Milkweeds
A Conservation Practitioner's Guide

Plant Ecology, Seed Production Methods, and Habitat Restoration Opportunities

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The Xerces Society
for Invertebrate Conservation

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Front Cover Photograph

Seed harvest underway in a milkweed seed production field at the Native American Seed farm in Junction, Texas. Photo: Native American Seed.

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Introduction

Native milkweeds (*Asclepias* spp.) are perhaps best known for their role as the larval food plants of the monarch butterfly, their distinctive pods, and their wind-borne seeds. There are also many other fascinating aspects of milkweed biology, ecology, and history, with volumes of research conducted on the plants' unique pollination process, novel chemical composition, and relationships with insect herbivores.

Over 70 milkweed species are native to the United States and Canada. The diverse *Asclepias* genus encompasses the almost leafless desert-adapted rush milkweed with photosynthetic stems (*A. subulata*), the aquatic milkweed with seeds uniquely adapted for water dispersal (*A. perennis*), the serpentine milkweed (*A. solanoana)* that only grows in magnesium and iron rich soils in a few locations in California and Oregon, and the colony-forming common milkweed (*A. syriaca*) that plays an indispensable role in the monarch butterfly migration, among others.

Ecologists, native plant enthusiasts, and butterfly watchers have long championed milkweeds, but recent monarch butterfly declines are now focusing greater attention on these plants. Specifically, milkweed loss across much of North America is believed to be a major factor contributing to monarch population declines. With agricultural intensification as a significant cause, milkweeds are disappearing on an unprecedented scale (Brower et al. 2012; Pleasants & Oberhauser 2012). Though milkweed loss is difficult to quantify based upon limited historical data, the losses resulting from the expansion of glyphosate-resistant corn and soybean crops in the Midwest have been well documented. Hartzler (2010) showed a 90% decline of common milkweed in Iowa corn and soybean fields between 1999 and 2009. Pleasants and Oberhauser (2012) estimated a 58% decline of milkweed density in the Midwest landscape between 1999 and 2010, with a corresponding 81% decline in potential monarch reproduction in the region. Urban development and aggressive management (e.g., mowing and herbicide applications) of roadside vegetation have also contributed to landscape-level decline of milkweed (Commission for Environmental Cooperation 2008).

The future of North America's monarch migration is now at risk. Both the protection of existing milkweed stands and the restoration of milkweed populations are key components of monarch conservation. Beyond their role in supporting monarchs and a broad diversity of other invertebrate wildlife, milkweeds are part of North America's legacy of biological diversity and are deserving of conservation efforts in their own right.

A key recommendation of the Commission for Environmental Cooperation's *North American Monarch Conservation Plan* is to plant regionally appropriate milkweed species in areas where milkweed is a limited resource. However, commercial sources of milkweed seed are scarce in many areas of the U.S. This limited seed availability is a major barrier to monarch breeding habitat restoration. At a population scale, this lack of host plants results in fewer butterflies returning to overwintering sites in California and Mexico each year.

To address this seed shortage and the scarcity of monarch host plants, the Xerces Society for Invertebrate Conservation launched Project Milkweed in 2010. The broad objectives of this project are to promote milkweed conservation and increase native milkweed seed availability. In collaboration with the native seed industry, the USDA Natural Resources Conservation Service (NRCS), and community partners, we initiated milkweed seed production in key areas of the monarch's breeding range where seed sources had been scarce: California, the Great Basin, the Southwest, Texas, and Florida. Concurrently, we have worked to increase awareness of the role that milkweeds play in supporting native bees, honey bees, and beneficial insects (including predators and parasitoids of crop pests). The Xerces Society's milkweed conservation work has been funded by a national Conservation Innovation Grant from the NRCS, support from the U.S. Forest Service International Programs' Monarch Joint Venture, Xerces Society members, and private foundations. Please refer to the *Acknowledgements* for a full list of funders.

To date, there has been very little written on propagating milkweed for large-scale seed production. We have produced this guide to: 1) provide the native seed industry with more information about optimizing milkweed seed production, 2) encourage restoration practitioners and land managers who want to incorporate milkweeds into revegetation efforts, and 3) highlight milkweeds' unique characteristics and value to wildlife. The information provided here was synthesized from scientific literature, interviews with native plant producers, and firsthand experience gained through Project Milkweed.

The scope of this document includes:

- An overview of milkweed biology and ecology.
- Descriptions of milkweeds' role in supporting monarchs, bees, and other beneficial insects.
- Guidelines on milkweed propagation and seed production, from seed germination through seed harvesting and processing.
- Profiles of milkweed specialist insects that may present challenges to commercial growers.
- A compendium of known milkweed diseases.
- Advice on including milkweeds in habitat restoration efforts.
- Information on which milkweed species are commercially available and appropriate for planting on a regional basis.

Milkweed Biology & Ecology

Species Diversity and Distribution

Excluding subspecies, there are 72 milkweed species native to the U.S. and Canada (Appendix I). Milkweeds are native to all of the lower 48 states, but do not occur in Alaska and are not native to Hawaii. However, *Asclepias curassavica* and *A. physocarpa*, along with the milkweed relatives *Calotropis gigantea* and *C. procera*, have been introduced to Hawaii from outside of the country. Milkweeds occur in nine of the ten Canadian provinces (excepting Newfoundland). A few species that occur in the U.S. have ranges that extend into Mexico and Central America (Woodson 1954). There are also many unique *Asclepias* species that occur in Mexico, Central America, South America, and Africa (Fishbein et al. 2011).

Within the U.S., Texas and Arizona have the highest species diversity, with 37 and 29 species, respectively. Diversity is comparatively low in the northern U.S., with Washington, Oregon, Idaho, Montana, North Dakota, and each of the New England states having 10 or fewer species. Arizona, California, Florida, Texas, and Utah are the only states that host endemic species (Appendix I).

Life Cycle

Milkweeds native to the U.S. and Canada are perennial and while a few species are evergreen (Appendix I), the majority are deciduous. Milkweeds typically flower between late spring and the end of summer. Following seed dispersal, their aboveground growth dies back to the ground. Two species native to the arid Southwest (*A. angustifolia*, *A. subulata*) flower sporadically throughout the year, in response to seasonal rainfall. Some spring-flowering species (e.g., *A. asperula*, *A. humistrata*, *A. viridis*) may produce a second flush of growth later in the season, in response to summer rains. The nonevergreen species remain dormant through the winter, and reemerge in the spring from established root systems.

Habitats

Across the U.S. and Canada, milkweeds occur in a diversity of habitats including prairies, plains, deserts, open woods, pine barrens, canyons, arroyos, bogs, marshes, and wet meadows (Woodson 1954). Some milkweed species successfully colonize disturbed areas such as roadsides, railways, and agricultural field borders.

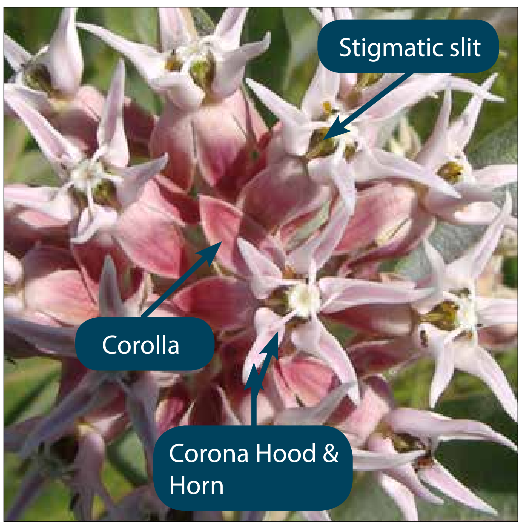
While a few milkweed species are considered weeds by some authorities (e.g., Southern Weed Science Society, Western Society of Weed Science, and Nebraska Department of Agriculture), *Asclepias* spp. are not listed as noxious weeds at either the state or federal level in the U.S.

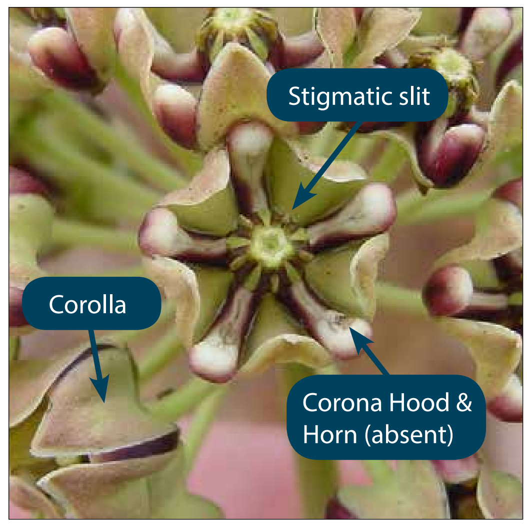
Plant Morphology

Milkweeds are named for their milky sap, which contains latex and complex chemicals (see the *Chemical Ecology* section of this document) that make the plants unpalatable to most animals. When injured, the stems, leaves, and pods ooze this sap. Butterfly milkweed (*A. tuberosa*) is the only species that does not produce this characteristic milky sap (Wilbur 1976).

Milkweed flowers are arranged in flat-topped or rounded flower clusters (umbels). Depending on the species, the stalks bearing these flowers may be either erect or drooping. The showy, upper part of each flower—where nectar is stored—is called the corona and consists of five hoods. Hood shape varies across species and some species' hoods have horn-like appendages. Five petals, together called a corolla, form the lower part of the flower and are reflexed backward in most species. Many authors describe floral morphology in detail, including Woodson (1954), Bookman (1981), and Wyatt & Broyles (1994).

Flower color is strikingly diverse within the genus and includes various shades of white, yellow, green, purple, pink, orange, and red. In some species, the corona and corolla are the same color. Often, though, they are different colors and the corolla's petals may be multicolored.





The structure of milkweed flowers remains consistent, despite one species appearing quite different from another. At left is showy milkweed; at right is antelope horns. (Photos: Eric Eldredge/USDA-NRCS (left); Linda Kennedy/National Audubon Society (right).)

Milkweeds' fleshy, pod-like fruits (follicles) split when mature, releasing the seeds. White, fluffy hairs—known as the pappus, coma, or floss—are attached to each seed and aid in wind dispersal. Aquatic milkweed (*A. perennis*) is the only native U.S. species without floss. Instead, the seeds are adapted for water dispersal (Woodson 1954). Across species, pods are highly variable in shape and size. Some are covered in soft hairs; others are hairless. Common (*A. syriaca*) and showy milkweed (*A. speciosa*) pods are large and teardrop-shaped and sometimes have spiny or warty projections. Narrowleaf (*A. fascicularis*) and swamp milkweed (*A. incarnata*) pods are narrow, tapered, and smooth-textured.

Growth habit is variable. Some species have stout, erect stems and grow up to six feet tall (e.g., common milkweed, showy milkweed), while others are low-growing and sprawling (e.g., pinewoods milkweed (*A. humistrata*), pallid milkweed (*A. cryptoceras*)). Some species are colony-forming and grow in dense stands while others grow in multi-stemmed clumps or as scattered individuals. Even within a species, plant height can vary greatly depending on local genetics and climate. For example, in Project Milkweed seed production fields, showy milkweed in California routinely reaches 5 to 6 feet in height, while in the cooler Maritime Northwest and northern Great Plains, the same species has been commonly observed by the authors to reach a maximum height closer to 3 feet.

Milkweed species vary widely in leaf shape and size: some have broad leaves with prominent veins; others have narrow, folded leaves; and the leaves of some desert-adapted species (e.g., white-stem milkweed (*A. albicans*) and rush milkweed) are highly reduced. Across species, leaf arrangement is opposite, alternate, or whorled. Some species' leaves and stems are densely covered in soft hairs; others are hairless, and some even have a waxy coating.

Milkweed root structure and depth are variable across species. Root morphology ranges from fleshy (*A. glaucescens, A. quadrifolia, A. variegata*) to tuberous (*A. lanceolata, A. longifolia*) to woody (*A. fascicularis, A. subverticillata, A. tuberosa*) (Woodson 1954). Many species are very deep-rooted (Woodson 1954). For example, after one year of growth, common milkweed's taproot may already be over six feet deep (Phippen 2007) and at maturity the species' root depth can exceed 12 feet (Evetts & Burnside 1974). Through their Prairie Roots Project, the University of Northern Iowa has documented that butterfly milkweed roots are more than six feet deep at maturity (Tallgrass Prairie Center, pers. comm.). However, some species, including those associated with aquatic habitats are known to have short, superficial roots (Woodson 1954).

In addition to reproducing by seed, some milkweeds reproduce vegetatively by producing new shoots from adventitious buds on their roots (Evetts & Burnside 1974). Shoots can even emerge from lateral roots located several feet away from the aboveground growth of the parent plant. Of all the species, common milkweed exhibits the highest degree of clonal reproduction. Other species known to reproduce vegetatively, but typically to a lesser degree than common milkweed, are horsetail milkweed, narrowleaf milkweed, plains milkweed (*A. pumila*), prairie milkweed (*A. sullivantii*), showy milkweed, and whorled milkweed (*A. verticillata*) (Authors' personal observations; Anurag Agrawal, pers. comm.; Chip Taylor, pers. comm.). Though they do not produce shoots from lateral roots, some milkweeds (*A. incarnata, A. quadrifolia, A. subulata, A. tuberosa*) have the ability to produce multiple stems from a single root crown (Price & Willson 1979; Anurag Agrawal, pers. comm.).

Aquatic milkweed pod, showing seeds without floss attached. (Photo: Jeff Norcini.)

This 77-inch-long butterfly milkweed root (at front and center) was grown by the University of Northern Iowa's Prairie Roots Project as part of their work to document the root structure of numerous native prairie species. (Photo: Carmen Pellish, UNI Prairie Roots Project, Tallgrass Prairie Center.)

Pollination

Most milkweed species are largely or entirely self-incompatible (Wyatt & Broyles 1994). To produce fruits and seeds, self-incompatible species depend on insects to transfer pollen between unrelated plants. Milkweed flowers have a unique structure and are pollinated in a more specific way than most other insect-visited flowers. Rather than occurring as individual pollen grains that cling to a flower visitor, milkweed pollen is contained in pairs of small, waxy sacs (pollinia) that are located inside five vertical grooves (stigmatic slits) in the flowers. Each pollinium contains several hundred grains of pollen (orchids are the only other group of plants that bear pollinia (Wyatt & Broyles 1994)). Since milkweed pollen is enclosed within pollinia and inaccessible to flower visitors, nectar is the only reward that milkweeds offer to pollinating insects. Milkweed flowers attract a tremendous variety of insects with the abundant, high quality nectar that is readily accessible in their floral hoods.

Honey bee visiting spider milkweed, with numerous pollinia attached to its legs. (Photo: Nancy Lee Adamson, The Xerces Society.)

When an insect visits a milkweed flower to obtain nectar, its tarsi (leg sections), tongue, or mouthparts may slip into a stigmatic slit and come into contact with the corpusculum, a pollinia-bearing gland. A pair of pollinia then attaches to the insect and pollination occurs when the insect inadvertently transfers a pollinium into the stigmatic slit of a milkweed flower of the same species. In addition to an insect's legs or mouthparts, pollinia can be transported on any barbed or hairy surface of the body (Woodson 1954). Although milkweeds have a very specialized pollination mechanism, they do not need specialist insects to pollinate them. Any insect that is large enough to remove and carry pollinia can be an effective pollinator (Ivey et al. 2003).

Though some milkweed hybrids have been documented in nature, most frequently between *A. syriaca* and *A. speciosa* (Woodson 1954; Kaul et al. 1991), interspecific hybridization is rare among *Asclepias* species (Woodson 1954; Wyatt & Broyles 1994). While there are some mechanical barriers to hybridization (e.g., pollinia from large-flowered milkweeds do not fit into the smaller flowers of other species), physiological barriers appear to play a more significant role in preventing hybridization (Wyatt & Broyles 1994).

Great black wasp bearing pollinia on its leg. (Photo: Linda and Robert Scarth.)

