating consequences for milkweed and the monarchs that depend on them. CRP land is the major remnant habitat for Midwest monarchs. Conversion to corn and soybeans resistant to glyphosate (and other herbicides, see Section 5) could well push migratory monarchs from their precarious position today onto the road to extinction. Only serious measures to reclaim agricultural habitat from intensive spraying with glyphosate and other herbicides stands a chance of reversing this trend.

5. NEW GENETICALLY ENGINEERED CROPS WILL FURTHER DEGRADE MONARCH HABITAT

PESTICIDE FIRMS ARE POISED to introduce a host of new genetically engineered crops resistant to both glyphosate and other potent herbicides. These crops will further degrade monarch habitat in two ways: by continuing the decimation of milkweeds on cropland; and by reducing populations of wildflowers that provide Monarch adults with essential nectar.

5.1 HARMS TO MILKWEED

5.1.1 GLYPHOSATE-RESISTANT WEEDS SPAWNED BY ROUNDUP READY CROPS

Roundup Ready crops have not only dramatically increased the extent and intensity of glyphosate use, as discussed above. They have also generated an epidemic of glyphosate-resistant weeds (Service 2013, 2007). Roundup Ready crops have been marketed by Monsanto, and used by farmers, as a complete weed control system involving total reliance on post-emergence applications of glyphosate to the exclusion of other weed control tactics (Hartzler et al. 2004; Hartzler 2004), especially in soybeans and cotton. As both weed science (Neve 2008) and history show, this is the perfect recipe for resistance. Glyphosate was introduced in the mid-1970s. Despite widespread use, there were no documented glyphosate-resistant weeds for two decades. The epidemic of resistance only began soon after Roundup Ready crops came on the scene in 1996 (Benbrook 2009). In the U.S. alone, 135 populations of 14 different weed species have evolved resistance to glyphosate in 36 states (ISHRW 2014). These resistant weeds infest from 50-62 million acres of U.S. cropland (Benbrook 2012, Fraser 2013), an area the size of Wyoming. A survey of farmers found that the problem is expanding rapidly, with 49% of farmers reporting glyphosate-resistant weeds in 2012, up from 34% in 2011 (Fraser 2013).

5.1.2 NEXT-GENERATION HERBICIDE-RESISTANT CROPS

For pesticide companies, glyphosate-resistant (GR) weeds represent a huge marketing opportunity for GE crops resistant to other herbicides that will still kill them, at least for a time (Kilman 2010). In fact, the agribusiness consulting firm Stratus Research tracks GR weeds to help “companies [ ] capitalize on business opportunities arising from glyphosate resistance” (Stratus 2014). To this end, all of the Big Six agricultural biotechnology/pesticide firms have developed GE crops resistant to one or more non-glyphosate herbicides (Table 2).

Petition No.	Company	Crop	Herbicides	Status
13-262-01p	Dow	Cotton	2,4-D, glufosinate, **glyphosate**	Pending approval
12-215-01p	Bayer/Syngenta	Soybeans	HPPD inhibitors, glufosinate, **glyphosate**	Approved 2014
12-185-01p	Monsanto	Cotton	Dicamba, glufosinate, **glyphosate**	Approved 2015
11-234-01p	Dow	Soybean	2,4-D, glufosinate, glyphosate	Approved 2014
10-188-01p	Monsanto	Soybean	Dicamba, **glyphosate**	Approved 2015
09-349-01p	Dow	Soybean	2,4-D, glufosinate, **glyphosate**	Approved 2014
09-328-01p	Bayer	Soybean	Isoxaflutole, glyphosate	Approved 2013
09-233-01p	Dow	Corn	2,4-D, ACCase inhibitors, **glyphosate**	Approved 2014
09-015-01p	BASF	Soybean	Imidazolinones	Approved 2014
07-152-01p	DuPont-Pioneer	Corn	Imidazolinones, glyphosate	Approved 2009

Table 2. Partial list of genetically engineered, herbicide-resistant crops recently approved or pending approval by USDA. Source: USDA APHIS (2014). Where glyphosate is bolded, the company has announced plans to breed a glyphosate resistance trait into commercial cultivars to be sold to farmers.

However, virtually all of these next-generation crops will be offered to farmers in varieties that are ***also*** resistant to glyphosate. The rationale for "stacking" glyphosate resistance is that glyphosate kills a broader range of weeds than practically any other herbicide, and will continue to be used at current rates to control the many weed species that are not well-controlled by the additional herbicide(s) to which the crop has been made resistant. Thus, the little remaining common milkweed in corn and soybean fields will continue to be sprayed with glyphosate, but most often in combination with one or more additional herbicides.

5.1.3 IMPACT OF 2,4-D AND DICAMBA-RESISTANT CROPS ON MILKWEED

It is anticipated that crops resistant to the herbicides 2,4-dichlorophenoxyacetic acid (2,4-D) and dicamba will be the most widely grown of the next-generation crops (Mortensen et al. 2012). Dow is poised to introduce 2,4-D-resistant corn and soybeans in 2015 (Gillam 2014), while the company's 2,4-D-resistant cotton is pending approval. USDA recently approved Monsanto's dicamba-resistant soybeans and cotton. All five will be stacked with glyphosate resistance (Table 2).[30] Monsanto is also developing dicamba-resistant corn (Monsanto 2010b), wheat and canola.[31] What will these new

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[30] Several are also resistant to other herbicides (e.g., glufosinate, ACCase inhibitors).

[31] USDA permit for dicamba-resistant wheat field trial issued 3/19/13, see http://www.isb.vt.edu/getRelDetail.aspx?bp=13-057-103n; dicamba-resistant canola field trial permit issued 3/20/12, see http://www.isb.vt.edu/getRelDetail.aspx?bp=12-075-109n; last visited 6/2/14.

crops mean for monarchs? This depends on how effectively these herbicides, when used as part of their respective herbicide-resistant crop systems, suppress common milkweed, and to what extent they kill off flowering plants that supply adult monarch butterflies with indispensable nectar.

5.1.3.1 Current uses of 2,4-D and dicamba

2,4-D and dicamba are members of the synthetic auxin family of herbicides. Synthetic auxins mimic natural plant hormones (auxins), and kill broadleaf plants by stimulating abnormal cell growth (Grossman 2010). Grasses and cereal crops have a certain tolerance to auxins, helping explain why the chief agricultural uses of 2,4-D and dicamba are to kill weeds in pastureland and cereal crops like wheat[32] (US EPA 2012; Monsanto 2010a, Table VIII-12, p. 199).

2,4-D and dicamba are relatively little used in corn and soybean production at present. The latest USDA figures show that 9% and 7% of corn were treated with 2,4-D and dicamba, respectively, while 16% and less than 1% of soybeans were treated with 2,4-D and dicamba, respectively (USDA NASS 2013, 2011). Corn is typically treated pre-emergence and/or early post-emergence, at rates of 0.3 to 0.4 (2,4-D) and 0.1 to 0.25 (dicamba) lbs/acre. Because both herbicides are toxic to soybeans, they must be applied pre-emergence, at typical rates of 0.5 lbs/acre for 2,4-D and 0.1-0.2 lbs/acre for dicamba (USDA NASS 2013, 2011). As discussed below, both the area treated with these herbicides and the rates used are expected to jump dramatically with the introduction of 2,4-D and dicamba-resistant crops.

5.1.3.2 Efficacy of 2,4-D and dicamba on common milkweed

A number of greenhouse and field studies have assessed the efficacy of 2,4-D and dicamba on common milkweed. As discussed in Section 2.2.3, while many herbicides can damage the aboveground plant, few are able to prevent regrowth of new shoots from the root system. Thus, the experiments discussed below focus on the herbicide's ability to suppress regrowth.

In greenhouse experiments conducted by Cramer and Burnside (1981), six-week old common milkweed seedlings were sprayed with various herbicides, clipped one week later, then evaluated for regrowth four weeks after clipping. Regrowth was modestly suppressed by either 2,4-D or dicamba, almost to the same degree as by glyphosate (Cramer and Burnside 1981, Table 1). In another iteration of this experiment, dicamba almost entirely stopped regrowth (*Ibid*, Table 2). Overall, dicamba was more effective than 2,4-D. The authors were unable to explain the variability in the experiments they conducted, noting merely that herbicidal control of common milkweed "is variable …

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[32] Flowering plants are traditionally divided into two classes: "monocots" such as grasses, from which cereal crops like wheat, corn and oats are derived; and "dicots" or broadleaf plants, which include crops like soybeans, cotton, vegetables and fruits. Grass-family crops tolerate moderate doses of 2,4-D and dicamba, but are injured or killed at higher rates.

and appears to be dependent on growth stage, growth rate, time of herbicide application, climatic variables, and other factors."

In field studies on older plants, Bhowmik (1982) found that neither 2,4-D nor dicamba provided much control of common milkweed in the year or two following a single application (Bhowmik 1982). However, these experiments involved modest rates, and application in the fall when milkweed was past its reproductive phase (post-flowering),[33] and so presumably less susceptible to herbicidal control.[34]

The Ohio State University extension service recommends a high rate of glyphosate (2.25 lbs a.e./acre) as the first option for control of common milkweed in non-crop or fallow field situations, but also notes that a lower rate of glyphosate (1.5 lbs a.e./acre) combined with 2,4-D ester "can provide good control as well" (Loux et al. 2001). Likewise for corn, one or two post-emergence applications of glyphosate are recommended if the corn is Roundup Ready. Dicamba is the top choice for non-Roundup Ready corn, alone or combined with one of several other herbicides.

North Dakota State University also conducted tests evaluating the effectiveness of various herbicides on common milkweed (Zollinger 1998). The herbicides were applied once in June of 1988, and the common milkweed stands were evaluated the following spring. Results were expressed as "percent control," with 100% equivalent to eradication of the original stand and 0% signifying no change. A high rate of glyphosate (3 lbs/acre) provided the best (99%) control. Higher than normal rates of dicamba (1 lb/acre) and 2,4-D (2 lbs/acre) provided lesser but still considerable levels of control rated at 61% and 48%, respectively, or reduction of milkweed stands by roughly half.

Although neither 2,4-D nor dicamba is as consistently effective as glyphosate, both partially suppress regrowth of common milkweed and thus have been recommended specifically for milkweed control by agronomists at several universities.

5.1.3.3 Use of 2,4-D and dicamba with resistant crops

2,4-D- and dicamba-resistant crops would exacerbate the impacts of these herbicides on common milkweed for precisely the same reasons that Roundup Ready crops heightened the adverse effects of glyphosate. Higher rates would be applied more frequently; more applications would occur later in the season during milkweed's most vulnerable reproductive phase; and in most cases 2,4-D and

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[33] In one experiment in which 2,4-D, dicamba and various mixes were in fact applied during milkweed's reproductive phase (Bhowmik 1982), milkweed stands were reduced by only 10-20% in the year following the treatment, though the author failed to report the rates of 2,4-D and dicamba.

[34] As discussed above, it is well established that glyphosate is less effective when applied post-flowering; the same would likely be true of 2,4-D and dicamba.

dicamba would be applied in combination with glyphosate. Moreover, vastly more cropland would be sprayed with these auxin herbicides than at present.

Rates, frequency and timing of application

As discussed above, corn and soybean farmers who apply 2,4-D today typically use low rates of 0.3 to 0.5 lb/acre to avoid crop injury. Dow conservatively projects that 2,4-D would be applied at 0.875 lbs/acre on its resistant corn and soybeans, double to triple current rates, though up to 1 lb/acre per application is allowed by the proposed label (CFS 2014a). Dicamba is currently applied at 0.1 to 0.2 lb/acre to soybeans. Monsanto projects rates of 0.38 to 0.5 lb/application on its resistant soybeans, two to five times current use (Monsanto 2010a). These higher rates are enabled by the crops' genetically engineered resistance. In fact, experiments show that 2,4-D-resistant corn and soybeans can withstand up to 4 lbs/acre of 2,4-D (Wright et al. 2010), while dicamba-resistant soybeans exhibit "complete resistance to dicamba" at 2.5 lbs/acre (Behrens et al. 2007).

Frequency of use would also increase. Proposed labels would allow up to 3 applications per year, for a seasonal total of up to 3 lbs/acre (2,4-D) and 2 lbs/acre (dicamba) on crops resistant to these herbicides (CFS 2012b, CFS 2012c).

Applications would occur weeks to a month or more later in the season. While most 2,4-D applications to corn are today applied early-season, to young plants up to 8" tall, 2,4-D-resistant varieties can be sprayed on corn up to 48" in height. In the case of soybeans, today 2,4-D and dicamba can only be used before planting or crop emergence, but will be applied a month or more later, up to soybean's flowering stage, on resistant crops (CFS 2012b, CFS 2012c). Application timing would be similar to that of glyphosate with Roundup Ready crops, which as shown in Figure 14 overlaps common milkweed's vulnerable reproductive stages.