A broad spectrum of insects visit milkweed flowers, including bees, wasps, butterflies, moths, flies, beetles, and true bugs (Woodson 1954; Frost 1965). However, these groups of insects are not equally effective at extracting and transferring pollinia, and some do not play a significant role in milkweed pollination (Willson et al. 1979). Large bees, wasps, and butterflies are considered to be the most important pollinators of various milkweed species (Betz et al. 1994; Wyatt & Broyles 1994; Kephart & Theiss 2004). However, the relative importance of each group of pollinators appears to vary across milkweed species (Willson et al. 1979; Kephart 1983; Kephart & Theiss 2004). Also, the visitation rate of particular pollinators to a given milkweed species can vary significantly across years (Fishbein & Venable 1996) and from population to population (Kephart 1983).

Bumble bees (*Bombus* spp.) frequently visit milkweed flowers and their role as milkweed pollinators is well documented (Macior 1965; Jennersten & Morse 1991; Betz et al. 1994; Fishbein & Venable 1996). Eastern carpenter bees (*Xylocopa virginica*), which are very large, strong insects, are frequent visitors and effective pollinators of some milkweed species (Ivey et al. 2003; Theiss et al. 2007). Also, the introduced honey bee (*Apis mellifera*) is a significant pollinator of several milkweed species (Willson & Bertin 1979; Betz et al. 1994; Fishbein & Venable 1996). Large wasps (*Myzinum, Polistes, Prionyx, Sphex, Tachytes, Vespa*) are important vectors of milkweed pollinia (Willson et al. 1979; Betz et al. 1994; Ivey

Black and gold bumble bee visiting butterfly milkweed. (Photo: Sarah Foltz Jordan, The Xerces Society.)

Showy milkweed with western tiger swallowtail. (Photo: Claudia Street, Lake County Farm Bureau.)

et al. 2003). Lepidopteran visitors typically transport and insert fewer pollinia than do bees and wasps (Theiss et al. 2007). However, important butterfly pollinators include swallowtails (*Papilio* spp.) and those in the family Nymphalidae (Betz et al. 1994). Though monarch butterflies frequently visit milkweed flowers, they often do not effectively transfer pollinia (Willson et al. 1979; Betz et al. 1994). Nocturnal moths are documented pollinators of *A. syriaca* and *A. verticillata* (Willson & Bertin 1979; Willson et al. 1979). The majority of milkweed pollination studies have been conducted in eastern states. Thus, comparatively little is known about the suite of pollinators associated with milkweeds that are native to the western and central U.S.

For some flower visitors, there are costs associated with obtaining milkweed nectar. For example, the corpusculum structure that bears the pollinia can remain attached to an insect long after the pollinia have been deposited (Kephart & Theiss 2003). Insects may accumulate strings of corpuscula and pollinia (Frost 1965; Morse 1982) that reduce their foraging speed and cause them to have difficulty maintaining their footing while foraging (Morse 1981). However, one study documented that the "turnover time" for pollinia (on bumble bees) ranges from ½ to 2 days (Morse 1981). While the turnover time of pollinia on any individual insect will be highly variable, the involuntary transport of corpuscula and pollinia is a temporary rather than permanent condition. At higher cost than bearing pollinia, insect legs or mouthparts sometimes become trapped in the stigmatic slits of milkweed flowers. Some insects lose claws or tarsal segments when they struggle to break free (Frost 1965; Morse 1981) while others may become fatally trapped or fall prey to predators (Robertson 1887).

Chemical Ecology

Milkweed plant tissues contain complex chemicals called cardenolides. Molecularly, cardenolides are steroids and are categorized within a broader class of compounds called cardiac glycosides (Malcolm 1991). Numerous other plant genera also include cardenolide-bearing species, some of which have significant medicinal value (Malcolm 1991). Recent studies evaluated the chemical compounds contained in milkweed for their potential role in treating breast cancer (Araya et al. 2012a, 2012b).

Cardenolides are present in all milkweed plant parts (i.e., roots, leaves, stems, latex sap, seeds) (Feir & Suen 1971; Malcolm 1991), and play a role in defending the plants from herbivores, parasites, and pathogens (Malcolm 1991). Yet, monarch caterpillars and other milkweed specialist herbivores have physiological adaptations that allow them to sequester cardenolides and use them in their own defense against predators. However, cardenolides can be toxic or lethal when ingested by animals (including humans) that cannot metabolize or sequester them.

Each milkweed species contains multiple types of cardenolides, which vary in their chemical structure and in the way that they are metabolized by insect herbivores (Brower et al. 1982). Through laboratory analyses, cardenolide profiles (sometimes called "cardenolide fingerprints") can be constructed for a given milkweed species and used to determine which species monarch butterflies fed on as larvae (Brower et al. 1982). Using cardenolide fingerprinting analyses, studies have indicated that the majority (85–92%) of monarchs overwintering in Mexico fed on common milkweed as caterpillars (Seiber et al. 1986; Malcolm et al. 1993). Studies such as these demonstrate that the protection of common milkweed populations is essential to sustain the eastern monarch migration.

The cardenolide concentrations (typically described in micrograms per 0.1 gram of dry leaf tissue) of multiple milkweed species have been investigated or summarized by many researchers including Seiber et al. (1982), Malcolm & Brower (1989), Malcolm (1991), and Panter et al. (2007). However, cardenolide content of a given species can fluctuate seasonally and also varies across populations (Malcolm 1991). Species with relatively low cardenolide concentrations include butterfly milkweed, swamp milkweed, and whorled milkweed (Malcolm et al. 1991; Panter et al. 2007). Species with relatively high cardenolide concentrations include rush milkweed, Utah milkweed (*A. labriformis*), tropical milkweed, woollypod milkweed (*A. eriocarpa*), and pinewoods milkweed (Malcolm et al. 1991; Panter et al. 2007). Research has demonstrated that monarchs that fed on milkweeds with low cardenolide concentrations during their larval stage are potentially palatable to predators, whereas butterflies that fed on milkweeds with high cardenolide concentrations will induce vomiting in most vertebrate predators (Brower 1969).

Potential Toxicity to Livestock

The cardenolides contained in milkweed plant tissues make the plants potentially toxic to livestock such as sheep, cattle, horses, and goats (Panter et al. 2011). Of these animals, sheep and goats are the most likely to be poisoned because they are browsers and often prefer to feed on weeds over other forages (Kingsbury 1964; Dwyer 1978). Milkweed poisoning has also been documented in chickens and turkeys, but avian species are less likely to eat the plants than grazing mammals (Panter et al. 2011). For some milkweed species, consumption of less than 1% of an animal's body weight in fresh material can be a lethal dose (Kingsbury 1964).

Milkweeds are bitter-tasting and unpalatable; animals will avoid eating them when sufficient forage is available (Fleming et al. 1920; Kingsbury 1964; DiTomaso & Healy 2007). Loss of livestock to milkweed poisoning usually results from mismanagement, such as turning hungry animals out where the plants are present or over-stocking animals where milkweed occurs (Fleming et al. 1920; DiTomaso & Healy 2007; Panter et al. 2011). Poisoning may also occur if animals are fed hay containing milkweed (Panter et al. 2011). Milkweed plant material may be more palatable once dried but it retains its toxicity (Fleming et al. 1920; DiTomaso & Healy 2007).

While cardenolide content and composition vary among plant tissues (Malcolm 1991), all milkweed plant parts are potentially toxic, whether fresh or dry (Schultz 2003), and milkweeds are potentially toxic year-round (Fleming et al. 1920). It has been stated that narrow- and whorled-leaved milkweeds are generally more toxic than broad-leaved species (Fleming et al. 1920; DiTomaso & Healy 2007; Panter et al. 2011). However, *A. eriocarpa*, which is broad-leaved, is considered to be one of the most toxic species (Panter et al. 2011).

Symptoms of poisoning include extreme dullness, depression, weakness, unsteady gait, diarrhea, loss of appetite, labored breathing, and seizures (Fleming et al. 1920; Burrows & Tyrl 2006; Forero et al. 2011). For more detailed information about toxic dosages and signs of potential poisoning please consult the cited references.

This paddock has been heavily grazed by horses yet the showy milkweed remains uneaten. (Photo: Brianna Borders, The Xerces Society.)

Preventing Livestock Poisoning

Milkweed poisoning can be prevented through proper range management and by avoiding hay and other prepared feeds that may be contaminated with milkweed.

Best management practices include:

- Stocking pastures at low enough density to ensure that animals have adequate forage (Fleming et al. 1920).
- Not grazing hungry animals where milkweed is present (Fleming 1920).
- Keeping milkweeds out of stock driveways or trails (Schultz 2003).
- Making close observation of animals that are new to an area where milkweed occurs (Schmutz et al. 1968).

Ethnobotanical, Industrial, and Commercial Uses

Milkweeds were historically used as a source of fiber, medicine, food, insulating material, and for the manufacture of flotation devices. More recently, milkweed plant materials were evaluated for industrial applications.

Native Americans' earliest uses of milkweed included weaving cloth from milkweed stem fibers and using the fibers to make cords and ropes (Stevens 2001). They also had numerous medicinal uses for the plants, including treating ringworm and bee stings with milkweed sap and taking infusions of the roots to cure coughs or treat venereal disease (Stevens 2000a, 2000b). Butterfly milkweed root, called "pleurisy root", has many medicinal uses, such as relieving lung inflammation and stimulating lymphatic drainage (Stevens 2001). It is currently sold as an over-the-counter herbal medicine.

Native Americans boiled and ate milkweed tissues including young shoots, leaves, buds, flowers, and immature fruits (Berkman 1949; Stevens 2000, 2001). There are even specific reports of Native Americans adding milkweed buds to deer broth soup and cornmeal mush (Berkman 1949). Common milkweed is still viewed by some as an edible plant and recipes for milkweed preparation are available online. However, it must be noted that although common milkweed is considered to be one of the least toxic milkweeds, even this species' tissues must be boiled for safe consumption. Other milkweed species with higher toxicity may not be safe to eat, even after boiling. We do not recommend the consumption of milkweed.

Milkweeds were strategically and economically important during World War II, when more than 2 million pounds of milkweed seed floss were used to fill life preservers and other flotation equipment (Berkman 1949; Gaertner 1979). Prior to Japan's 1942 seizure of the Dutch East Indies (modern Indonesia), the U.S. had filled life preservers with seed fibers of the kapok tree (*Ceiba pentandra*) that were imported from Asia (Berkman 1949). When access to kapok supplies ceased, the U.S. government sought alternative materials. With its excellent lightweight, water repellant, and insulating properties (as well as its natural buoyancy), milkweed floss was identified as an ideal kapok substitute. In 1943, the federal government established a milkweed processing plant in Petoskey, Michigan. To acquire the needed raw material, the government organized a massive pod collection effort that involved the cooperation of farm organizations, youth clubs, and school children. Within one year, participants collected 25 million pounds of milkweed pods from 26 states, which were then shipped to Michigan via train for processing. Private oil industries used the millions of pounds of seed produced as a by-product of the effort, eager to evaluate the material for industrial applications (Berkman 1949).

During the 1970s and 1980s, milkweeds were investigated as a potential source of biofuels in the U.S. (Adams et al. 1984), but research found the process to be uneconomical (Phippen 2007). However, as recently as 2011, Romanian scientists were evaluating milkweeds as a potential substitute for crude petroleum (Roşu et al. 2011). Milkweed latex has been evaluated as a possible source of natural rubber (Beckett & Stitt 1935; Gaertner 1979), but the plants have not ultimately been cultivated on a large scale for that purpose.

Milkweed floss is currently used as a hypoallergenic filling for pillows and comforters and milkweed seed oil is featured in novel body care products (Knudsen & Zeller 1993; Ogallala Comfort Company 2014).

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The Value of Milkweeds to Wildlife

In addition to their vital role in the monarch butterfly's life cycle, milkweeds provide food or shelter for a diversity of other insects. This includes nectar-seeking bees, butterflies, wasps, and flies, as well as specialist herbivores like seed bugs, longhorn beetles, and leaf beetles. While less is known about vertebrate wildlife interactions with milkweed, hummingbirds use some *Asclepias* species as a nectar source. Additionally, some birds use milkweed seed floss as a nesting material. While this section focuses primarily on milkweeds' value to non-herbivore insects and birds, there is additional information about specialist insect herbivores in the later *Managing Production Fields* section. For specific guidance on designing habitat for wildlife using milkweeds, also see the section *Using Milkweeds in Habitat Restoration Plantings.*

Showy milkweed with monarch butterfly (*Danaus plexippus*), honey bee, and leafcutter bee. (Photo: John Anderson, Hedgerow Farms, Inc.)

Monarch Butterflies

During spring, summer, and early fall, monarchs breed throughout the U.S. and southern Canada, laying their eggs on milkweeds. Several generations of butterflies are produced during each breeding season. Butterflies born in late summer or early fall will likely migrate to either central Mexico or the California coast to spend the winter congregated in forest habitats. Though there are documented exceptions, fall monarchs produced east of the Rocky Mountains typically migrate to Mexico, while monarchs produced west of the Rockies tend to migrate to coastal California. Tens of millions of butterflies overwinter in Mexico (the "eastern population"), whereas hundreds of thousands overwinter in California (the "western population"). Though identified as two different populations, microsatellite marker analyses have revealed that the two are not genetically differentiated (Lyons et al. 2012).

Regardless of which population they belong to, in late winter and early spring, monarchs that have overwintered will begin breeding, then flying northward and eastward in search of milkweeds to lay their eggs on. Once hatched, caterpillars feed on the plants for up to two weeks before forming chrysalises.

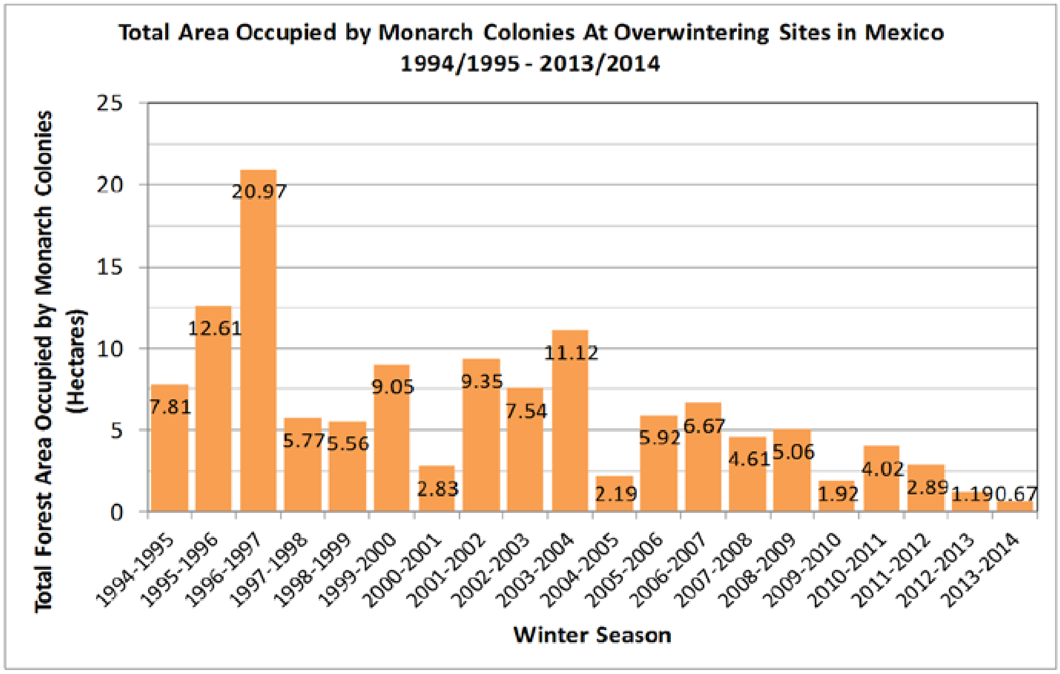
Population Declines

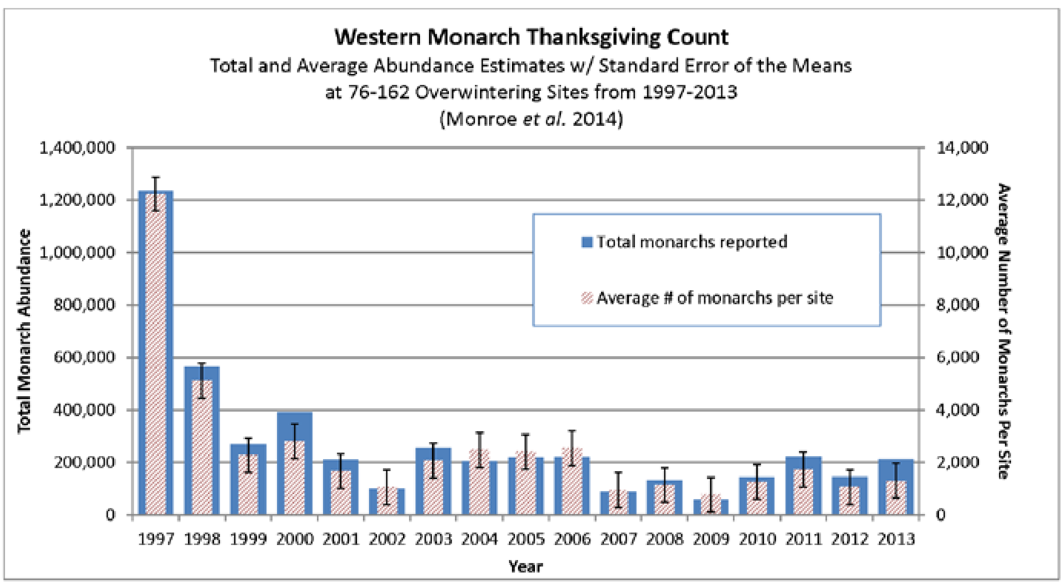
Multi-year annual monitoring of both Mexican and Californian overwintering monarchs has revealed significant population declines (graphs, following page). Over the last 20 years, the average forested area occupied by monarchs in central Mexico was 15.79 acres (6.39 hectares). The 2012–2013 and 2013–2014 populations have been the two smallest (1.19 ha and 0.67 ha, respectively) since comprehensive monitoring began in 1994 (Rendón-Salinas & Tavera-Alonso 2014). Similarly, monitoring of the western population over a 17-year period shows a decidedly downward trend in both the total number of butterflies reported per year and the average number of monarchs per site in a given year (Monroe et al. 2014).