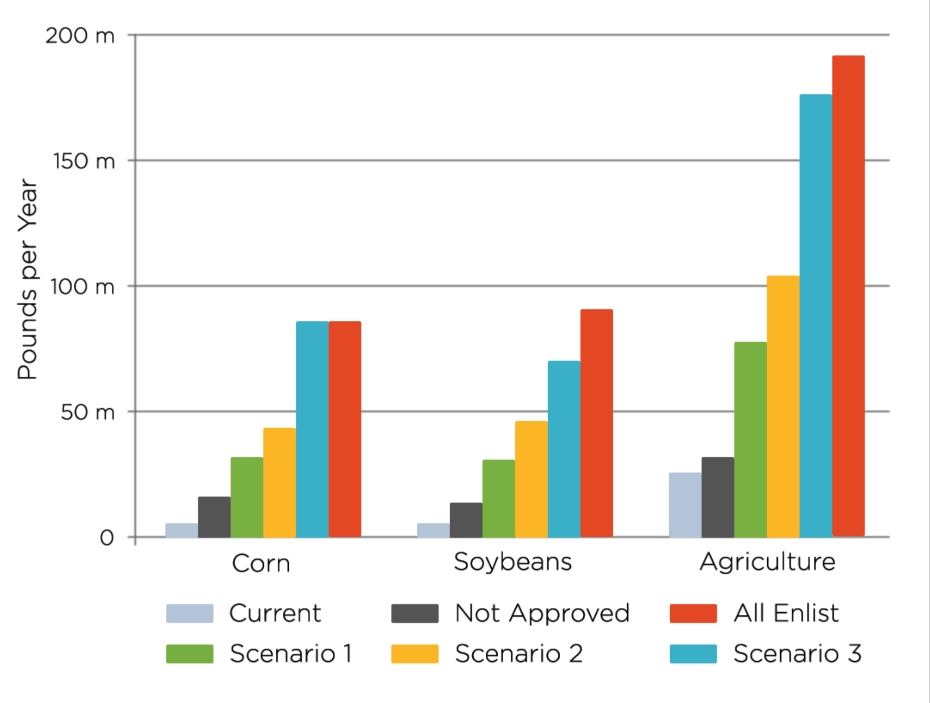
Application together with glyphosate

In most cases, these resistant crops will be sprayed post-emergence with a pre-mix formulation of glyphosate and the additional herbicide(s) to which the crop is resistant. Dow AgroSciences has developed Enlist Duo, which contains both 2,4-D and glyphosate, to be sold in tandem with its dual 2,4-D/glyphosate-resistant soybeans, corn and cotton (CFS 2014a). Monsanto has likewise developed Roundup Xtend herbicide, which combines dicamba and glyphosate, for dicamba/glyphosate-resistant soybeans (Monsanto 2012). Both companies will heavily market these dual products in packages with the resistant crops. As noted above, most growers would in any case supplement 2,4-D or dicamba with glyphosate because of the latter's greater effectiveness on most non-glyphosate-resistant weeds.

Greatly increased use of 2,4-D, dicamba and herbicides overall

Dow has projected that its 2,4-D-resistant corn and soybeans would increase agricultural use of 2,4-D by three- to seven-fold over current levels by 2020: from 25.6 million lbs/year at present to anywhere from 77.7 to 176 million lbs/year, depending on how widely it is grown (Figure 25). Dow's mid-range Scenario 2 (based on "reasonably possible" planting of 2,4-D-resistant corn and soybeans on 40.5% and 45% of total corn and soybean acres, respectively, by 2018-2023) would lead to a nearly ten-fold increase in use of 2,4-D on corn and soybeans, from about 10 million to 90 million lbs/year.

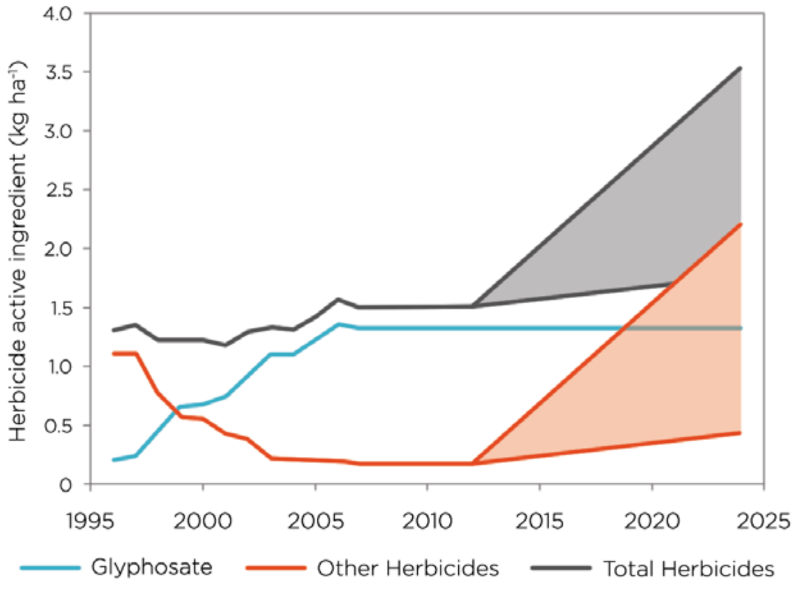
Figure 25. Projected use of 2,4-D by 2020 with and without 2,4-D-resistant corn and soybeans



Source: CFS (2014a), based on projections made by Dow in USDA APHIS (2013), Appendix 4. Scenarios 1, 2, 3 and All Enlist represent differing assumptions about the percentage of U.S. corn and soybean acres that are both 2,4-D-resistant and sprayed with 2,4-D by 2020. Scenario 1: 30% of corn and soybeans; Scenario 2: 40.5% of corn and 45% of soybeans; Scenario 3: 80% of corn and 68% of soybeans; All Enlist: 85% of corn and 89% of soybeans.

Pennsylvania State University weed scientists have also projected a substantial increase in use of 2,4-D and dicamba on soybeans if resistant varieties are approved (Mortensen et al. 2012). Their mid-range scenario for 2024 would result in combined 2,4-D and dicamba use of 77 million lbs/year on soybeans (Figure 26), up over ten-fold from the current 6-7 million lbs/year. Assuming continued use of glyphosate at current rates, overall soybean herbicide use would rise to 167 million lbs/year.[35]

Figure 26. Projected herbicide use with soybeans resistant to 2,4-D and dicamba



Source: Mortensen et al. (2012), Fig. 4, original caption omitted. Figures for 1996-2007 from NAS (2010), Figure 2-1. Assumptions: 1) Herbicide use constant from 2007-2012; 2) 2,4-D- and/or dicamba-resistant soybeans introduced 2013, with combined adoption on 91% of soybean acres by 2024 (mirroring rate of glyphosate-resistant soybean adoption); 3) Glyphosate use rate constant; 4) “Other herbicides” primarily 2,4-D and dicamba; 5) 2,4-D and dicamba rates range from low-end of 0.28 kg/ha (typical rates currently used on wheat and corn) to high-end of 2.24 g/ha, representative of rates being researched and promoted by Dow and Monsanto for use on 2,4-D/dicamba-resistant crops.

5.1.4 CHEMICAL ARMS (RESISTANCE) RACE WITH WEEDS

The vast increase in synthetic auxin herbicide use that would ensue from widespread planting of 2,4-D and dicamba-resistant crops—combined with continued heavy applications of glyphosate—would ensure continuing eradication of common milkweed from crop fields, and impede efforts to restore them. However, there are two more important aspects to this story. The first involves the impact that 2,4-D and dicamba will have on flowering plants that monarch adults require for sustenance, and is addressed in Section 5.2.

The second is that scientists already anticipate that these “next-generation” crop systems will spur rapid evolution of resistance to 2,4-D and dicamba—often in weeds ***already*** resistant to glyphosate and/or other herbicides (Mortensen et al. 2012, CFS 2012b, CFS 2012c). Multiple herbicide-resistant weeds are even today a rapidly growing problem for farmers (Mortensen et al. 2012). Because they would spur still greater use of more toxic herbicides, they threaten human health and the environment as well.