Researchers believe milkweed loss from the monarchs' breeding range is a significant contributor to these declines (Commission for Environmental Cooperation 2008; Brower et al. 2012; Pleasants & Oberhauser 2012). Specifically, a scarcity of milkweeds in the landscape can lead to prolonged search time by gravid female monarchs (Zalucki & Lammers 2010), increasing their susceptibility to predation, inclement weather, pesticide exposure, and other threats. This scarcity also leads to decreased larval survival due to resource competition (Flockhart et al. 2012). As a species (*Danaus plexippus*), the monarch is apparently secure, however a recent NatureServe analysis found that the migratory subspecies that occurs in North America (*Danaus plexippus plexippus*) is considered vulnerable to extinction, and the eastern North American monarch population is considered critically imperiled (Jepsen et al., in press).

Known Monarch Host Plants

Less than half of the 72 milkweed species native to the U.S. are documented as monarch larval hosts (Appendix I). For the remaining species, there is no documentation of their suitability as hosts. Many of the milkweeds for which this information is unavailable have a fairly narrow distribution or are relatively uncommon in the landscape, which results in people having fewer opportunities to observe monarchs using the plants. Milkweed species are highly variable in the traits that defend them from herbivory, such as latex flow, cardenolide concentration of the latex and the leaves, and leaf hair density, so although female monarchs are documented to lay eggs on numerous milkweed species, not all species may be equally suitable larval hosts. Though no comprehensive analysis of which milkweeds can be considered optimal versus sub-optimal larval hosts exists, research suggests a reduction in monarch caterpillar survivorship and growth rate occurs when they feed on species with high latex flow and high cardenolide concentration (Zalucki et al. 2001).





Top: Estimated forest area occupied by colonies of overwintering monarchs in Mexico from 1994 to 2014 (Courtesy Monarch Joint Venture; data from World Wildlife Fund–Mexico and MBBR). Bottom: Estimated monarch numbers at California overwintering sites from 1997 to 2013.

Several plant genera (e.g. *Apocynum, Cynanchum, Funastrum, Matelea*) are classified in the same family as *Asclepias* (Apocynaceae), yet almost none of the species in these genera are suitable larval hosts for the monarch butterfly. Sand vine (or honey vine (*Cynanchum laeve*)) is one non-*Asclepias* species that is a suitable host for monarchs (Bartholomew & Yeargan 2001). In contrast, black swallow-wort (*C. louiseae*) and pale swallow-wort (*C. rossicum*), which are both introduced to the U.S., may function as population sinks for monarchs because butterflies will lay eggs on the plants, yet caterpillars are unable to feed on the foliage and die within a few days of hatching (Casagrande & Dacey 2007).

Other Butterflies and Moths

Adult butterflies and many moths feed primarily on nectar, and milkweeds are a valuable nectar source for many of those species. Common milkweed (*A. syriaca*) produces nectar both night and day and pollinators, including nocturnal moths, visit it 24 hours a day (Willson & Bertin 1979; Morse & Fritz 1983). Other milkweed species' nectar production and nocturnal visitation has not been well studied. Milkweeds are also larval hosts for moths and butterflies other than monarchs, including:

- Queen butterfly (*Danaus gilippus*)
- Dogbane tiger moth (*Cycnia tenera*)
- Unexpected cycnia (*Cycnia inopinatus*)
- Milkweed tussock moth (*Euchaetes egle*)
- *Pygoctenucha terminalis* [no common name ascribed]

From left: Milkweed tussock moth (Photo: David Cappaert, Michigan State University, Bugwood.org); Queen butterfly (Photo: Desert Botanical Garden); Dogbane tiger moth (Photo: David Cappaert, Michigan State University, Bugwood.org.)

Native Bees

Wild, native bees are essential pollinators of both native plants and commercial crops, yet many are threatened by human activity. Significant threats include loss and fragmentation of nesting and foraging habitat and pesticide poisoning. Adult bees require nectar as their primary food source and milkweeds play an important role in supporting a broad diversity of bee species. Some of the native bee genera and species that various milkweeds attract include:

- Many species of bumble bees (*Bombus* spp.), including the rusty-patched bumble bee (*Bombus affinis*), western bumble bee (*B. occidentalis*), American bumble bee (*B. pensylvanicus*), and yellow-banded bumble bee (*B. terricola*) (Frost 1965; Macior 1965; Jennersten & Morse 1991; Betz et al. 1994; Xerces Society unpublished data), all four of which have recently attracted conservation concern due to documented range reductions (Cameron et al. 2011; Xerces Society unpublished data).
- Various carpenter bees, including the eastern carpenter bee (*Xylocopa virginica*) (Kephart 1983; Ivey et al. 2003; Kephart & Theiss 2004; Theiss et al. 2007).
- Multiple species of solitary bees including various digger bees (*Anthophora* spp.), sweat bees (*Halictus* spp.), plasterer bees (*Colletes* spp.), leafcutter bees (*Megachile* spp.), and more (Betz et al. 1994; Fishbein & Venable 1996).

Honey Bees

Managed honey bees are essential for the pollination of numerous crops. Research has shown that they are healthier and more resistant to diseases when they have access to diverse and abundant floral resources (Alaux et al. 2010). Milkweed pollination studies have demonstrated that honey bees are some of the most frequent visitors of clasping milkweed (Betz et al. 1994), common milkweed (Willson & Bertin 1979), butterfly milkweed (Fishbein & Venable 1996), purple milkweed (Betz et al. 1994), prairie milkweed (Betz et al. 1994), swamp milkweed (Betz et al. 1994), and whorled milkweed (Betz et al. 1994). When milkweeds are planted in the vicinity of bee-pollinated crops or are growing wild within the foraging range of managed honey bees, they offer bees a nectar source that is especially valuable when the main crop is not blooming.

Numerous authorities on beekeeping have touted milkweeds' considerable value for high-quality honey production (Cook 1902; Pellett 1916; Lovell 1926; Root 1954). A large honey bee colony can potentially gather 13 to 17 pounds of nectar from common milkweed in one day (Lovell 1926; Root 1954) and beekeepers (in northern Michigan) have reported an average production of 50 pounds of honey per colony when bees had foraged on milkweed (Pellett 1976). The International Bee Research Association classifies North American milkweeds as class 1 or 2 for honey production, meaning that if milkweed occurred in a contiguous one-acre stand, that acre would have a theoretical yield of up to 45 pounds of honey (Ramsay 1987).

As quoted in Pellett (1976), apiculturist James Heddon wrote in 1887 of butterfly milkweed (*Asclepias tuberosa*; also known as pleurisy root): "If there is any plant to the growing of which good land may be exclusively devoted for the sole purpose of honey production, I think it is this. I would rather have one acre of it than three of sweet clover. It blossoms through July and the half of August, and the bees never desert pleurisy root for basswood or anything else. The blossoms always look bright and fresh, and yield honey continuously in wet and in dry weather. Bees work on it in the rain and during the excessive drought of the past season, it did not cease to secrete nectar in abundance."

Heddon continues, "It is the best honey yielding plant with which I am acquainted, white clover and basswood not excepted. It is eminently adapted to light sandy soil, doing well upon land too poor to produce ordinary farm crops."

Some honey bee losses are known to occur when the insects are either trapped in milkweed flowers or encumbered by chains of pollinia and corpuscula (pollen sacs and their associated structures) that they have inadvertently extracted from the flowers (Lovell 1926; Root 1954). Please see the *Pollination* section of this document for further details on milkweed reproduction. Also, milkweed pollinia sometimes accumulate at hive entrances (Willson et al. 1979), and bees that return to the hive heavily burdened with pollinia are sometimes expelled from the hive due to their inability to work efficiently (Cook 1902; Woodson 1954).

Beneficial Insects

In addition to attracting pollinators, milkweeds support a wide variety of insects that attack crop and garden pests. Among these predatory and parasitoid insects are multiple species of beetles, true bugs, wasps, and flies. Collectively, these types of beneficial insects provide an economically important check on populations of aphids, caterpillars, slugs, mites, whiteflies, mealybugs, and thrips. In nearly all cases, the beneficial insects attracted to milkweed use the plants' nectar as an alternative food source during one or more of their life stages. Unlike bees and butterflies, whose relatively long tongues enable them to access deep nectar reservoirs, most predatory and parasitoid insects have relatively short tongues and preferentially forage on flowers with easily accessible nectar, like milkweeds (Mäder et al. 2011).

Because of their attractiveness to beneficial insects, planting milkweeds (and other wildflowers) in agricultural landscapes is a strategy for enhancing natural biological control. In Michigan, swamp milkweed (*A. incarnata*) is documented as very attractive to natural enemies of crop pests (Fiedler et al. 2007), and in North Carolina, butterfly (*A. tuberosa*) and common milkweed have been included in field border plantings designed to provide beneficial insect habitat (Plush et al. 2013). A study conducted in Washington state vineyards evaluated 43 species of native flowering perennials for their potential to attract beneficial insects. Showy milkweed (*A. speciosa*) attracted the most beneficial insects of any plant species studied, including mite-eating lady beetles (*Stethorus* spp.), minute pirate bugs (*Orius* spp.), hover flies (Syrphidae), and parasitic wasps (Ichneumonidae, Braconidae) (David G. James, unpublished data). In Georgia, the USDA Agricultural Research Service has demonstrated that incorporating milkweed into peanut–cotton farmscapes can effectively increase the parasitism of cotton crop pests (stink bugs and leaf-footed bugs) by a tachinid fly (*Trichopoda pennipes*) (Tillman & Carpenter 2014). This benefit appears to be attributable to the milkweeds' ability to attract and support adult *T. pennipes* with floral nectar.

Vertebrate Wildlife

Information about milkweeds' role in vertebrate wildlife ecology is scarce, though researchers have documented some associations. For example, observers have seen the black-chinned hummingbird (*Archilochus alexandri*) and the red-throated hummingbird (*A. colubris*) nectaring on butterfly milkweed and common milkweed, respectively (Southwick 1983; Fishbein & Venable 1996). In addition, small passerine birds such as the vermilion flycatcher (*Pyrocephalus rubinus*) have used milkweed floss to line their nests (Hilton Pond Center for Piedmont Natural History 2013). Also, birds such as black-capped chickadees (*Poecile atricapillus*) and Baltimore orioles (*Icterus galbula*) sometimes harvest fibers from previous years' milkweed stalks to use as nesting materials (Stewardship Garden 2013).

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Milkweed Propagation and Seed Production

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Outside of the central Midwest, where a well-established native seed industry exists, the scarcity of commercially available sources of milkweed seed has limited greater incorporation of these plants into habitat restoration efforts. Even within the Midwest, fluctuations in native seed inventory among commercial producers can result in temporary milkweed shortages and high seed prices. The information provided here is intended to help change the status quo. We hope that with guidance acquired from successful seed producers across multiple regions, the latest research findings on milkweed pest and disease ecology, and our direct observations from milkweed seed amplification field trials that we managed in six states, growers will increase their commitment to the production of these vital plants, and milkweeds will more effectively contribute to the profit margin of this important industry.

These brown seeds are fully mature and since the floss fibers have not yet expanded, this is the ideal stage for efficiently hand-stripping seeds from the pod. (Photo: Brianna Borders, The Xerces Society.)

These yellow seeds are immature and are not likely to be viable. This pod was likely cut open for display purposes, rather than having opened on its own. (Photo: John D. Byrd, Mississippi State University, Bugwood.org.)

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Wild Seed Collection

Launching a seed production effort inevitably requires a source of foundation seed. In most cases, this entails harvesting seed from a wild population of plants. This can be an uncertain endeavor, its outcome highly dependent on timing and other factors beyond the collector's control. A wild seed collection effort consists of identifying suitable source populations, acquiring the necessary permission for land access and seed collection, and making appropriately timed visits to collect seed.

Delineating the extent of a plant population can be challenging. To do so accurately would require knowledge of a species' population genetics and an estimate of the potential for gene flow among individuals. For seed collection purposes, we define a population as one or more aggregations of plants that are collectively isolated from other individuals of the same species by at least one mile. Most milkweed species are self-incompatible, requiring pollen transfer between unrelated plants in order to produce fruits and seeds. Thus, the distance between interbreeding plants is largely influenced by the distance that their pollinators typically travel while foraging. While honey bees are known to forage (and thus potentially transport milkweed pollinia) over distances greater than one mile, most native bees typically fly shorter distances.

For milkweed species that reproduce vegetatively (please refer to the *Plant Morphology* subsection), such as the colony-forming common milkweed and showy milkweed, accurately assessing the number of individual plants in a stand or population can be difficult. It is possible that many (or all) of the flowering stems in a stand originate from the same root system and thus are genetically identical. However, if plants are separated by a distance of greater than 25 feet (within which no plant stems of that species occur), it is highly unlikely that they originate from the same rootstock. The authors once monitored a showy milkweed stand consisting of over 100 flowering stems that ultimately produced only one fruit over the course of two growing seasons, despite observed pollinator visitation and the apparently healthy condition of the plants. There were no other showy milkweed plants located within a several-mile radius and it is possible that the stand did not contain enough genetic diversity for cross-pollination and seed set to occur.

Permission to collect seed should be obtained in writing. In some instances (e.g., on public lands), you may need special permits from the land management agency and it may take several weeks to obtain them. Always carry copies of permits when scouting locations and collecting seed.

When seeds are mature, milkweed pods split open along lengthwise seams. Seed is brown when mature. Green, yellow, or white seed is immature and should not be collected. The center portion of a mature, "filled" seed should be swollen and firm, which indicates that it contains an embryo. In contrast, the center portion of an unfilled seed is depressed or easily collapses with gentle pressure.

The ideal time to hand-collect pods is when the seeds inside have matured and turned brown but the pod seams have not fully opened and the floss fibers have not yet expanded. At this stage, seed can be easily hand-stripped from the pod while leaving the unexpanded floss behind.[1] When pods have opened

[1] Aquatic milkweed (*Asclepias perennis*) is the only milkweed species native to the U.S. for which the seeds lack an attached pappus.

and the floss has expanded, efficient seed collection becomes much more challenging. You can test an unopened pod for maturity by applying gentle pressure to the seam. If the seam does not open readily, the seed inside is immature.

Obtaining the target amount of seed may require multiple trips into the field. On any given visit to a potential source population, pods may be immature or only a few might be ready for collection. Since seed is dispersed within a day or so of the pod seam beginning to split open, the window of opportunity to collect seed from any one pod is narrow. Accurately timing your visits to populations can be challenging, but there are a few tricks that effectively extend the seed collection window and increase your chances of making a successful collection.

For example, paper or fabric seed capture bags can be attached over maturing pods and retrieved at a later date. Using these bags can give a seed collector several days of flexibility in scheduling a return visit. Please refer to the *Seed Harvesting* section for a more detailed description of this method. Alternatively, rubber bands can be applied to the widest part of nearly mature pods to prevent them from fully dehiscing. Compared to seed capture bags, rubber bands are less conspicuous and less expensive, but their use may only extend the collection window by a couple of days. The seeds are likely to fall out of the pod if you do not return to collect them soon after the pod splits. Please refer to the *Seed Processing* section for guidance on how to clean small seed lots.

Even with careful planning, unanticipated events may still interfere with successful seed acquisition. As mentioned, plants that appear healthy may fail to produce fruits or seeds. Similarly, under drought conditions, plants may produce little to no viable seed, delaying collection efforts until at least the following year. Also, inclement weather during the plants' bloom period may interfere with pollination, impacting seed set (Betz & Lamp 1992). Potential source populations that are being monitored for seed maturation may be unexpectedly mowed, treated with herbicide, or browsed by herbivores before seed can be collected. Considering these potential scenarios, it is advisable to identify and monitor multiple populations.

Finally, it is important to avoid depleting wild populations by overharvesting seed. A recommended guideline is to collect no more than 20% of the seeds within a population on any given day (Bureau of Land Management 2012).

Rubber bands were placed around the widest part of maturing pods, several days before this photo was taken, to prevent pods from fully opening and dispersing their seeds before the seed collector could return. The species shown is pinewoods milkweed. (Photo: Jeff Norcini.)

Seed Germination

Milkweed seeds do not germinate upon dispersal in the summer or fall. Rather, the onset of germination is delayed until late winter or spring when the seeds have after-ripened and environmental temperatures increase to match the seeds' germination requirements (Baskin & Baskin 1977). This phenology is not unique to milkweeds; most perennial forbs native to the U.S. exhibit this pattern of seed dormancy during fall and winter.

The majority of milkweed germination studies have been conducted on common milkweed (*A. syriaca*), in some instances to document options for controlling the plants as undesirable weeds. A few germination studies have been done on butterfly milkweed (*A. tuberosa*). The germination requirements of most native milkweeds have not been described in the literature, and it is unknown whether the results from studies of common and butterfly milkweed apply to other species.

Stratification (exposure to cold, moist conditions) is likely to be the most effective seed treatment for native seed producers. When milkweed seed is direct-sown in the fall, stratification will happen naturally over the winter. We will briefly describe other seed treatments that have been conducted on milkweed, but compared to stratification they are either more labor-intensive or less effective at enhancing germination. Also, some of the treatments require the use of chemicals that may not be readily accessible.

Stratification

Several studies of common and butterfly milkweed have shown that the germination rate of milkweed seed is significantly enhanced by a period of cold, moist stratification prior to sowing (Berkman 1949; Jeffery & Robison 1971; Baskin & Baskin 1977; Bir 1986). Milkweed seed will germinate without exposure to a cold period, but germination is sporadic and proceeds at a much slower rate (Cullina 2000; Roşu et al. 2011). In these studies, researchers typically stratified seed at temperatures of 40–41°F (4–5°C). Following stratification, recommended germination temperatures for milkweed range from approximately 65 to 80°F (18 to 27°C) (Luna & Dumroese 2013). While research has shown percent germination to increase in response to just one week (Jeffery & Robison 1971; Baskin & Baskin 1977) or one month (Bir 1986; Roşu et al. 2011) of stratification, extending the treatment period for up to nine weeks may continue to increase germination (Baskin & Baskin 1977). However, the potential for seeds to rot will increase with the length of time that they are stored under damp conditions.

Some milkweed germination studies have not demonstrated a positive result from this treatment. (For example, Greene & Curtis' (1950) investigation of *A. tuberosa* and Skinner's (2008) work on *A. speciosa*). The effect of stratification may vary across years, regions, and different seed lots of the same species (the latter due to variability in levels of seed dormancy).

Although the effect of stratification has not been documented for most milkweed species, it is straightforward and easy to perform. As mentioned, when milkweed seed is planted in the fall, stratification

Directions for Artificial Stratification

Native American Seed staff blending milkweed seed with moist vermiculite before refrigerating the mixture for several weeks in preparation for spring planting. (Photo: Native American Seed.)

Combine the seeds with an equal or greater volume (up to three times) of dampened sand, perlite, vermiculite, or other sterile media. The media should be moist but not wet; it should not drip when squeezed. Place the seed and media in a sealed plastic bag and store the bag in a refrigerator for 4–6 weeks. The standard temperature range of a household refrigerator will be perfectly suitable for this seed treatment. The seeds should be chilled but not frozen, because the formation of ice crystals can damage seed. Store the seeds in the fridge until you are ready to plant. Sow the contents of the bag immediately upon removing it from cold storage. Whether seeds are sown indoors or outdoors, the soil in the planted area must be kept moist for the entire germination period.

happens naturally over the winter and no additional seed treatment will be required. When propagating seedlings or direct-sowing seed in the spring, artificial stratification in a refrigerator is recommended to enhance germination. As long as stratified seed does not become moldy and is not allowed to dry out during the germination period, there is little risk in performing the treatment. For more information about producing milkweed transplants, please see the *Transplanting* section of this document.

If you have more seed than is needed for immediate propagation, consider experimentally stratifying only a portion of the seed lot and comparing the germination rate between treatments.

Additional Seed Treatments

Beyond stratification, there are other seed treatments that can be performed on a small scale in a laboratory or greenhouse setting. However, these treatments are typically less feasible for treating large seed lots (e.g., pounds of seed) due to the labor and materials involved.

Mechanical Scarification or Seed Coat Manipulation

Cutting the seed coats, pricking seeds with a dissecting needle, and rubbing seeds between sandpaper have been documented to improve germination, compared to no seed treatment (Evetts & Burnside 1972; Oegema & Fletcher 1972). However, Evetts and Burnside (1972) found that stratification produced a two-fold increase in germination rate as compared to pricking seeds or rubbing them with sandpaper. Removing the entire seed coat can quickly produce 100% germination of all viable seeds, but requires extreme care and skill (Oegema & Fletcher 1972). The Phytophagy Lab at Cornell University, which has considerable experience with milkweed propagation, prepares milkweed seeds by nicking their coats with an X-acto knife, storing them between moist filter paper in the dark at 40°F (4°C) for 1–2 weeks, and then germinating them in the dark at 82°F (28°C) (Anurag Agrawal, pers. comm.).

Chemical Treatments

Evetts and Burnside (1972) attempted to chemically scarify common milkweed seeds by soaking them in sulfuric acid, acetone, and ethanol. Concentrated sulfuric acid caused a reduction in germination, and acetone and ethanol had no significant effect on germination. They also primed seeds with potassium nitrate, which produced a significant increase in germination (but to a lesser extent than did cold, moist stratification). Treating milkweed seed with growth regulators such as kinetin and gibberellic acid has been shown to have a positive effect on germination (Evetts & Burnside 1972; Oegema & Fletcher 1972). Describing the methodology behind these chemical treatments is beyond the scope of this document; please consult the scientific literature for more information.

Other Factors Influencing Germination

Light

There is little documentation as to whether milkweed seed requires light to germinate. In reference to the entire *Asclepias* genus, Cullina (2000) states that light is a requirement, while Mitchell (1926) reports that light does not affect butterfly milkweed germination. Deno (1993) describes variable responses within the genus, with light being required for swamp milkweed (*A. incarnata*) germination, beneficial to poke milkweed (*A. exaltata*), and having no effect on butterfly milkweed or green comet milkweed (*A. viridiflora*). Deno suggests that dependence on light for germination is determined more by a species' environment than its phylogeny.

Length of Dry Storage

Whether dry storage aids in breaking down germination inhibitors is not well documented. Cullina (2000) states that a year of dry storage may enhance the germination rate of untreated milkweed seed. Bir (1986) reports that 3 months of cold dry storage had no measurable effect on butterfly milkweed germination. When common milkweed seed was stored at room temperature for 18 months and then germinated at 79°F (26°C), germination was only about 10% higher than when seed was freshly harvested (Oegema & Fletcher 1972). While there is little evidence to suggest that a period of dry storage will increase germination, further documentation would be helpful.

Field Establishment

Depending on your access to planting equipment and production field scale, multiple approaches are available for establishing milkweed fields for mass seed production. Before examining field establishment methods, note that all native milkweeds are perennials and while some (e.g., *A. eriocarpa, A. fascicularis, A subulata*) will likely flower and produce seed within the first year, others (e.g., *A. asperula, A. cordifolia, A. incarnata, A. syriaca, A. tuberosa, A. viridis*) may require multiple years to reach reproductive maturity (Hedgerow Farms, Inc., Native American Seed, Arizona Western College, pers. comm.). Even within a single species, maturation rates may vary depending on the source population's origin and where it is planted for seed production. For example, in California, showy milkweed plants may reach reproductive maturity within a single growing season when established from seed, while the same species may require two or more years to reach maturity in the northern Great Plains. For some species, establishing a production field with the use of transplants or root segments[2] (Western Illinois University 2007) rather than seed may allow for a seed harvest within the first growing season.

Researchers have reported that peak seed production of butterfly and common milkweed occurs during the second growing season and that field stands typically remain productive for 3–5 years (Houseal 2007; Phippen 2007). It is unknown whether this holds true of other milkweed species. Of course, both seed production and stand life can be variable and somewhat unpredictable from year to year. For example, there is an anecdotal report of a butterfly milkweed stand producing a peak seed harvest in its 10th year, even though the field had not been actively managed. In another case, the authors have received reports of a butterfly milkweed field in Michigan (used for commercial floss production) that has persisted for decades.

Here, we outline three potential methods for establishing seed production fields (Table 1), and then provide further details about each method.

[2]This approach will likely only work for species that display clonal root growth. When sourcing root segments, keep in mind that those located within a few feet of each other may be genetically identical. Harvesting roots from multiple locations within a source population and from more than one population will help incorporate genetic diversity into the field. Milkweed root harvest should only be conducted with appropriate landowner permission and in a sustainable manner that does not threaten the survival of the source population.

Table 1: Approaches to Establishing Seed Production Fields

Method: Drill Seeding

Requirements	Benefits
• Specialty seed drill designed or modified to handle wildflower seeds; note that seed drills configured for sunflower planting may effectively handle milkweed seed. • Sufficient amount of foundation seed (you will likely need a minimum of one-half pound of pure live seed (PLS) to seed a ¼-acre field and make it worthwhile to utilize a seed drill)[3]. • Adequate site preparation to reduce weed cover and the amount of weed seeds in the soil.	• Requires minimal time and labor. • Seeds can be planted at a chosen depth and rate, in evenly spaced rows. • Achieves excellent seed-to-soil contact.

Additional Considerations

- Renting or utilizing a seed drill is likely only cost-efficient for fields with a minimum size of ¼ acre.
- Irrigation may be required when seasonal rainfall is limited.
- If seed is planted in the fall, cold, moist conditions during winter will enhance germination in the spring. For spring planting, stratifying seed for 4–6 weeks prior to planting is recommended.

[3] Example: When single rows are spaced 40 inches apart, there are an estimated 13,800 linear feet in a 1-acre field. Given this row spacing, to seed a 1-acre field at a rate of 12 live seeds per linear foot, approximately 165,600 seeds would be needed. Although variable with the milkweed species being planted, this translates to roughly 2–4 PLS pounds.

Method: Transplanting

Requirements	Benefits
• Sufficient growing space (e.g., a greenhouse, lath house, or other similar setup), propagation supplies, and expertise to produce healthy transplants or the financial resources to establish a grow-out contract with a professional plant nursery. • Adequate site preparation to reduce weed cover and the amount of weed seeds in the soil. • Available labor force that matches the scale of the transplanting effort. • Equipment and labor force for irrigating transplants during the first growing season.	• Plants may produce seed during their first growing season, whereas plants started from seed may require two or more growing seasons. • With adequate pre-planting site preparation, transplants will have a competitive advantage over weeds. • Requires less foundation seed (i.e., grams or ounces rather than pounds) than drill-seeding. • If seed supplies are limited and every seed is valuable, this approach allows for greater influence over the survival of each individual plant (as compared to direct seeding). • Is feasible on any scale, provided that a sufficient labor force is available for larger efforts.

Table 1: Approaches to Establishing Seed Production Fields	
Method: Transplanting (cont'd)	
Additional Considerations	
• Transplanting should only be done after the threat of frost has passed and should also be timed to avoid prolonged periods of hot, dry, or windy weather. Use of dibble sticks or mechanical vegetable transplanters is recommended for ease of establishing transplants. In addition, we have found that deep pot transplant trays provide enhanced root growth in milkweed transplants and likely increase transplant survival.	
Method: Hand-sowing *To establish a small-scale production plot (e.g., from a few hundred square feet up to 1/8 acre) when neither planting equipment nor the labor and resources required to produce transplants are available, seeds can be hand-sown.*	
Requirements	Benefits
• Adequate site preparation to reduce weed cover and the amount of weed seeds in the soil.	• Requires no equipment.
Additional Considerations	
• If planting seed in the fall, cold, moist conditions during winter will enhance germination in the spring. For spring planting, we recommend stratifying the seed for 4–6 weeks prior to planting. • Supplemental water may be necessary to facilitate establishment if rainfall is limited. • Incorporate seed into the upper inch of soil, using a rake. To achieve good seed-to-soil contact, you can then tamp the soil down with a turf roller or by walking over the planting site.	

Drill Seeding

Suitable Equipment

Grain drills, unlike specialty native seed drills, generally do a poor job of handling small or fluffy wildflower seeds. However, given milkweed seeds' larger size, some modified grain drills may be effective for planting milkweed. Milkweed seeds are generally best planted just below the soil surface, so drills with adjustable depth settings should be modified accordingly.

Additionally, vegetable seed drills (such as 'Planet Junior'[4] type seeders) may be effective for planting milkweed when the appropriate seed plates are used. The shape and size of milkweed seeds are similar to some vegetable seeds, such as cucumber and melon, for which custom seed plates exist. Similarly, seed drills capable of planting sunflower seed will likely handle milkweed seed of comparable size. For some seeders, blank seed plates are also available that can be custom cut to accommodate seed of a specific milkweed species. Again, adjust depth settings accordingly (see the *Planting Depth* subsection).

Timing of Seeding

Fall seeding can be advantageous because it approximates the timing of natural seed dispersal, and exposure to cold, moist soil conditions during winter will stimulate germination in the spring. Alternatively, spring seeding provides opportunities to control weed growth during winter and early spring using mechanical or chemical methods, without concern for disturbing the seedbed. Spring seeding may also reduce the potential for seed predation because the seeds will spend less time in the soil before germinating. Artificial stratification of seed is recommended prior to spring planting to enhance germination.

Regardless of the timing of seeding, it is important to keep the seedbed free of competing weeds, as milkweeds typically germinate after annual winter weeds. There may be a window of opportunity to control weed growth with a post-emergent herbicide during winter or early spring, before milkweeds germinate. (Note: ensure that milkweed germination has not occurred before applying any broadleaf herbicide!)

Planting Depth

A planting depth of ¼ to ¾ inches is ideal, according to scientific literature and milkweed seed producers (Jeffery & Robison 1971; Evetts & Burnside 1972; Houseal 2007). Sowing at depths greater than ¾ inch will likely have a negative effect on seedling emergence.