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[35] Mid-range scenario defined as 1.125 lbs/acre/year of auxin herbicide (2,4-D or dicamba), the average of the low- and high-end rates projected by Mortensen et al. (2012), Fig. 4, and 75 million acres total soybean acreage. See caption to Figure 26 for other assumptions.

Dow has discounted the weed resistance threat (Egan et al. 2011), just as Monsanto scientists denied that glyphosate-resistant weeds would evolve (Bradshaw et al. 1997). But the company's reassurances on this score are belied by its actions. For instance, buried in an obscure patent on Dow's 2,4-D-resistant soybeans is evidence that the company is already anticipating 2,4-D-resistant weeds, and staking claims to still more toxic and profitable responses:

> Thus, the subject invention **[2,4-D-resistant soybeans]** can be combined with, for example traits encoding glyphosate resistance … glufosinate resistance … acetolactate synthase (ALS)-inhibiting herbicide resistance … bromoxynil resistance … resistance to inhibitors of HPPD … enzyme … resistance to inhibitors of phytoene-desaturase (PDS), resistance to photosystem II inhibiting herbicides (e.g., psbA) **[e.g., atrazine]**, resistance to photosystem I inhibiting herbicides **[e.g., paraquat]**, resistance to protoporphyrinogen oxidase IX (PPO)-inhibiting herbicides … resistance to phenylurea herbicides … dicamba-degrading enzymes … and others could be stacked [sic] alone or in multiple combinations to provide the ability to effectively control or prevent weed shifts and/or resistance to any herbicide of the aforementioned classes (Cui et al. 2013, section 0077, boldface added).

Dow has a similar patent on 2,4-D-resistant corn (Cui et al. 2011, section 0061). The listed traits represent resistance to most major classes of herbicides, including those that include extremely toxic weedkillers like paraquat and atrazine. There would be no need to add resistance to additional herbicides if 2,4-D were to remain effective. The other major biotech firms have quite similar patents. The spiraling herbicide use stemming from this chemical arms (resistance) race between crops and weeds would harm not only milkweed and monarchs, but many other species as well, including our own.

5.2 HARMS TO THE MONARCH BUTTERFLY'S NECTAR PLANTS

ALTHOUGH MONARCH LARVAE can only thrive on milkweeds, the adult butterflies feed on a wide variety of nectar-producing flowers (Tooker et al. 2002). They depend on flowers that are in bloom in their breeding habitat during the spring and summer, and then along migration routes to their winter roosts (Brower and Pyle 2004). Monarchs that are breeding during spring and summer require energy derived from nectar for flying, laying eggs, mating, and other activities. In addition, the generation that migrates in the fall depends on nectar sugars (stored in the form of fat) to sustain themselves while overwintering, and perhaps also to fuel their northern migration the following spring (Brower et al. 2006).

Herbicides are toxic to plants, by definition, and they frequently drift beyond the boundaries of crop fields to affect wild plants growing nearby. Various models of herbicide spray drift[36] suggest that

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[36] Modeling ground, not aerial application; the latter involves more drift at greater distances.

from 1% (commonly) to 25% (occasionally) of the applied herbicide dose drifts beyond the field boundaries to affect wild vegetation (Holterman et al. 1997, Wang and Rautmann 2008, Boutin et al. 2014), though these models made no attempt to account for unpredictable volatilization (see below), and models generally do not account for extreme situations. Areas surrounding cropland provide most of the biodiversity in agriculture-dominated landscapes (e.g., Boutin and Jobin 1998) such as the Midwest. Thus, it is important to understand the impacts of herbicide drift on these wild plants and the organisms that depend on them, such as monarchs and a vast array of other pollinators. This task is made more urgent by the imminent introduction of next-generation herbicide-resistant crops, such as those resistant to 2,4-D and dicamba, discussed above, which will lead to sharply increased herbicide use, drift and associated damage to wild plants.

Figure 27. Nature preserve downwind of field recently sprayed with herbicide in southern Indiana. Common milkweed and nectar plants in the nature preserve are vulnerable to herbicide drift. Photo © M. L. Crouch, taken May 19, 2013.

5.2.1 HERBICIDE DRIFT

Herbicide drift comes in several forms. Spray drift refers to the movement of an herbicide off the field as it is being applied, and is affected by wind speed, direction, application method and droplet size, among other factors. Some volatile herbicides can drift days to months after application (USGS 2003), a phenomenon known as vapor drift. This occurs when an herbicide previously deposited on plant surfaces and the ground during the spray operation "volatilizes" (evaporates) and moves offsite, and is favored by hot conditions and temperature inversions (Johnson and VanGessel 2012). Drift can also occur when herbicide-laden dust is carried by the wind.

Most of what we know about herbicide drift concerns damage to sensitive crops. We first discuss this evidence for the light it sheds on the scope and impacts of drift before turning to herbicidal injury to wild plants, and its impacts on monarchs.

Two surveys of state pesticide regulatory agencies found that on average over 2,100 pesticide drift complaints were received annually in the six years from 1996 to 1998 and 2002 to 2004, most involving herbicides and crop damage (AAPCO 1999, 2005). However, the true number of drift episodes is certainly much higher, because many go unreported. According to EPA scientists who have studied pesticide drift for many years, farmers often settle drift cases without reporting them; and when lawsuits are filed, the majority are settled out of court, with confidentiality clauses that prevent disclosure even to the government (Olszyk et al. 2004, p. 225). It is often difficult to determine the source of damaging drift (Bennett 2006), which may discourage farmers who would otherwise report in hope of obtaining compensation. All of these factors suggest that the true scope of herbicide drift is far greater than implied by the number of reported cases, which in any case is substantial. Experience with Roundup Ready crops shows clearly that drift becomes more frequent and damaging when an herbicide is used in the context of an herbicide-resistant crop system.

5.2.2 THE ROUNDUP READY CROP EXPERIENCE

Glyphosate has low volatility, and thus is not ordinarily considered a drift-prone weedkiller (Lee et al. 2005, p. 135). Nevertheless, since the Roundup Ready era began, it has become one of the top two herbicides (along with 2,4-D) implicated in herbicide drift complaints nationwide (AAPCO 1999, 2005). The high incidence of glyphosate drift injury is partly attributable to the expanded acreage and increased volume of use with Roundup Ready (RR) crops. However, the late application period—mid-season with RR crops versus early season with conventional varieties—is clearly a contributing factor. In a comprehensive study of the potential for herbicide drift to injure crops in Fresno, CA, EPA scientists found that:

> Increased use of herbicide-resistant technology by producers creates the possibility of off-site movement onto adjacent conventional crops. … Postemergence application of a herbicide to a genetically-modified (GM) crop often occurs when non-GM plants are in the early reproductive growth stage and are most susceptible to damage from herbicide drift. Consequently, most drift complaints occur in spring and summer as the use of postemergence herbicide applications increases (Lee et al. 2005, p. 15, internal citations omitted).