Seeding Rate

Suitable seeding rates for establishing milkweed production fields typically range from 2–20 live seeds per linear foot, based upon the feedback of commercial producers. Having your seed lot professionally tested for viability can help inform how densely to seed the field. When seed supplies are limited and every seed is valuable, or if seed viability is known to be high, using a lower seeding rate is a conservative approach. However, if germination is uneven, there may be a greater degree of weed encroachment into the stand or a need to fill in gaps with transplants. If seed supplies are not limited, or if seed lot viability is low or unknown, it can be advantageous to seed at a higher rate to promote vigorous germination and establishment. This may result in the need to hand-thin seedlings that germinate at high density, but it will be a more favorable outcome than uneven stand establishment.

[4] Brand names that appear in this document are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned.

First year growth of a direct-seeded showy milkweed production field. (Photo: John Anderson, Hedgerow Farms, Inc.)

In this direct-seeded showy milkweed production field, seeds germinated densely and seedlings had to be thinned to reduce competition. (Photo: John Anderson, Hedgerow Farms, Inc.)

Calculating Your Potential Production Field Size

If you have a target seeding rate in mind, you can calculate how large of an area can be planted with your available seed. If your foundation seed has been professionally tested for purity and germination, you can base your calculations on pure live seed (PLS). PLS is the amount of seed in a bulk seed lot that is viable and has the potential to germinate. If a current seed test is unavailable, you can refer to existing estimates of bulk seeds per pound for your target species (some seed count data is presented in Table 4). You can also conduct your own seed count, and base your calculations on bulk seed.

Pure Live Seed (PLS) Calculations

The formula for calculating PLS is:

Percent (%) purity x percent (%) total germination / 100 = % PLS

Sample pure live seed calculation:

If you have a seed lot with 95% purity and 85% germination -> 95 x 85 / 100 = 80.75% PLS

If your seed lot weighs two pounds and there are an estimated 75,000 bulk seeds per pound, you have 150,000 bulk seeds on hand. Since you know the PLS for the lot, you can calculate that 121,125 (150,000 x 0.8075) of the seeds are viable and will potentially germinate.

If your target seeding rate is 4 live seeds per linear foot, you can determine the rate at which bulk seed needs to be sown by dividing the target PLS seeding rate by the percent PLS: 4 / .8075 = 4.95. Rounding up, if you will sow 5 bulk seeds per linear foot, you can plant 30,000 linear feet (150,000 / 5).

Due to a high level of seed dormancy in many native species, restoration practitioners sometimes calculate PLS based on the percent viability of a seed lot, rather than percent germination. If tetrazolium chloride (TZ) test results are available, the TZ value can be plugged into the formula above, in place of percent total germination. Alternatively, the sum of percent germination and percent dormancy (with the latter value derived from a TZ test) can be plugged into the formula.

For a more thorough discussion of PLS, please refer to Houck (2009).

Sample Bulk Seed Calculation

Borrowing from the sample PLS calculation above, if a two-pound seed lot has an estimated 75,000 bulk seeds per pound, there are approximately 150,000 bulk seeds. When seed lot viability is unknown, you may want to seed at a comparatively higher rate to increase the chance of sufficient germination and even stand establishment. If you were to seed at a rate of 12 bulk seeds per linear foot, for example, 12,500 linear feet (150,000 / 12) could be planted.

These sample calculations illustrate the benefits of having a professional seed test conducted on wild-collected foundation seed so that purity and germination data is available for performing these planting calculations.

Conducting In-house Seed Counts

If a professional seed count or a seed counting machine is unavailable, you can conduct your own seed count, using a digital scale with an accuracy of at least 0.1 grams. Counts will be most accurate for seed lots that have been finely cleaned and include minimal amounts of inert material. There are thousands of milkweed seeds per ounce, and it would be unreasonable to manually count a one-ounce quantity. Thus, to estimate the number of seeds per unit weight for any given seed lot, you can weigh at least five replicate samples of 1/10 of an ounce, count the total number of seeds in each sample, average the results, and then extrapolate the number of seeds per ounce or pound.

Transplanting

When specialty seed drills are not available or foundation seed is limited, a production stand can be established using transplants. Transplants are typically started by artificially stratifying seed for a few to several weeks before sowing, which often produces more rapid, even germination (for more information about stratification, please refer to the *Seed Germination* section.) If you have access to a walk-in refrigerator, you can sow seeds in prepared flats, cover the flats in plastic to prevent moisture loss, and stratify them for the desired amount of time. Once seeds are removed from the refrigerator and sown into potting media that is kept consistently moist, germination will likely begin within one week.

The amount of time required to produce seedlings suitable for outplanting (based on root mass formation and plant vigor) varies across species and is partially dependent on ambient temperatures during the propagation period and the size and type of containers used. Seedlings should be allowed to grow until their tap roots reach the bottoms of their containers and begin to air-prune; this stimulates lateral root formation.

Seedlings may be ready to transplant within as little as 8 weeks (Hunt et al. 2006; Anurag Agrawal and Greenheart Farms, pers. comm.) but some species may require 5 or more months (Luna & Dumroese 2013). Thus, it is difficult to offer a rule of thumb as to how far in advance seed should be sown in order to meet a target transplanting date. However, one available spring transplanting guideline is to sow seed in a greenhouse two months before the last frost date (Houseal 2007). In a hypothetical scenario where seed is stratified for four weeks and seedlings are propagated in a greenhouse for eight weeks, the stratification process should be started approximately three months prior to the target transplanting date. This is a conservative timeline, since seedling propagation may take longer than eight weeks.

Milkweed growers in regions with mild winters where freezing temperatures are uncommon have reported that milkweeds can survive the winter in plug trays. The plants' foliage will die back at the end of the growing season but the root masses will persist. Once the threat of frost has passed, dormant milkweed plugs can be transplanted in late winter or early spring, even if their foliage has not yet reemerged.

Do not use systemic insecticides when growing milkweed transplants. These products can harm or kill foliage-feeding insects such as monarch caterpillars and beneficial insects that visit milkweed flowers for nectar. For more information about these products, please see the *Protecting Beneficial Insects from Pesticides* section of this document.

Container Type

Milkweeds initially devote a significant amount of energy to root development. Use the deepest containers available for plug production to accommodate their root growth. Over the course of the Xerces Society's Project Milkweed, our partners have successfully propagated milkweeds in Ellepots (72-cell trays), 200-cell 1" x 1" x 2.5" plug trays, 2.5" x 4.5" seedling trays, and peat pots (#524 Jiffy Strip, Jiffy 520 Poly Pak). Additionally, other growers have reported success with propagating milkweeds in 288-cell plug trays, 400 mL pots, and Ray Leach "cone-tainers" (Manhattan, Kansas USDA-NRCS Plant Materials Center, pers. comm.; Anurag Agrawal, pers. comm.; Bartow 2006; Skinner 2008).

Milkweed seed has been sown in flats containing moist media and then placed in a walk-in refrigerator to be stratified for several weeks. (Photo: David Dreesen, USDA-NRCS.)

Certain container types can help reduce transplant shock by minimizing root disturbance. Ellepots feature a degradable paper membrane that holds soil around the root mass during transplanting. Peat pots are biodegradable and can be planted directly in the ground. However, peat pots have a potential drawback: their bottoms can become waterlogged when the pots are kept in a greenhouse for several months.

Additional details about milkweed seedling propagation are available from the Native Plant Network's Propagation Protocol Database: http://www.nativeplantnetwork.org/Network/. Also, Luna & Dumroese (2013) provide a helpful synthesis of milkweed propagation techniques.

Calculating Target Number of Transplants or Size of Planting Area

You can calculate how large of an area to prepare for planting based on the available or target number of transplants and the desired spacing between plants. If you have 1,000 transplants and would like to plant them on 2-foot centers (e.g., four square feet allocated for each plant), you will need to prepare an area of 4,000 square feet (or approximately 1/10 of an acre).

Alternatively, if you know the size of the stand you want to establish, you can work backward to determine how many transplants will be needed. For example, if you want to establish a ¼-acre field stand and install transplants on 2-foot centers (e.g., four square feet allocated for each plant), you would require 2,722 transplants, given that there are 10,890 square feet per ¼-acre.

Reducing Transplant Shock

If seedlings were grown indoors, it is advisable to move them to a shadehouse or other protected outdoor location for a few days prior to planting, to acclimate them to outdoor conditions. To further reduce transplant stress, the Phytophagy Lab at Cornell University cuts milkweed seedlings back to just below the first true leaves (yet above the cotyledons) right before planting. Once in the ground, plants will produce new growth from subterranean stem buds or from dormant buds at the cotyledons, and the emerging leaves will be adapted to field conditions (Anurag Agrawal, pers. comm.).

Planting into Weed Barrier Fabric

Where weed pressure is high, weed barrier fabric or a plastic mulch layer can be installed prior to transplanting. There are a range of products available that vary in durability and longevity, some of which can be mechanically installed using a bed-shaper equipped with a plastic mulch layer. However, installation can be done manually when equipment is unavailable.

After installing weed barrier or plastic mulch, you can manually or mechanically cut planting holes into the barrier. To limit potential weed growth, do not create holes larger than necessary. You can also quickly burn planting holes using a variety of available propane torch devices.

Clockwise from top left:

Spider milkweed transplant produced in an Ellepot by Greenheart Farms of California. (Photo: Rodney Thurman, Greenheart Farms.)

Showy milkweed transplants produced in a 2.5" x 4.5" seedling tray by Hedgerow Farms, Inc. of California. (Photo: John Anderson, Hedgerow Farms, Inc.)

Broadleaf milkweed seedlings propagated in Jiffy strips at the USDA-NRCS Plant Materials Center in Los Lunas, New Mexico. (Photo: David Dreesen, USDA-NRCS.)

Pinewoods milkweed seedlings grown in Jiffy Poly Pak trays at the USDA-NRCS Plant Materials Center in Brooksville, Florida. (Photo: USDA-NRCS Brooksville Plant Materials Center.)

Installing Transplants

Milkweed plugs can be mechanically transplanted with water wheel-type transplanters or other vegetable plug transplanting devices. While some transplanters are designed to punch through thin plastic films (such as those used for a single growing season), most transplanters cannot make holes in heavier weed barrier fabric (David Dreesen and John M. Row, pers. comm.) and planting holes will likely need to be created in advance when these heavier fabrics are used.

When manually installing transplants, it is often more time-efficient to dig planting holes in advance with dibble sticks, hand-held drills fitted with soil augers, or other similar tools. After installation, eliminate air pockets around the roots by firmly packing soil around the planting area and deeply water the seedlings. The need for continued irrigation will depend upon weather and specific site conditions, but transplants are likely to need at least 1 inch of water per week during the establishment year (except during natural rain events). Mulching is recommended to reduce weed competition and to retain moisture during the establishment phase. Suitable mulching materials include wood chips, bark dust, rice straw, nut shells, or other locally available, weed-free materials.

Note that some growers have reported that milkweeds' lack of fibrous roots makes it difficult to keep soil around the roots during transplanting (Bartow 2006; John Anderson, pers. comm.). Careful handling is therefore recommended.

Row Spacing and Plant Spacing

The distance between rows should be based on the growth form of the plants and the amount of space needed to implement weed control (e.g., cultivation, hoeing, or spraying). However, row spacing may be dependent on the planting equipment used and is not always manipulable. Most milkweed species have an upright growth form and may lend themselves to close row spacing, while others such as green milkweed, spider milkweed or antelope horns, and pinewoods milkweed (*A. humistrata*) tend to have a sprawling growth form and may perform best in widely spaced rows. Some species, including common milkweed, prairie milkweed (*A. sullivantii*), and whorled milkweed (*A. verticillata*) expand via clonal root growth and stand density may increase over time.

From top to bottom: Mechanized equipment for efficiently installing weed barrier fabric. (Photo: Eric Eldredge, USDA-NRCS); Equipment used to create planting holes at the USDA-NRCS Plant Materials Center in Manhattan, Kansas. (Photo: USDA-NRCS Manhattan Plant Materials Center); A water wheel transplanter used for mechanized plug planting. (Photo: Brianna Borders, The Xerces Society); Using a cordless drill with an earth auger is a very efficient way of creating holes for transplanting. (Photo: Brianna Borders, The Xerces Society.)

Right: Spider milkweed seedlings transplanted into weed barrier fabric at the Painted Lady Vineyard in Arizona. (Photo: Brianna Borders, The Xerces Society.)

Western Illinois University researchers conducted a field study on common milkweed production and reported that an inter-row spacing of approximately 2.5 feet (76 cm) maximized the total number of pods produced per field. They also evaluated row spacing intervals of 0.62 feet (19 cm) and 1.25 feet (38 cm) for comparison (Phippen 2007). For butterfly milkweed (*A. tuberosa*) seed production, when transplanting into bare soil, the Tallgrass Prairie Center recommends planting rows spaced 30–36 inches apart (76–91 cm) (Houseal 2007). When transplanting into a plastic mulch layer, the Center spaced butterfly and swamp milkweed rows eight inches apart (pers. comm.).

The ideal distance between plants within a row is also largely influenced by the growth form of the plants. For plants with an upright growth form, a minimum distance of one foot between plants will prevent significant crowding. Based on their study of common milkweed production, Western Illinois University researchers reported that a plant spacing of 8–12 inches (20–30 cm) maximized the total number of pods produced per field (Phippen 2007). It is possible that closer within-row spacing of plants could facilitate the ease of mechanical harvesting, but wider spacing will allow room for plants to mature and fill out over consecutive growing seasons. Species with a decumbent (sprawling) growth form may need several feet of space between plants.

Managing Production Fields

In addition to pest and disease management (covered in later sections of this document), weed control, soil fertility, and age-related plant decline are the three primary management concerns for mature seed production fields.

Depending on the particular species of weeds and amount of weed seed present in the soil, mature milkweed stands can be relatively competitive against weed encroachment. In particular, common and showy milkweed can spread via lateral root growth and have tall foliage and possible allelopathic defenses that make them competitive against many less-aggressive weeds. However, weed management in any milkweed production field, regardless of species, may be required. Currently, common practices include the use of pre-emergent herbicides in mature fields and dormant glyphosate applications in either mature or newly established fields (with the herbicide applied to actively growing, cool-season weeds during the winter when milkweeds have not yet germinated or emerged). Note that dormant glyphosate treatments are inherently risky and should be tested on a small scale over multiple seasons before being used more widely. At this time, milkweed resistance to particular herbicide classes is not well understood, and we cannot recommend any "milkweed-safe" herbicides.

In addition to herbicides, a potential strategy for weed suppression in milkweed stands is planting inter-row crops such as grasses, and possibly some compatible forbs or legumes. For example, winter-killed oats and small-statured native grasses (such as buffalo grass, June grass, or side-oats grama) may perform this function while also providing protective soil cover. Similarly, we believe that inter-planting canola (or similar non-invasive mustards) between rows of established milkweed fields could offer multiple benefits including weed suppression, the production of root exudates that may inhibit root-feeding milkweed insects, and the provision of early season nectar for parasitoid wasps that attack pests such as milkweed aphids. Intercropping can potentially reduce milkweed seed yields due to competition for resources between the milkweed crop and the intercropped plants. However those yield losses may still be advantageous when compared to monoculture production where significant levels of pest and disease pressure can require intensive management. Currently, additional research and testing is needed to understand the species combinations optimal for inter-cropping.

In general, milkweeds grown within their native range and preferred soil type are well adapted to non-irrigated conditions. Production field irrigation may be necessary for drought-sensitive species under dry conditions, and for wetland-adapted milkweeds grown in an upland setting. Light, supplemental irrigation under otherwise normal growing conditions may increase seed yield when supplied immediately before flowering, and later during pod development, but is not essential.

The extent to which milkweed production stands benefit from supplemental fertilizer applications is largely unknown, and is likely variable depending on specific soil conditions and cropping history of the land. Where soil analyses identify deficiencies in N-P-K (nitrogen, phosphorus, potassium), corrective fertilizer applications may be warranted. Seed production fields may also benefit from other supplemental micronutrient applications, especially sulfur, which has been recognized as a limiting nutrient in other seed crops. Organic soil amendments like compost may also enhance soil nutrients.