It is because Roundup Ready crops have enabled "large quantities" of glyphosate to be used "throughout the season" that it poses a greater threat than more damaging but lesser used herbicides like 2,4-D and dicamba: "Glyphosate may be applied as a preplant or postplant postemergent herbicide. It is not as damaging to sensitive crops as 2,4-D and dicamba and other high potential risk herbicides but has greater potential to damage sensitive crops because it is applied throughout the year in large quantities." (Lee et al. 2005, p. 47)

The problem is not confined to California. Glyphosate drifting from application to Roundup Ready crops has repeatedly caused extensive damage to wheat (Baldwin 2011) and especially rice (Scott 2009) in Arkansas; to rice (Wagner 2011) and corn (Dodds et al. 2007) in Mississippi; to rice in Louisiana (Bennett 2008); and to tomatoes in Indiana and adjacent states (Smith 2010), to cite just a few of many examples.[37] Such episodes sometimes give rise to lawsuits, as when farmers won compensation for onions damaged by glyphosate applied to Roundup Ready soybeans in Ontario, Canada (Lockery vs. Hayter 2006).

Glyphosate drift injury has been extensive, damaging 30,000 to 50,000 acres of rice in Mississippi in 2006, for example (Wagner 2011). Glyphosate drift damage to wheat has prompted suggestions that it simply not be grown in Arkansas (Baldwin 2011). Tomato growers in Indiana, Michigan and Ohio suffered over $1 million in glyphosate drift damage over four years (Smith 2010). Arkansas corn growers felt so threatened that they switched to Roundup Ready varieties out of "self-defense" against glyphosate drifting from Roundup Ready soybean and cotton fields (Baldwin 2010). While most drift damage occurs near treated fields, weed consultant Ford L. Baldwin has documented glyphosate drifting 0.5 to over 2 miles to damage rice in Arkansas (Baldwin 2008).

We are not aware of any surveys of wildflowers in agricultural landscapes before and after commercialization of Roundup Ready crops. However, the frequency of crop injury from glyphosate drift implies a high potential for damage to wild plants as well. Several studies suggest that glyphosate applied to resistant crops may have already reduced the abundance and diversity of nectar plants in and around agricultural fields, from direct applications as well as spray drift (e.g., Gove et al. 2007,

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[37] A search of the online farm publication Delta Farm Press using the search term "glyphosate drift" turned up 128 articles (search conducted 9/11/14, www.deltafarmpress.com).

Blackburn and Boutin 2003). The cultivation of new herbicide-resistant crops treated with volatile herbicides like 2,4-D and dicamba have an even greater potential to cause drift injury and so reduce nectar resources needed by monarchs and other pollinators (Brower et al. 2006).

5.2.3 2,4-D AND DICAMBA DRIFT

2,4-D and dicamba are volatile herbicides that are prone not only to spray drift (like glyphosate), but also to vapor drift, which is much more unpredictable and difficult to prevent and control (Behrens and Lueschen 1979, Sciumbato et al. 2004). When 2,4-D was first introduced in Iowa, vineyard operators suffered substantial losses and lobbied unsuccessfully for restrictions on its use by corn growers (Anderson 2005). 2,4-D and dicamba drift has been so problematic that many states did eventually restrict their use in areas where sensitive crops are grown, at certain times of year (Feitshans 1999). Drift problems were also one factor leading to sharp reductions in 2,4-D and dicamba use in favor of less toxic and less drift-prone herbicides in the 1980s and 1990s. Despite restrictions and reduced use, however, problems continue.

2,4-D ranked 1st or 2nd in herbicide drift complaints in the six years from 1996-1998 and 2002- 2004 (AAPCO 1999, 2005). Dicamba was also among the top drift culprits. Crops damaged by 2,4-D and dicamba drift, often at quite low levels, include grapes, cotton, soybeans, sunflower, and many fruits and vegetables (Hebert 2004, Egan et al. 2014a, Doohan and Mohseni-Moghadam 2014). Though damage often occurs to crops in adjacent fields, area-wide impacts are not uncommon. For instance, in 2006 volatilization of 2,4-D damaged cotton on "upwards of 200,000 to 250,000 acres" in five counties in Arkansas, an impact likely due to multiple applications in the area and weather conditions that promoted vapor drift (Bennett 2006). In 2012, a single 2,4-D application damaged 15,000 acres of California cotton as well as a pomegranate orchard, with damage to cotton verified as far as 100 miles from the application site (Cline 2012). 2,4-D continues to cause widespread crop injury despite numerous restrictions on formulation types and application methods (Hebert 2004).

5.2.4 HERBICIDES UBIQUITOUS IN WATER, AIR AND RAIN

The discussion above makes clear that while volatility can exacerbate drift, even non-volatile herbicides like glyphosate are problematic when used in large quantities. The same is true of herbicides polluting our water bodies, air and rain: the best predictor of presence is the amount used. As U.S. Geological Survey scientists concluded in an exhaustive analysis of pesticides in U.S. waters from 1992-2001: "[t]he pesticides detected most frequently in streams and ground water were primarily those with the greatest use…" as well as mobility and persistence in water (Gilliom et al. 2006, p. 10).

Despite being both non-volatile and non-persistent in the environment, glyphosate is detected as or more frequently than other herbicides, and at equal or higher concentrations, in the air, rain and waterways of areas like Iowa and the Mississippi Delta where it is heavily used (Coupe et al. 2012, Chang et al. 2011). This underscores the overriding importance of usage level over physical properties when assessing the potential for environmental pollution and associated harms.

Even so, high-level use combined with volatility will in most cases yield the worst outcomes. Many pesticides can "volatilize into the lower atmosphere, a process that can continue for days, weeks, or months after the application, depending on the compound" (USGS 2003), and are then brought back to earth when it rains.

In the Canadian Prairies, where auxin herbicide use is common on wheat fields, measurable levels of 2,4-D, dicamba and other herbicides are frequently found in the air and in rain (Tuduri et al. 2006). At the high end of concentrations detected in rainfall in Alberta, Canada, a mixture of four herbicides (2,4-D, dicamba, MCPA and bromoxynil) was found to negatively impact test plants, leading the researchers to conclude that: "…based on our bioassay results and those of Kudsk et al. (1998), it is our opinion that the occasional high levels of herbicides detected in southern Alberta rainfall could adversely affect dry beans and tomatoes grown in the area." (Hill et al. 2002). Extensive monitoring in Washington State has shown that 2,4-D injury to grapes occurs "from regional nonpoint sources estimated to be as far as 10 to 50 miles away," and correlates with airborne 2,4-D concentrations rather than local pesticide use (Hebert 2004).

Dow AgroSciences and BASF have developed new, lower-volatility salts of 2,4-D and dicamba, respectively, which they claim will mitigate drift damage to crops. However, whatever improvements have been made will be swamped by the massively increased use projected with introduction of resistant crops, and the shift to later-season application (Section 5.1.3.3). Even if many growers use the new salts,[38] 2,4-D and dicamba would drift more, and become much more prevalent in water bodies, the air and the rain. Whether from local drift, regional transport, or toxic rainfall, one can expect substantially more damage to wildflowers in the Midwest. This assessment is supported by a number of studies examining the impact of drift on wild plant communities, to which we now turn.