The lifespan of individual milkweed plants is unknown, although in some cases relative observations on the longevity of various species in comparison to one another do exist. For example, based upon our observations in California, *A. fascicularis* tends to grow rapidly in its first year and then decline after several seasons; in contrast, *A. speciosa* is relatively slow-growing as a young plant but tends to persist over many years. Lifespan-related crop declines tend to occur gradually over several years, with no readily identifiable causative factors present (although soil pathogens, viruses, and root-feeding insects are probably contributors). When crop decline does occur, few options may exist for revitalizing the planting. For example, transplanting new plants into a declining crop where previous plants have died has not been effective (possibly due to unobserved soil pathogens). Where milkweed production fields decline to the point of no longer being profitable to maintain, we recommend establishing a new production field elsewhere (using genetically diverse foundation seed) and converting the old field to native grass production.

Identification and Management of Milkweed Herbivores

Though milkweeds contain toxic chemicals that help protect them against herbivores, parasites, and pathogens (Malcolm 1991), there is a suite of specialist insects adapted to feed on various milkweed plant parts. These insects often colonize milkweed crops and can cause enough damage to negatively impact seed production. Indeed, these insects may reach higher densities in milkweed production fields than in wild milkweed stands due to the concentrated abundance of their host plants. Some of these insects directly affect seed production by feeding on floral structures, immature seed pods, and mature seeds. Others feed on foliage, roots, stems, or plant sap, indirectly impacting seed production by weakening the plants.

Milkweed specialist insects exhibit both physiological and behavioral adaptations to reduce the effects of milkweeds' toxic chemicals and the thick, sticky latex released by wounded plant tissues. Several species store the milkweeds' chemicals in their bodies to defend themselves against predators. These insects often have bright warning coloration meant to advertise their unpalatability. Monarch butterfly caterpillars, primarily foliage feeders, will partially sever leaf veins to allow the latex sap to drain out before they commence feeding. Latex production is a very effective defense against herbivory; mortality of early instar monarch larvae can be high due to becoming stuck or drowned in latex (Zalucki & Brower 1992).

In this section, we profile the key species and groups of insects that are potentially significant pests of milkweed crops. Each profile features photos, descriptions of the insects' life cycle and the damage they can cause, and strategies for managing outbreaks. Some additional milkweed specialist insects are not mentioned here, as they are unlikely to become pests in production fields.

Protecting Beneficial Insects from Pesticides

With the exception of the oleander aphid (*Aphis nerii*), the species profiled here are native and share a long evolutionary history with milkweeds. In many instances, their presence may not warrant chemical control. Please exercise caution when deciding whether to manage outbreaks with insecticides! Although dependent on timing, rate, and method of application, all insecticides can harm or kill beneficial insects including bees, butterflies, and natural enemies of crop and garden pests. Beyond selecting products with relatively low toxicity and short residual toxicity, strategies for preventing or minimizing harm to flower visitors and milkweed herbivores include applying insecticide only when plants are not flowering and spot treating localized infestations as necessary, rather than spraying the entire field.

Queen butterfly caterpillar on rush milkweed. Queen caterpillars look very similar to monarchs except queens have three pairs of tubercles (fleshy projections) instead of two and often have some red color in addition to black, yellow, and white. (Photo: Desert Botanical Garden.)

Chemical Control — Pesticide Selection

A group of insecticides with "systemic" action have recently received significant attention for the threats they pose to pollinators, aquatic invertebrates, and birds (Hopwood et al. 2012; Hopwood et al. 2013; Minneau & Palmer 2013). Systemic insecticides are applied as seed coatings, soil drenches, or foliar sprays and are absorbed by plants as they grow. The translocation of these chemicals throughout treated plants makes them potentially toxic to wildlife that eat pollen, drink nectar, or feed on plant tissues. Thus, these chemicals can harm or kill the pollinators that are required for milkweed seed set and the butterfly caterpillars that feed on milkweed foliage. Due to their long residual toxicity and high potential to harm beneficial insects, we do not recommend using these products in seed production fields. The most widely used class of systemic insecticides is the neonicotinoids, which are synthetic chemical insecticides that are similar in structure and action to nicotine and work by blocking nerve impulses in insects and other invertebrates. Imidacloprid, dinotefuran, clothianidin, and thiamethoxam are examples of neonicotinoids that are sold for use on farms and in gardens. There are also some organophosphate pesticides with systemic action that are used to control plant pests. Many organophosphates are highly toxic to bees, other wildlife, and humans.

In contrast to systemic insecticides, "contact" insecticides kill insects only on contact and the products are not absorbed by plants. Carbaryl, malathion, permethrin, and pyrethrin are examples of active ingredients in contact insecticides that can be very effective. However, some contact insecticides tend to have relatively long residual toxicity and the evolution of pesticide resistance is a possibility.

Horticultural oils and insecticidal soaps are the least toxic to beneficial insects of all available products, if they are applied when plants are not in flower or at night when bees are not present. Oils and soaps work as contact insecticides and do not have residual toxicity. To be effective, they must be applied directly to target insects and cover them thoroughly. Please consider that both oils and soaps may have phytotoxic effects; treat a test area first to observe whether they will damage plants.

For information on the estimated residual toxicity of pesticides, please refer to the Pacific Northwest Extension Publication, "How to Reduce Bee Poisoning from Pesticides" (http://www.step-project.net/NPDOCS/PNW%20591.pdf). However, the document does not contain information on residual toxicity to monarch butterflies (to the authors' knowledge, such information is not available from any source).

If you are unsure of which products to use to control a pest outbreak in your production field, an Agricultural Pest Control Adviser (PCA) in your area may be able to provide advice. Always make sure to follow all product label recommendations.

Note that organic-approved pesticides can be as harmful to bees as products labeled for conventional use. For example, there are some insecticides derived from microbes (e.g., spinosad or *Beauvaria bassiana*) that have long residual toxicity and are harmful to bees, and thus are not recommended for use in bee-pollinated crops. For more information about chemical pest control in organic systems, please refer to the Xerces Society publication, "Organic-Approved Pesticides" (http://goo.gl/XNQdtz).

Monarch caterpillar. (Photo: David Cappaert, Michigan State University, Bugwood.org.)

Monarch Butterflies and Other Lepidopteran Larvae

Monarch butterflies breed in the U.S. from spring through early fall, and females often lay eggs in milkweed production stands. Monarch caterpillars have a voracious appetite for milkweed and can potentially defoliate numerous plants. Leaves and stems will regenerate after larvae feed, but the plants' reproductive capacity may be diminished, depending on the timing and intensity of feeding activity. Also, caterpillars may directly impact plants' reproductive output by feeding on buds, flowers, and immature seed pods. Caterpillars of the queen butterfly (*Danaus gilippus*), the milkweed tussock moth (*Euchaetes egle*), and the dogbane tiger moth (*Cycnia tenera*) may also feed on milkweed crops, but these species are not as abundant or as broadly distributed as the monarch.

In some situations, the presence of monarch caterpillars in a milkweed production stand can present a quandary for growers related to: 1) the desire to protect caterpillars from insecticide application meant to target other milkweed-feeding insects (such as oleander aphids), or 2) caterpillars defoliating the stand to the point that seed production potential is threatened.

Protecting Caterpillars from Insecticide

Butterfly and moth caterpillars are vulnerable to all insecticide products. Thus, caterpillars present on plants that are treated for an outbreak of other milkweed specialist insects will likely be poisoned or killed. To minimize or avoid impacts to caterpillars when applying chemicals, consider transferring them to an area of the production stand that will not be sprayed. Monarch caterpillars go through five stages of development ("instars") and while late instar larvae are conspicuous on plants, eggs and early instar larvae are much harder to detect. Monarch eggs are small (approximately 1 mm in height and width, and are slightly taller than they are wide) and typically laid on the undersides of leaves, while early instar larvae are less than 10 mm long (University of Minnesota 2014).

Preventing Damage to Milkweed Crops

In most situations, caterpillars do not occur at densities high enough to significantly affect seed production. Growers can certainly allow caterpillars to feed unabated, though this approach may result in a reduced seed yield. If caterpillars truly appear to threaten crop health, we offer these management options:

- *Collect and transfer caterpillars to other milkweed plants*. This strategy will require a modest investment of time (to scout the crop and collect caterpillars as necessary) plus knowledge of local milkweed populations and/or existing connections to people who will adopt caterpillars. Caterpillars can potentially be transferred to nearby milkweed stands along roadsides, in parks, or on neighboring properties. Local schools, nature centers, gardeners, or butterfly enthusiasts who can supply their own milkweed may also be interested in providing foster homes for caterpillars.
- *Control caterpillars through insecticide application*. This should be considered a last resort, for instance when there appears to be significant potential for total milkweed crop failure and caterpillar relocation is not feasible. While implementing this control measure appears at odds with monarch conservation goals, the value in producing a milkweed seed crop that will be used to restore monarch habitat outweighs the sacrifice of one group of caterpillars.

Gravid female monarchs are so effective at finding milkweeds that they have even made their way into greenhouses and laid eggs on flats of milkweed seedlings. (Photo: Eric Lee-Mäder, The Xerces Society.)

Aphids (Aphididae)

*Oleander Aphid (*Aphis nerii*)*

Distribution
Widely distributed in temperate, tropical, and subtropical areas around the world; believed to be native to the Mediterranean region. In the U.S., this insect is characterized as a well-established invasive species (Harrison & Monder 2011).

Appearance
Bright yellow-orange body. Legs, antennae, and cornicles (tube-like projections near the hind end of the body) are black.

Host Plants
Various species in the family Apocynaceae, which in North America includes: milkweeds; dogbane (*Apocynum* spp.); and the introduced ornamental species oleander (*Nerium oleander*), periwinkle (*Vinca major, V. minor*), and wax plant (*Hoya carnosa*). Oleander aphids are a nearly ubiquitous milkweed pest, infesting plants in gardens, nurseries, and natural areas.

Damage
Oleander aphids feed exclusively on plant sap. They use piercing-sucking mouthparts to penetrate stems, leaves, and sometimes pedicels and flower buds, sucking sugary liquids from phloem vessels. They prefer tender, new leaf growth and typically aggregate in the upper portions of plants. They are known to colonize plants at high densities, i.e., over 100 individuals per leaf terminal (Braman & Latimer 2002). At such densities, their feeding activity can weaken plants, impacting flowering and seed production.

Aphids are a potential vector of phytoplasma, a group of plant diseases (for more information, please refer to the *Plant Disease Diagnosis and Management* section of this document). Sooty mold, a fungus, is also associated with aphid infestations. The "honeydew" that aphids excrete accumulates on their host plants and encourages fungal growth. High fungal density on leaves can interfere with plant growth if the plant cannot absorb a sufficient amount of sunlight.

Oleander aphids on narrowleaf milkweed. (Photo: John Anderson, Hedgerow Farms, Inc.)

Biology
All oleander aphids are female. They reproduce asexually, without mating, and give live birth to nymphs that are clones of the parent aphid. It takes approximately eight days for a nymph to reach reproductive maturity and each adult can produce more than 30 offspring (Groeters 1989). Multiple generations are produced per year and their numbers can increase exponentially over a short time

period. Adult aphids are winged or wingless. Like many other insects that feed on milkweed, oleander aphids sequester toxic chemicals from the plants, making them distasteful to many predators (Rothschild et al. 1970). Unlike many other aphid species, oleander aphids are not tended by ants.

Oleander aphids can overwinter as adults in areas where freezing temperatures during winter are uncommon. If they have overwintered in proximity to milkweeds, aphids may appear on plants in early spring and their numbers will quickly increase. In areas with severe winters during the growing season, aphids must locate and colonize plants via the dispersal of winged adults, and therefore may not appear on milkweeds until later in the season. Due to their ability to reproduce asexually, aphid colonies can be founded by a single migrant (Groeters 1989).

The oleander shrub is evergreen and can potentially support oleander aphids throughout the year where winter temperatures are mild. Thus, oleander plants may play a role in sustaining source populations of aphids that then colonize native milkweeds each growing season. Oleander aphid infestations on milkweed may be more problematic in areas of the southern U.S. where oleander has been widely planted as an ornamental species. However, more information is needed about this insect's phenology, migration, and overwintering ecology.

A female *Aphidius colemani* wasp lays a single egg inside a living aphid. After the aphid dies, the wasp larva spins a pupal cocoon within the aphid, which "mummifies" it. Once the pupa completes its development, the new adult wasp chews a circular exit hole in the mummified aphid and emerges. A female wasp can lay several hundred eggs in a lifetime. (Photo: David Cappaert, Michigan State University, Bugwood.org.)

Control and Management

Natural Enemies
Several natural insect enemies can play a role in controlling aphid populations. Lady beetle (family Coccinellidae) larvae and adults, hoverfly larvae (family Syrphidae), and brown and green lacewing larvae (families Chrysopidae and Hemerobiidae) are all predators of the oleander aphid. Additionally, two species of braconid wasp (*Aphidius colemani, Lysiphlebus testaceipes*) parasitize and kill oleander aphids (Hall & Ehler 1980; Braman & Latimer 2002; Hartbauer 2010). However, these beneficial insects may not always appear in sufficient numbers until after aphids have become abundant (Dreistadt et al. 2004). Please consider that applying insecticide to control oleander aphids will also harm the beneficial insects that prey on or parasitize them. Similarly, the release of commercially acquired lady beetles for this purpose has not been studied and may have unintended ecological consequences. We cannot recommend intentionally releasing them to control oleander aphids.

Habitat enhancement practices may help support the parasitic wasps *Aphidius colemani* and *Lysiphlebus testaceipes*, though, at present, little is known about these species' shelter and nectar source preferences. They live for one or two weeks and do not build nests. Thus, providing tunnel nesting blocks is not a viable support strategy. There are other wasp species that parasitize aphids, but oleander aphids are unsuitable hosts for them due to their sequestration of toxic cardenolides from milkweeds (Desneaux et al. 2009).

Insecticide Application
Insecticidal soaps can very effectively control soft-bodied insects like aphids. Soaps kill on contact only and do not have residual activity. As long as direct contact is avoided, soaps will not cause harm to

A close-up view of oleander aphids. (Photo: Daren Mueller, Iowa State University, Bugwood.org.)

beneficial insects such as pollinators and natural predators of crop pests. Soaps can, however, have toxic effects on plants. Thus, we recommend treating a small test area before proceeding with a larger-scale application.

Insecticides that kill on contact can be used to spot-treat dense aphid infestations. There are numerous products of this type to choose from but at least one milkweed producer has reported that spot-spraying malathion provides quick control of oleander aphids. The potential for oleander aphids to develop resistance to any particular active ingredient is unknown.

A variety of systemic neonicotinoid insecticides are commonly used to control aphids. However, due to the risks that these insecticides pose to beneficial insects, we recommend against using them in milkweed seed production fields. Flonicamid, a non-neonicotinoid chemical, is a systemic insecticide formulated to have selective activity against insects with piercing-sucking mouthparts (Morita et al. 2007). At the time of this writing, it is marketed as having no negative impacts on beneficial insects (Ishihara Sangyo Kaisha, LTD.). However, we still recommend caution in using this product. Also, please note that flonicamid may not be registered in your state or labeled for open-field use.

Aphis asclepiadis

This species (which lacks a common name) has been documented on several milkweed species, but its potential to be a significant pest of milkweed production fields is unknown. Like the oleander aphid, it feeds gregariously and prefers tender, new leaves (Smith et al. 2008). Compared to the oleander aphid, *A. asclepiadis* has a lower reproductive rate, a lower feeding rate, and reduced dispersal capability (Mooney et al. 2008). Though *A. asclepiadis* sequesters cardenolides from its host plants, it does not have bright warning coloration (Mooney et al. 2008). Rather, it is typically green or brown and rather inconspicuous (Smith et al. 2008). It has a mutualistic relationship with ants and is nearly always tended by them (Smith et al. 2008).