5.2.5 HERBICIDE DRIFT CAN ALTER THE COMPOSITION OF PLANT COMMUNITIES

Particular species of plants are more or less sensitive to specific herbicides (Olszyk et al. 2013, Boutin et al. 2004), and at different growth stages (Carpenter and Boutin 2010, Boutin et al. 2014), so that exposure can change plant population dynamics in affected areas. 2,4-D, dicamba and other auxin-like herbicides are particularly potent poisons for many species of plants (Rasmussen 2001, US EPA 2006, CFS 2012a), especially broadleaf (flowering) plants that are sensitive to very low drift levels. Even monocots such as members of the grass and lily families can be killed by higher doses of 2,4-D

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[38] Many farmers would likely use cheaper, more volatile formulations.

or dicamba, and suffer sub-lethal injuries from drift levels at certain times in their life cycles (US EPA 2005, 2006; Nice et al. 2004).

Plants—both crop and wild species—are often very sensitive to herbicide injury as flowers and pollen are forming (Olszyk et al. 2004). This has been clearly shown with dicamba injury to tomato plants (Kruger et al. 2012) and soybeans (Griffin et al. 2013), and with glyphosate injury to rice flowers (Wagner 2011). Drift levels of dicamba have also been shown to affect asexual reproduction in potatoes (Olszyk et al. 2010), and seed production in peas (Olszyk et al. 2009), sometimes without accompanying vegetative injury. Glyphosate drift to potato plants impairs the reproductive capacity of the potatoes formed by the exposed plant; when planted the next year, they may grow abnormally or not at all (Worthington 1985). This occurs even when the exposed plant's growth is not affected by glyphosate (Potato Council 2008). There are many other examples of differential sensitivity to particular herbicides (Boutin et al. 2014). Injury affecting flowers and tubers but not the rest of the plant can easily go undetected, but nevertheless have a large impact on reproduction and thus subsequent generations.

Differential sensitivity to herbicides can lead to changes in species composition of plant communities. For example, dicamba or 2,4-D movement away from crop fields in mid-spring may kill sensitive wildflowers at seedling stages, cause male sterility in less sensitive grasses about to flower, but have little effect on younger grasses or still-dormant perennials (Olszyk et al. 2004). These impacts can cause long-term changes in the mix of plant species, favoring annual weeds and grasses over native plants, for example (Boutin and Jobin 1998, Boutin et al. 2008). And if there are herbicide-resistant plants in these habitats, they will of course be better able to withstand drift and may become more abundant (Watrud et al. 2011, CFS 2013a).

Comparison of the plant species mix in the field margins around herbicide-treated (Kleijn and Snoeijing 1997) versus organically-managed (Boutin et al. 2008, 2014) fields reveals differences in plant populations that indicate just these sorts of species shifts from herbicide exposure. Also, "[i]n controlled experiments with plant communities, Pfleeger and Zobel (1995) demonstrated that variable species responses to herbicide exposure may alter the competitive interactions within a community. Such shifts in a community could result in changes in frequency and production and even extinction of desired species…" (Olszyk et al. 2004).

Animals depend on plant biodiversity for most of their needs, so it would be surprising if herbicide induced changes in plant populations had no effects on animal biodiversity around crop fields. Freemark and Boutin (1995) reviewed the literature on how herbicide use has affected wildlife, and found that, as expected, biodiversity has been affected in areas adjacent to sprayed crop fields, including types and abundance of small mammals, birds, and insects.

Pollinators are at particular risk from changes in plant populations and flowering behavior. Recently published comparisons of flowering plants in natural areas around fields that have been exposed to herbicides on a regular basis versus those near fields managed without herbicides show striking differences in the types and abundance of plants in flower, and also in the time of plant flowering (Boutin et al. 2014). Hedgerows next to organic farms had more species, and many of them flowered earlier in the season and for a longer time span. These field observations confirmed greenhouse studies that showed significant delays in flowering of several species after exposure to herbicides (Boutin et al. 2014). Such changes in which plants flower, and when, could affect monarchs as they breed and migrate, disrupting coordination between the butterflies and needed host plant and nectar resources.

5.2.6 BROADLEAF HERBICIDES SUCH AS DICAMBA AND 2,4-D HARM NECTAR PLANTS

Herbicides such as 2,4-D and dicamba that selectively kill broadleaf plants may deprive many insects of nectar and pollen, including butterflies—especially with frequent application over a broad area, as would occur with 2,4-D and dicamba-resistant crops. A study of pesticide effects on butterflies in agricultural areas of England makes this point:

> The frequency and number of pesticide applications, the spatial scale of treatment and the degree of field boundary contamination during each spray occasion will determine the extent of damage to butterfly habitats and populations, and the rate at which populations will return to their original densities. (Longley and Sotherton 1997, p. 8)

These scientists conducted experiments to determine whether restricting the use of "persistent broadleaf herbicides" near field edges would result in more butterflies in the landscape. In one experiment, they sprayed the bulk of the field with the usual complement of pesticides, but modified the spraying apparatus such that only selective grass-killing herbicides were applied to the field edges. They found that there were indeed more butterflies after implementing this measure, and also that there were more flowering plants, "thereby increasing the availability of nectar resources for butterfly species," as well as more biodiversity in general (Longley and Sotherton 1997, pp. 8-9).

Several new field studies in the U.S. —undertaken to assess the potential effects of dicamba use with dicamba-resistant crops—support the English findings. Bohnenblust (2014) found that drift-level doses of dicamba delayed flowering of alfalfa; and both delayed and reduced flowering of common boneset (*Eupatorium perfoliatum*), a wildflower that provides resources to many insect species. In addition, common boneset flowers were less visited by all pollinators when treated with dicamba at rates simulating drift.

A second study explored the impact of a range of drift-level dicamba doses on the plant and arthropod communities in agricultural "edge" habitats (Egan et al. 2014b). The most striking result was a significant decline in the abundance of broadleaf plants over time and with increasing dicamba dose.

Impacts were observed at substantially lower levels—about 1% of the dicamba field application rate—than have been reported to affect plant communities in other studies. This study was conservative in design: dicamba alone was applied just once per year over two years, while farmers often make multiple applications of several different herbicides consistently over many years. More severe impacts would be expected with longer-term use, and with the dicamba-glyphosate mix to be used with dicamba-resistant crops, which could be applied up to three times per year according to the proposed label (CFS 2012c).

In general, the complementary action of glyphosate and either 2,4-D or dicamba, applied in the form of Enlist Duo or Roundup Xtend to resistant crops, would kill or injure a broader range of plants more effectively, and over a broader range of plant growth stages, than either component alone. For instance, standard tests conducted for the EPA show that 2,4-D and dicamba pose a 400- and 75-fold greater risk, respectively, than glyphosate in suppressing seedling emergence of non-target plants; and a 12- and 3-fold greater risk of reducing vegetative vigor (Peterson and Hulting 2004). Conversely, glyphosate is more effective than 2,4-D or dicamba on grass weeds and perennials. Applied together on auxin-resistant crops, drift from these dual products will likely cause greater harm to field-edge plant communities than either component alone.