Myzocallis asclepiadis

This aphid (again, lacking a common name) has only been documented on butterfly milkweed, common milkweed, and purple milkweed (*A. purpurascens*) (Blackman & Eastop 2007; McMartin & Malcolm 2008). Its potential to be a significant pest of milkweed production fields is unknown. The aphids' coloration changes over the course of a season, ranging from a pale green-yellow to having orange spots or being entirely orange (McMartin & Malcolm 2008). All *M. asclepiadis* adults are winged and the species is very mobile (McMartin & Malcolm 2008). *M. asclepiadis* feeds in a dispersed pattern rather than aggregating in colonies (Smith et al. 2008). In the northeastern U.S., where all three milkweed aphids co-occur, *M. asclepiadis* appears on plants in early spring, followed closely by *A. asclepiadis*, and finally *A. nerii* in mid-to-late summer (Smith et al. 2008).

Aphids

Beyond the three milkweed specialist aphids, several additional species have been documented to feed on one or more milkweed species. Their potential to become significant milkweed pests is unknown but is likely low. Those species are:

Black aphid (*Aphis rumicis*), black bean aphid (*A. fabae*), melon or cotton aphid (*A. gossypii*), spirea aphid (*A. spiraecola*), *A. helianthi,* black citrus aphid (*Toxoptera aurantii*), foxglove aphid (*Aulacorthum solani*), green peach aphid (*Myzus persicae*), leaf-curling plum aphid (*Brachycaudus helichrysi*), potato aphid (*Macrosiphum euphorbiae*), and red aphid (*M. rudbeckiae*) (Betz et al. 2000; Blackman & Eastop 2007).

Milkweed Bugs (Lygaeidae)

*Large Milkweed Bug (*Oncopeltus fasciatus*)*

Distribution

From southern Canada to Central America (Miller & Dingle 1982).

Appearance

Adults are bright orange with large black markings on both ends of the body and a black band across the middle of the forewing. Nymphs are bright orange with abdominal ridges; they develop small black spots and black wing pads as they mature.

In comparison, adult small milkweed bugs (*Lygaeus kalmii*) are orange, black, and gray, sometimes have white spots on the forewing, and lack a distinct black band on their forewings. Boxelder bugs (*Boisea*

Large milkweed bug nymphs on milkweed. (Photo: Sheryl Pollock, www.discoverlife.org.)

Large milkweed bug. (Photo: David Cappaert, Michigan State University, Bugwood.org.)

trivittata) look very similar to large milkweed bugs, but are mostly black with only a few orange accents and do not have black bands across their forewings.

Host Plants

Primarily milkweeds (*Asclepias* spp.), but they may also feed on seeds of milkweed relatives in the genera *Apocynum*, *Cynanchum* (formerly *Metastelma*), and *Nerium* (Duffey & Scudder 1972).

Damage

Large milkweed bugs suck the contents out of milkweed seeds, rendering the seeds inviable. Their piercing–sucking mouthparts are collectively known as a "rostrum." Adults and late instar nymphs pierce through the walls of unopened pods to feed on seeds. Young instar nymphs typically cannot penetrate the thick pod walls and must find pods that are already open, damaged, or thin-walled (Ralph 1976; Ralph 1977). The insects are gregarious and cluster together while feeding. Because seed damage caused by milkweed bugs is difficult to see, photo comparisons of viable and inviable seed are unavailable.

Biology

Five nymphal instars precede the adult stage (Dingle 1968). The large milkweed bug requires milkweed seeds—the main component of its diet—for optimal growth and reproduction, (Ralph 1976). When seeds are not yet ripe, the bug feeds on young leaves, flowers, and developing pods (Duffey & Scudder 1972; Isman et al. 1977). Adults lay their eggs on milkweed plants, near developing pods (Dingle 1968; Sauer and Feir 1973). *Oncopeltus fasciatus* sequesters cardenolides from milkweed seeds (Duffey & Scudder 1972) and is distasteful to most predators (Sauer & Feir 1973). The feeding behavior of the large milkweed bug has been well-documented in both field and laboratory settings. Additionally, scientists have used the species in laboratory research investigating invertebrate developmental and reproductive biology (Feir 1974).

The large milkweed bug is a migrant that colonizes the northern part of its range from the south (Dingle 1968). Adults reportedly overwinter in parts of the southern U.S. (Sauer & Feir 1973), but the species is not believed to overwinter in most of North America (Ralph 1977). The number of generations produced per year is variable; sometimes only one generation is produced in the north and four or more are produced in the southern U.S (Dingle 1972). The species' phenology has been better documented in Illinois, Iowa, and Missouri than in other parts of the country. In the lower Midwest, *Oncopeltus* first appears between late spring and mid-summer, with the exact timing of its arrival dependent on weather conditions (Dingle 1968). Its numbers increase throughout the summer and typically peak from mid-August to mid-September (Dingle 1968; Sauer & Feir 1973).

Researchers have suggested that the large milkweed bug transmits a protozoan parasite, *Phytomonas elmassiani*, to multiple milkweed species (McGhee & McGhee 1971). The large milkweed bug is considered the parasite's primary host, while milkweeds are a secondary host. However, there is not a good description of the parasite's effect on either the insects or the plants.

Management

If hand-harvesting pods, avoid collecting pods on which large milkweed bugs are aggregated. Make sure that milkweed bugs are not present in harvested plant material being dried or stored prior to seed processing.

Control

Due to their bright colors and gregarious feeding behavior, these insects are easy to spot. Control is probably unwarranted if large milkweed bugs are present on only a fraction of the total plants or pods within a stand. If infestations become dense and numerous, they can be killed with insecticidal soap, horticultural oil, neem oil, or a contact insecticide as necessary. Note, however, that bugs on the undersides of pods may go unobserved; consequently, follow-up monitoring may be advised.

Related species

There are four additional *Oncopeltus* species known to occur in the U.S. (Feir, 1974) but their biology and distribution have not been well studied.

Small milkweed bug, (Photo: Susan Ellis, Bugwood.org.)

*Small Milkweed Bug (***Lygaeus kalmii***)*

Distribution

Southern Canada and most of the U.S. *Lygaeus kalmii* may be separable into eastern and western subspecies (Slater and Knop 1969).

Appearance

Adults are orange (or red), black, and gray, and sometimes have white spots on the forewing. The color patterns on their forewings are not always consistent, but sometimes include a gray heart shape towards the anterior end and a nearly complete orange "X" shape across most of the body. Nymphs are deep orange to red with ridges on their abdomens. They develop black wing pads as they mature, and sometimes also have off-white markings.

In comparison, adult large milkweed bugs (*Oncopeltus fasciatus*) are orange and black only (never with white or gray) and have a distinct black band across the middle of their forewings.

Host Plants

Possibly all milkweeds (*Asclepias* spp.). However, the small milkweed bug's diet is not restricted to milkweeds and some have questioned whether the species should be categorized as a milkweed specialist (Wheeler Jr. 1983). Reportedly, it can complete its development using a variety of species in the Asteraceae, including dandelion (*Taraxacum officinale*) (Wheeler Jr. 1983; Fox & Caldwell 1994).

Small milkweed bug nymph on showy milkweed pod. (Photo: Brianna Borders, The Xerces Society.)

Damage

Small milkweed bugs suck the contents out of milkweed seeds, rendering the seeds inviable. Like large milkweed bugs, their piercing–sucking mouthparts are collectively known as a "rostrum." Seed damage caused by milkweed bugs is difficult to see and photos are unavailable. When milkweed seeds are unripe, small milkweed bugs will feed on young leaves, buds, flowers, stems, and developing pods (Duffey & Scudder 1972; Isman et al. 1977; Root 1986).

Biology

Small milkweed bugs overwinter as adults and sometimes become active in the spring before milkweeds emerge (Root 1986). After mating, females lay eggs in the hollow stems of dried forbs, in crevices between terminal leaves of milkweeds, and on the surfaces of fallen leaves (Root 1986). The nymphs are gregarious and cluster together while feeding. Adults are less often seen feeding in clusters. Small milkweed bugs are not strictly herbivorous and are known to prey upon insects trapped in milkweed flowers, feed on monarch butterfly pupae, and even engage in cannibalism (Root 1986). Two generations may be produced per year (Root 1986). *Lygaeus kalmii* sequesters cardenolides from milkweeds (Duffey & Scudder 1972), making it distasteful to most predators.

Management

If pods will be hand-harvested, avoid collecting pods on which small milkweed bugs are aggregated. Make sure that milkweed bugs are not present in harvested plant material being dried or stored prior to seed processing.

Control

Due to their bright colors and often gregarious feeding behavior, these insects are easy to spot. If small milkweed bugs are present on only a fraction of the total plants or pods within a stand, control is likely unnecessary. If infestations become dense and numerous, they can be treated with insecticidal soap, horticultural oil, neem oil, or a contact insecticide as necessary.

Related species

Lygaeus reclivatus is known from the southwestern U.S. (Slater and Knop 1969) but has not been widely studied.

Leaf Beetles (Chrysomelidae)

*Blue Milkweed Beetle (*Chrysochus cobaltinus*)*

Distribution

Restricted to the western U.S. Occurs in California, Oregon, Washington, Idaho, western Nevada, western Montana, and central Utah (Dobler and Farrell 1999).

Appearance

The head, body, and antennae are metallic green or blue, sometimes appearing almost black. No photos of larvae are known to exist.

Blue milkweed beetles on showy milkweed. (Photo: John Anderson, Hedgerow Farms, Inc.)

Blue milkweed beetle emergence holes. (Photo: John Anderson, Hedgerow Farms, Inc.)

Host Plants

Woollypod milkweed, showy milkweed, narrowleaf milkweed, heartleaf milkweed, dogbane (*Apocynum cannabinum*) (Dobler and Farrell 1999, John Anderson, pers. comm.). It is unknown whether the beetle feeds on other milkweeds or milkweed relatives in the plant family Apocynaceae.

Damage

Adults eat leaves and can cause severe localized defoliation when they occur at high densities. Larvae feed exclusively on roots, thus negatively affecting plant fitness. While it can be difficult to identify a causative relationship between larval feeding activity and aboveground symptoms of poor plant health, please note that root damage caused by larvae may produce what appear to be plant disease symptoms. Larval feeding activity may also increase the plants' susceptibility to bacterial or fungal infections.

Biology

Adult beetles typically emerge from the soil in late spring (Sady 1994; Hedgerow Farms, Inc., pers. comm.). Reproduction is rapid and the number of individuals can potentially double in less than three days (Sady 1994). While adult beetles tend to aggregate at high densities, their distribution within a given milkweed stand is often uneven, with many plants remaining uncolonized (Sady and Seiber 1996; Dobler and Farrell 1999). A single generation is born each year (Dobler and Farrell 1999) and adults live for 6–8 weeks (Peterson et al. 2005). Mating occurs on host plants and eggs are laid on host plants or surrounding vegetation. Larvae hatch during the summer, drop to the ground, burrow into the soil, and begin feeding on host plant roots (Peterson et al. 2005). They pupate in the soil before emerging the following spring as adults.

Blue milkweed beetles do not sequester significant amounts of cardenolides in their body tissues (Isman et al. 1977b). Rather, they accumulate cardenolides in special glands near the surface of their body, releasing cardenolide-containing secretions upon disturbance as a form of defense (Labeyrie and Dobler 2004).

Control & Management

Blue milkweed beetles are conspicuous and slow-moving. They can be removed by hand if the labor force is available. Beetles can be collected in a bucket or similar receptacle and then disposed of. Since they typically occur in dense, localized aggregations rather than colonizing entire stands, overspraying of insecticide is usually unwarranted and likely ineffective. Spot treatment with a contact insecticide can be conducted as necessary. At least one milkweed grower has reported that malathion is effective at controlling blue milkweed beetles. There are limited options for controlling larvae; applying insecticide to the soil would have substantial negative impacts on the local soil invertebrate community, which includes many beneficial organisms.

Related Species

The dogbane leaf beetle (*Chrysochus auratus*) has a much broader range that includes all of the eastern and central U.S., and extends into some western states. The ranges of *C. auratus* and *C. cobaltinus* are nearly exclusive, but with some overlap in south-central British Columbia and parts of Washington and Oregon (Peterson et al. 2001). The dogbane leaf beetle feeds on dogbane (*Apocynum androsaemifolium, Ap. cannabinum*) and does not typically eat *Asclepias* species (Dobler and Farrell 1999). However, a small proportion of *Chrysochus auratus* individuals in south-central Washington state have been observed feeding on milkweed (Peterson et al. 2001).

*Swamp Milkweed Leaf Beetle (*Labidomera clivicollis*)*

Distribution

This insect is found in every state east of the Rocky Mountains. It also occurs in northern Mexico and southeastern Canada.

Taxonomy

Two subspecies exist. *L. clivicollis* ssp. *clivicollis* is broadly distributed across the northeastern U.S. (Eickwort 1977), whereas *L. clivicollis* ssp. *rogersii* occurs in the southern U.S. These subspecies have been studied in New York and Texas, respectively.

Appearance

The wing covers are shiny and orange or yellow with black spots. The head, the pronotum (the body segment just behind the head), legs, and antennae are black, often with a blue-green metallic sheen.

Host Plants

Though this beetle is primarily associated with swamp milkweed, it has also been documented using butterfly milkweed, common milkweed, tall green milkweed (*A. hirtella*), and whorled milkweed. In Texas, the primary host is talayote (*Cynanchum racemosum* var. *unifarium*) (Palmer 1985; Dickinson 1992).

Swamp milkweed leaf beetle. (Photo: David Cappaert, Michigan State University, Bugwood.org.)

Damage

Both larvae and adults eat leaves. These beetles tend to occur at low densities in small, isolated patches (Dickinson 1992) and are unlikely to be a significant pest of swamp milkweed or common milkweed production stands.

Biology

Like many other milkweed specialist insects, these beetles have bright colors. However, they do not sequester cardenolides from milkweeds (Eickwort 1977). Adults are not very mobile; they move primarily by walking, rather than flying (Dickinson 1992). Eggs are laid either on host plants or non-host plants (Dickinson 1992).

Labridomera clivicollis ssp. *clivicollis* produces a single generation per year. Overwintering adults emerge in late May and breed during the summer (Dickinson 1992). In contrast, *L. c.* ssp. *rogersii* has two active periods per year. Beetles overwinter as adults, emerge from the soil in the spring, and breed. The adult offspring burrow underground during the summer and then emerge in the fall to produce a second, overwintering generation (Dickinson 1992).

Control & Management

These beetles are large and slow-moving enough to be removed by hand, if the labor force is available. They are unlikely to reach high densities and chemical control will not likely be warranted. However, spot treatment with a contact insecticide can be conducted if absolutely necessary.

Longhorn Beetles (Cerambycidae)

*Milkweed Longhorn Beetle (*Tetraopes *spp.)*

Diversity

Fourteen species of milkweed longhorn beetle occur in the U.S., with additional species known from Mexico and Central America (Farrell & Mitter 1998; Chemsak & Noguera 2003). A dichotomous key for distinguishing the species is available from Chemsak & Noguera 2003.

Appearance

Robust bodies, typically bright red or deep orange, usually with small black spots and prominent antennae almost as long as the body. Body length ranges from 5–20 mm (0.2–0.8 in) (Chemsak & Noguera 2003). Size is quite variable across species, and females are larger than males. Nearly all body parts are covered with very fine hair. While most species are red or orange, some (e.g., *T. discoideus*, *T. linsleyi*) have a significant amount of gray coloration and at least one species (*T. pilosus*) is pale-colored. Of all the species, *T. tetraophthalmus*,

Milkweed longhorn beetle. (Photo: Anurag Agrawal.)

Milkweed longhorn beetle on common milkweed. (Photo: Nancy Lee Adamson, The Xerces Society.)

which is associated with common milkweed (*A. syriaca*), has been the most frequently studied and photographed.

Host Plants

Some have stated that each *Tetraopes* species is largely restricted to its own distinct milkweed species (Farrell & Mitter 1998), but others (Chemsak 1963; Betz et al. 2000) have documented a single beetle species on multiple milkweed species.