The implications of these studies are clear for use of dicamba and 2,4-D with resistant crops: these are herbicides that selectively kill broadleaf plants, the main nectar source for adult butterflies, including monarchs. Dicamba and 2,4-D are also likely to be used more often during a season, more extensively in an area, and more continuously over years with resistant crops than they are currently used in agriculture (Section 5.1.3.3). This is precisely the use pattern that the studies discussed above suggest would have long-term, harmful effects on butterflies and other species.

5.2.7 MONARCHS MAY ALSO BE HARMED BY EXPOSURE TO HERBICIDES

Herbicides may directly harm exposed insects, such as monarchs. Some herbicides have been shown to leave residues that cause lepidopteran larvae to stop feeding on herbicide-exposed plants, and also some herbicides directly inhibit enzymes within the exposed insects (as discussed in Russell and Shultz 2009 and Bohnenblust et al. 2013).

For example, glufosinate may have direct effects on lepidopteran pollinators when larvae eat glufosinate-containing pollen, nectar or leaves, either after direct over-spray or from drift. Laboratory experiments with the skipper butterfly *Calpodes ethlias* showed that larvae fed glufosinate-coated leaves were injured or killed by inhibition of glutamine synthase, at doses "comparable to the amount that might realistically be acquired by feeding on GLA [glufosinate]-treated crops." These studies were done with the active ingredient, not a full formulation, and so may have underestimated field toxicity (Kutlesa and Caveney 2001). Glufosinate is applied to several currently grown GE crops, and its use will rise as other glufosinate-resistant crops are introduced (See footnote 10, Table 2, and CFS 2013b).

5.2.8 EPA REGULATIONS DO NOT PROTECT NECTAR PLANTS FROM HERBICIDE DRIFT INJURY

The EPA is charged with regulating the use of pesticides in a manner that protects the environment. However, the frequent occurrence of herbicide drift injury to both sensitive crops and wild plants, as discussed above, demonstrates clearly that EPA regulation is inadequate (see also CFS 2012a, 2012b, Lee et al. 2005, Pfleeger et al. 2012).

The EPA recognized its failure in this arena in 2001, when it proposed that pesticide manufacturers include stronger statements to mitigate drift on pesticide labels, among other measures (US EPA 2001). However, even this weak guidance was never finalized and is not in effect (Goldman et al. 2009), presumably due to stakeholder concerns that certain restrictions such as those prohibiting application at wind speeds greater than 10 mph would be "impractical" in windy areas (US EPA 2001). Flaws in EPA regulation include excessive reliance on computer models that have not been calibrated to predict pesticide drift under real-world production conditions, and the assumption that pesticide applicators comply perfectly with complex, vague and unworkable application restrictions (CFS 2014b). EPA knows that important restrictions are often not obeyed. For instance, over a decade ago the Association of State Pesticide Control Officials told EPA that it "has experience that supports that there are numerous pesticide applications made when it is too windy" (AAPCO 2002). EPA often does not assess volatilization (vapor drift), as for instance in its assessment of dicamba (US EPA 2005), although it is an acknowledged hazard. In fact, the European Food Safety Authority flagged vapor drift as a "critical area of concern" for dicamba use: "[d]icamba has the potential for long-range transport through the atmosphere" (EFSA 2011).

Finally, EPA guidelines for protecting non-target plants from drift injury are deficient. The Agency does not require registrants to test mixtures, for instance the combination of 2,4-D and glyphosate in Enlist Duo, despite the clear potential for greater harms than would be caused by either component alone (Section 5.2.7). Toxicity tests are conducted on too few plant species; and because plants are tested only at a few points in their vegetative development, and not during more sensitive reproductive phases, impacts on communities of wild species are underestimated (Pfleeger et al. 2012, White and Boutin 2007, Olszyk et al. 2013, Boutin et al. 2014). These deficiencies in assessment of herbicide impacts will put the monarch's nectaring and larval habitats at further risk should new herbicide-resistant crops be introduced.

CONCLUSION

In this report, we have shown how the monarch butterfly is threatened by changes in herbicide use that have accompanied adoption of herbicide-resistant crops across the Midwest. Monarch butterflies absolutely require milkweed plants, and common milkweed has been nearly eradicated from Midwestern agricultural fields by the use of glyphosate on Roundup Ready corn and soybeans. These fields had been the main breeding area for monarchs. Monarch numbers have since plummeted, putting the population at risk.

If someone were to intentionally concoct a recipe for how to get rid of milkweed, he/she could do no better than the Roundup Ready crop system. Glyphosate is one of the very few herbicides that kills common milkweed, and is particularly effective when sprayed later in the season on Roundup Ready corn and soybeans.

Thus, only about 1% of milkweeds present in corn and soybean fields in the Midwest in the late 1990s remain, now that over 90% of fields are sprayed with glyphosate, year after year. Although milkweeds are still found in roadsides, CRP land, pastures and other non-crop areas, these habitats cannot begin to make up for the loss of milkweed in corn and soybean fields. Nor is milkweed in non-crop land secure, as more of this land is converted to corn for biofuels, developed, or managed to eliminate it.

The devastation extends beyond milkweed. Flowering plants that provide monarch adults with nectar are also under siege from increasing herbicide use and drift. Next-generation genetically engineered crops resistant to volatile herbicides as well as glyphosate will dramatically exacerbate these impacts. Because most wildflower habitat is found near corn and soybean fields in the Midwest, increased herbicide use and drift will reduce nectar resources that monarch adults require for breeding and for their epic migration.

This outcome should not surprise us. After all, the goal of engineering crops to withstand herbicides is to eradicate all non-crop plant life in agricultural fields. And leading scientists did in fact predict that Roundup Ready corn and soybeans would be disastrous for monarchs.

The ecological impacts of weed eradication as a goal are brought into sharp focus by the fate of milkweeds and monarchs in Roundup Ready corn and soybean fields. Although there are unique features of this monarch story, it serves to illustrate the importance of preserving biodiversity within and around crops, including a variety of weeds at some level. Technologies that help achieve the misguided ideal of total weed eradication threaten not only monarchs but a host of beneficial insects, birds, and other organisms as well. Pollinators, natural enemies of crop pests, and other valued wildlife are suppressed by the collateral damage wrought by heavy and frequent use of plant-killing chemicals with herbicide-resistant crop systems.

This loss of biodiversity in agroecosystems can be mitigated to some extent by restoration schemes outside of crop fields. Wildflower strips at field edges or in natural areas; planting of milkweeds and other important host and nectar plants along roadsides, in parks, schools and other public spaces; restoring flowering plants to riparian areas—these are all important efforts and may help to slow down monarch and pollinator decline.

However, such efforts are doomed to failure if we continue to allow our agricultural fields to become biological deserts—"empty matrices" devoid of all life but corn or soybean. There is simply not enough habitat outside of cropland to ensure a viable monarch population. Common milkweed must be restored to cropland if monarchs are to rebound.

Weed *management* according to agroecological principles and methods must replace herbicidal weed *eradication*. This will require a fundamental shift in the mindset of many farmers and weed scientists, who for decades have operated on the principle that the only good weed is a dead one. While weeds of course require management, it is neither necessary nor desirable to completely eliminate them. Studies show that crops managed organically can yield as well as their conventionally grown counterparts despite several-fold higher weed densities (Ryan et al. 2010, Ryan et al. 2009). And weeds can benefit crops by providing ground cover that inhibits soil erosion and attendant loss of soil nutrients, habitat for beneficial organisms such as ground beetles that consume weed seeds, and organic matter that when returned to the soil increases fertility and tilth (Liebman 1993).

A related fallacy is the false doctrine—taught by pesticide industry representatives and their academic collaborators—that herbicides and tillage are the only practicable means of weed control (Green and Owen 2011), and that tillage is invariably soil eroding and so to be avoided. In fact, farmers and agronomists have developed numerous *cultural* techniques that suppress weeds and in some cases provide other benefits as well, such as reduced soil erosion and increased soil fertility. These include complex crop rotations, cover crops, intercropping (Liebman 1993), fertilization methods that favor the crop over weeds, and closer plant spacing, among other methods (Mortensen et al. 2012). And when used sparingly in conventional systems (Venterea et al. 2006) or more frequently in organic farming (Teasdale et al. 2007), tillage is consistent with the maintenance of high soil carbon levels, which inhibits soil erosion.

The fact that common milkweed has only rarely been a problematic weed for farmers (Section 2.2.5) should lessen concern about its re-introduction to cropland, especially since quite low densities should be sufficient to support viable monarch populations. Milkweed restoration strategies could be pursued in the context of President Obama's recently announced plan to promote monarchs, honey bees and other pollinators (Obama 2014).

A transition from weed eradication to nuanced weed management would provide a number of benefits beyond restoring milkweed and monarch populations. Herbicide-resistant crop systems exert tremendous selection pressure for weed resistance, and have exacerbated an expensive and ultimately futile chemical arms (resistance) race with weeds. As weeds and crops acquire resistance to ever more herbicides (by evolution and biotechnology, respectively), the number and quantity and cost of herbicides applied all increase. Herbicides drift for miles, move with wind-blown dust, rise to the lower atmosphere and literally rain down upon us. The result is herbicide contamination just about everywhere. The negative impacts of pervasive pesticide contamination on health and the environment are being documented from pollinators to frogs to humans.

Restoring common milkweed to agricultural lands is not only vital for monarchs. The changes required to accomplish this goal would be an important first step towards a more sustainable agriculture and a healthier environment for everyone.

POLICY RECOMMENDATIONS FOR RESTORING MILKWEEDS AND MONARCHS

Listing monarch butterflies under the Endangered Species Act (ESA) is essential to their recovery and continued survival. ESA listing would complement and promote other efforts to restore monarchs on the part of government agencies, scientists, monarch support groups, farmers, and pesticide firms. We must utilize all the tools at our disposal to stem further monarch declines and provide the best chance of their survival and recovery. First and foremost, phasing out the use of herbicide-resistant crops would be the best means to restore milkweed and therefore monarchs.

Policy recommendations that have been proposed by organizations and scientists committed to protecting monarch butterflies include but are not limited to the following:

RECOMMENDATIONS FOR THE U.S. FISH AND WILDLIFE SERVICE (FWS)

1. **The FWS should act expeditiously to list the monarch as a threatened species under the Endangered Species Act (ESA).** Listing would be followed by development of a recovery plan and provide resources for restoration of breeding habitat. Earlier this year, Center for Food Safety and colleagues provided the Agency a legal and scientific blueprint for that listing. Listing would also lead to analysis of effects of future federal agency actions on monarchs and consultation with the FWS to address those effects, including developing reasonable and prudent alternative actions when appropriate.

2. **During the development of monarch recovery plans, the FWS should actively engage citizen-scientist groups involved with monarch restoration efforts, public interest groups, and agronomists with expertise in sustainable agriculture.**

RECOMMENDATIONS FOR THE U.S. DEPARTMENT OF AGRICULTURE (USDA)

3. **The USDA should reject applications to approve new herbicide-resistant crops, and EPA should deny registrations of herbicides for use on them, unless or until appropriate restrictions are enacted to ameliorate their harms to milkweeds, monarchs and pollinators.** Those agencies should consult under the ESA with the FWS to develop the appropriate restrictions.

4. **Based on this significant new information regarding monarchs, the USDA should reopen its past assessments of herbicide-resistant crops pursuant to the National Environmental Policy Act (NEPA).** The USDA should undertake new assessments of the effects of those approvals in full Environmental Impact Statements (EIS) or Supplemental EISs, and re-consider whether and if continued cultivation of these crops can occur without further threatening monarch populations.

5. **The USDA should work with farmers and landowners to establish programs to foster populations of common milkweed on land enrolled in the Conservation Reserve Program.**

6. **The USDA should provide incentives to farmers to plant biodiverse "edges" around crop fields that are rich in milkweed and diverse flowering plants for pollinators that are protected from pesticides.**

7. **For anyone growing herbicide-resistant GE crops, the USDA, in consultation with EPA, should:**

a. **Require that growers follow mandatory integrated weed management protocols** with an emphasis on non-chemical modes of weed management that allow for reduced use of herbicides; and

b. **Establish geographic, temporal and/or spatial restrictions for the use of herbicides, in particular glyphosate, so as to protect the main summer breeding habitat of monarchs.**

RECOMMENDATIONS FOR THE U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

8. **The EPA should consider the ongoing and imminent harm from the most damaging herbicidal products to monarchs and suspend, cancel or amend the current registrations for those products to mitigate that harm.** Restrictions imposed via amended registrations and product labels could include but are not limited to: monarch/milkweed "refuge" requirements, geographical or temporal restrictions on use, requiring alternative weed control measures, stronger warnings and directions for use, and other measures.

9. **The EPA should rapidly conclude its Registration Review of glyphosate, taking full account of the impacts on milkweed and monarchs.**

RECOMMENDATIONS FOR CONGRESS

10. **Levy a small fee on the sale of herbicide-resistant crop seed and/or on associated herbicides to fund education on and deployment of sustainable weed management techniques and restoration of milkweed to agricultural lands.** A precedent for such an approach is Iowa's Groundwater Protection Fund, a portion of which partially funds the Leopold Center for Sustainable Agriculture.

11. **Revoke or reduce the tax credits, subsidies and mandates for ethanol that are driving the conversion of grasslands and Conservation Reserve Program land to herbicide-resistant corn production.**

12. **Appropriate funds to facilitate regular monitoring and reporting on the health and population status of the monarch butterfly.**

13. **Create an Interagency Phase-Out Task Force that will provide Congress and Federal Agencies with a 10-year plan to phase out the use of herbicide-resistant crops.**

RECOMMENDATIONS FOR STATES

14. **States should reform roadside weed management practices to spare milkweed (e.g., eliminate use of glyphosate and other milkweed-toxic herbicides, and time mowing for optimum monarch development).**

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