Damage

Adults eat leaves, buds, and flowers, while larvae feed exclusively on roots (Matter 1996). The combined damage to reproductive parts and root tissues can significantly impact plant vigor and seed production. Adults feed on leaves in a characteristic pattern, starting at the tips and working inward, ultimately consuming only a small percentage of each leaf (Agrawal 2004). While one experimental study (Matter 2001) reported that adult feeding activity had little to no impact on plant reproduction, another described a 33% reduction in common milkweed fruit production as a result of *Tetraopes* herbivory (Erwin et al. 2014). While it can be difficult to identify a causative relationship between the feeding activity of beetle larvae and aboveground symptoms of poor plant health, it is possible that root damage caused by larvae may produce what appear to be plant disease symptoms. It is also possible that larval feeding activity increases the plants' susceptibility to bacterial or fungal infection.

Biology

Adult milkweed longhorn beetles typically emerge from the soil during spring or early summer (Agrawal 2004). After mating, females typically lay eggs inside thick, drying grass stems (Agrawal 2004) located near milkweed plants. Oviposition has also been documented in thin, hollow milkweed stems still standing from the previous year (Chemsak 1963). However, oviposition into fresh milkweed stems has only been observed under controlled laboratory conditions (Chemsak 1963). Females might also lay eggs in the soil near plants or within the root crowns of milkweed plants, but there is no documentation of this (Chemsak 1963). Once hatched, the larvae drop to the ground and burrow into the soil to search for milkweed roots to eat (Farrell & Mitter 1998). Larvae feed on roots both from the outside and by burrowing through them (Chemsak 1963). Larval feeding continues until late fall, when they form overwintering cells (Matter 1996). In the spring, they pupate near the soil surface (Matter 1996). Only one generation is produced each year (Davis 1984). While milkweed longhorn beetles are considered relatively sedentary, adults can fly short distances between host plant patches (Davis 1984). *Tetraopes* beetles sequester some cardenolides from milkweeds, but at far lower concentrations than monarch caterpillars or the small milkweed bug (*Lygaeus kalmii*) (Isman et al. 1977).

Management

Reducing the abundance of grasses near milkweed crops may help suppress beetle population growth by eliminating egg-laying sites. *Festuca* and *Bromus* have been specifically mentioned as suitable for *Tetraopes* oviposition (Matter 2001; Agrawal 2004). The suitability of other grasses is undocumented. Beetles also occasionally lay eggs in thin-bodied stems of various forbs (Agrawal 2004), but details regarding species preference are unavailable. Removing milkweed crop stubble at the end of the growing season, to the extent possible, may also help.

Top: Milkweed longhorn beetle larvae feeding on showy milkweed roots in Nevada. Roots were excavated for the purpose of observing larval activity. Bottom: Multiple life stages of the milkweed longhorn beetle, including multiple larvae and a pre-pupa shown to the left of the adult. (Photos: Eric Eldredge, USDA-NRCS.)

Control

Adult beetles have been documented to reach densities of over 20 individuals per square meter (1 m^2 = 10.8 square feet) of common milkweed plants (Agrawal 2005). Insecticidal soap, horticultural oil, neem oil, or a contact insecticide can be used to kill locally dense infestations as necessary. While adult feeding activity may not significantly harm plants, controlling insects before they breed and lay eggs will help reduce larval feeding on plant roots later in the season. Anecdotal observations suggest that the quantity of longhorn milkweed beetles in milkweed seed production fields can increase over consecutive years. Thus, early detection and control may help prevent long-term crop colonization.

Options for controlling larvae are limited because applying insecticide to the soil would have substantial negative impacts on the local invertebrate community. An experimental study conducted in New York indicated that entomopathogenic nematodes (insect parasitoids that live in the soil) can potentially play a role in controlling *Tetraopes* larvae and preventing the loss of milkweed root tissue (Rasmann et al. 2011). The researchers used nematodes of the species *Heterorhabditis bacteriophora* that were collected from local field sites (rather than purchased commercially). Please note that we do not recommend the introduction of commercially available nematodes as a strategy for *Tetraopes* control. This practice may have unintended nontarget effects on beneficial soil organisms. Further investigation is needed to determine whether nematode introduction or augmentation could be an ecologically responsible option for controlling *Tetraopes* in milkweed crops. However, we strongly suspect that efforts to conserve and enhance soil biodiversity, such as reduced tillage and understory cover-cropping to increase soil organic matter content, may help enhance natural control of milkweed beetles.

Snout and Bark Beetles (Curculionidae)

*Milkweed Stem Weevil (*Rhyssomatus lineaticollis*)*

Distribution

According to Blatchley and Leng (1916) this species' range extends from Massachusetts to Michigan and Kansas, then south to Florida and Texas. Beyond this vague description, occurrences have been tentatively confirmed in the eastern half of Canada and several states within the Great Lakes, Mid-Atlantic, and New England regions (Bug Guide 2014). In the central U.S., occurrences have been reported in North Dakota, Nebraska, Kansas, Texas, and Mississippi. The species has not been documented in the western U.S.

Appearance

Adult milkweed stem weevils are grayish-black and 5–8 mm long (0.2–0.3 in) (St. Pierre & Hendrix 2003). Their mouthparts are formed into a long snout ("rostrum") that bears two elbow-shaped antennae. In contrast to most milkweed specialist insects, milkweed stem weevils do not sequester cardenolides and do not have bright coloration to deter predators. Adults tend to be nocturnal and may be hard to find during daylight hours (Betz et al. 2000).

Known Host Plants

This insect is known to feed upon butterfly milkweed (Price & Willson 1979), clasping milkweed (*Asclepias amplexicaulis*) (Price & Willson 1979), common milkweed (Fordyce & Malcolm 2000; Agrawal & Van Zandt 2003), Mead's milkweed (*A. meadii*) (Betz 1989), poke milkweed (Betz et al. 2000), purple milkweed (*A. purpurascens*) (Betz et al. 2000), and swamp milkweed (Price & Willson 1979).

Damage

Adults feed primarily on young leaves but also on pedicels, leaf petioles, immature fruits, and upper portions of the main stem (Weiss & Dickerson 1921; Fordyce & Malcolm 2000; St. Pierre & Hendrix 2003). Adults sometimes damage apical meristems (points where new growth originates), thus stunting plant growth (Fordyce & Malcolm 2000). Larvae feed on stem tissues and maturing seed pods. Consumption of seed pods directly impacts seed production and stem damage caused by feeding may increase the plants' susceptibility to pathogens (Fordyce & Malcolm 2000). The likelihood of a substantial weevil infestation occurring in milkweed production stands is unknown, but the species has been described as an "extremely important" herbivore of common milkweed. One study showing that 37% of milkweed stems per patch had been attacked by the weevil (Fordyce & Malcolm 2000). Also, milkweed gardeners in the eastern U.S. have reported substantial weevil-caused damage that has resulted in high rates of plant mortality.

Milkweed stem weevil. (Photo: Ken, BugGuide contributor.)

Biology

In the spring, appearance of the adults is closely timed with milkweed emergence (Fordyce & Malcolm 2000; Agrawal & Van Zandt 2003). Females lay eggs throughout the summer. One to two generations are produced each year (Fordyce & Malcolm 2000). Early in the season, female weevils chew small holes in milkweed stems and lay a single egg in each hole. Upon hatching, larvae feed on pith tissue in the stems. Larvae appear to complete their development within the space between two leaf nodes rather than passing between nodes (Fordyce & Malcolm 2000). Later in the season, females lay eggs in the walls of immature seed pods in addition to ovipositing in stems. Larvae at high densities may completely consume seed pod contents (Weiss & Dickerson 1921). Once larvae are full grown, they drop to the ground and pupate in the soil. Fresh adults emerge before the end of summer, feed on milkweed, and then overwinter (Weiss & Dickerson 1921). Adult weevils are relatively sedentary. They do not frequently move between plants and are not believed to move distances larger than 1 kilometer (0.62 mi) (Agrawal & Van Zandt 2003; St. Pierre & Hendrix 2003).

Control & Management

If weevil activity appears to significantly impact seed production or was a known problem in previous years, controlling adults with a contact insecticide early in the season, before eggs are laid, is likely the best way to suppress their population growth. Once eggs are laid, it will likely be impossible to control the larvae with insecticide since they mature inside of stems and pods. Controlling adults in late summer will prevent them from overwintering, thus reducing the number of weevils that will emerge the following spring. Since adults tend to be nocturnal, control measures may need to be implemented after dark.

Interestingly, scientists with the USDA's Agriculture Research Service recently discovered that an experimental pheromone lure designed to attract the boll weevil (a pest of cotton crops) is also very attractive to milkweed stem weevils (Suh & Westbrook 2011, http://goo.gl/igrT19). At the time of this writing, the Agricultural Resarch Service was moving forward with developing a pheromone-based trapping system for the milkweed stem weevil.

Related species

Another species of milkweed stem weevil, *R. annectans*, is little studied and few photographs are available. It is documented to use swamp milkweed as a host (Weiss & Dickerson 1921) and has a life cycle similar to *R. lineaticollis*. It lays its eggs in plant stems early in the season and in developing seed pods during late summer. While it is known from Ohio, Indiana, Illinois, and New Jersey (Weiss & Dickerson 1921), its range is not well documented and its potential to significantly damage milkweed production stands is unknown.

Generalist Herbivores

Despite milkweeds' complex chemical defenses, they are sometimes susceptible to herbivory by generalist species. Documentation of milkweed herbivory by generalists is scarce in the scientific literature. Thus, the comments included here have been primarily compiled from informal reports and personal observations by the authors and Xerces Society collaborators.

Mollusks

The eastern heath snail (*Xerolenta obvia*), an invasive species introduced from Europe, has been observed feeding on the stems and leaves of wild milkweed plants in Montana (Montana Department of Agriculture, pers. comm.). It is unknown whether this snail feeds on milkweed in other parts of the U.S. and whether it has the potential to significantly impact wild plants.

Slugs (species unknown) have been observed feeding on young plants in California milkweed production fields, but not on mature plants.

Mammals

In California, black-tailed jackrabbits (*Lepus californicus*) have heavily browsed narrowleaf milkweed. However, milkweed herbivory by rabbits may be more likely to occur under drought conditions, when other plant food sources are limited. In Arizona, pocket gophers (*Thomomys* spp.) killed cultivated spider milkweed plants, feeding on the roots and dragging young plants underground. However, in this specific scenario, soil tillage (in preparation for transplanting) and subsequent irrigation may have encouraged gopher activity. Occasional browsing of milkweed by deer has also been documented (Wilbur 1976; Farnsworth & DiGregorio 2001).

Plant Disease Diagnosis and Management

Plant diseases—along with specialist insect herbivores—are typically the most significant production challenge that seed producers will encounter. In particular, as with other monocrop systems, larger milkweed production operations will likely face disease pressure that is both more frequent and more severe. Unfortunately, unlike major food crops and some ornamental plants, information on the diseases of most wild native plants, including milkweeds, is extremely limited and probably very incomplete. With our limited knowledge of milkweed diseases come limited treatment recommendations, and there are few conventional fungicide options that are labeled for use on native seed crops. However, with some understanding of the conditions that favor disease, and a general understanding of the major disease categories of plants, most growers can at least make informed decisions about possible treatment options.

Plant pathologists refer to three conditions that must co-occur in order for a plant disease to manifest itself (sometimes called the "plant disease triangle"). These conditions are: 1) a susceptible host plant, 2) a conducive environment, and 3) a pathogen.

In assessing the first condition it should be noted that milkweeds, like all plants, exhibit a variable range of disease susceptibility, even within a single species. Further, unlike with commercial food crops, no intentional breeding programs are underway to select for, and mass propagate, disease-resistant milkweed cultivars. Indeed, as genetic diversity is prized among native seed producers and conservation practitioners, there should—and will be—a range of disease susceptibility within a healthy milkweed seed production field.

Unfortunately, the second condition, a conducive environment, is inherent in the large, artificial scale and close plant proximity necessary for mass seed production. Despite this, we recommend chemical treatments only as a last resort (e.g. when significant disease outbreaks threaten crop yields). Other conditions that may favor plant disease include: climatic stress (uncharacteristically wet or dry seasons); nutrient deficiencies; insect feeding activity or mechanical damage to plants; pollution; and a lack of biological diversity, such as the absence of competition among microorganisms that cause disease and the other microorganisms that attack them.

Finally, there are the pathogens themselves. The diverse pathogens that attack milkweeds are broadly representative of those that affect all plants, consisting of bacteria, fungi, viruses, various other microscopic organisms (such as protozoa), and abiotic conditions (like pollution). With this wide array of pathogens there are correspondingly diverse infection pathways, including cell wall degrading enzymes, secretion of effector proteins (which send false signals to the host plant, triggering openings in the cell wall for pathogens to enter), and transmission by insects.

In the following sections we describe the pathogen groups, the symptoms they cause, their infection pathways, and some broad strategies for reducing their impacts.

Known Milkweed Diseases

While there are potentially many as-yet-unrecognized milkweed diseases, over 40 distinct pathogens have been identified and recorded within the *Asclepias* genus. We have compiled a compendium of known milkweed diseases, which to our knowledge is the most comprehensive resource of its kind available (Appendix II). Several of these pathogens were diagnosed and recorded between 2005 and 2008 when one of the authors (Eric Lee-Mäder) worked as a crop consultant for the native seed industry. Many of the pathogens listed potentially affect additional milkweed species on which they have not yet been documented, and it is very likely that additional pathogens exist.

Fungi

Fungal pathogens cause the greatest number of—and most devastating—plant diseases. While the vast majority of fungal organisms are benign and play an essential role in nutrient cycling by decomposing dead organic matter, others can attack even healthy hosts, feeding on live tissue and, in extreme cases, completely killing a host plant.

The life cycle of many fungal pathogens can be extremely complex and, as such, is beyond the limits of this guide. Note, however, that many fungal organisms can produce both sexual (resulting from genetic recombination) and nonsexual (clonal) spores, and that those spores can be spread long distances by wind, water, and soil particles. Fungal spores often remain dormant for years, waiting for the ideal combination of environmental conditions to germinate. Most fungal plant pathogens fall into three broad taxonomic categories (which represent the major taxonomic fungal groups): the Ascomycetes (or sac fungi), the Basidiomycetes (club fungi), and the fungi-like Oomycetes (or egg fungi).

Sac fungi comprise the majority of foliar milkweed diseases including leafspots, stem and leaf lesions, and powdery mildews. A few specific examples of milkweed sac fungal diseases include *Septori*a and *Cercospora* leafspots, and *Colletotrichum* stem lesions. These fungi produce multiple spore types including ascospores, contained within pouch-like sacs and resulting from sexual reproduction, and conidia, dark, seed-like resting spores that result from non-sexual reproduction and which can remain dormant for years, even under harsh environmental conditions.

Club fungi are represented among milkweed diseases by the rusts, a group of diseases that produce orange or black

Leafspot (*Passalora californica*) infecting narrowleaf milkweed (*Asclepias fascicularis*). (Photo: John Anderson, Hedgerow Farms, Inc.)

Leafspot fungus (*Cercospora* spp.) infecting butterfly milkweed. (Photo: Eric Lee-Mäder, The Xerces Society.)

pustules on the undersides of leaves. Rusts can produce up to five different spore types that alternate through complex life cycles based upon weather conditions, season, and the presence of host plants. The latter point is worthy of special attention because many rusts require two distinct host plants for full cycling of all life stages. For example, various milkweed rusts have been identified during other life stages on grass host plants, especially in the genera *Spartina*, *Bouteloua*, and *Chloris*.

Egg fungi are not true fungi. Rather, they are mobile, single-celled, fungal-like organisms with cell walls comprised of cellulose (similar to plants), and are found primarily in soil. Because they are mobile in soil and water, egg fungi can disperse over short distances toward the chemical signal of food sources (such as host plant roots). Consequently many well-known and devastating root rot plant diseases are egg fungi, such as *Pythium*, which affects milkweeds and many other species. Egg fungi also produce tough resting spores (oospores) that can remain dormant for extended periods of time. These can be dispersed in soil dust, or carried on the soles of shoes, on farm equipment, etc., where they may be introduced to new areas.

Depending on the specific pathogen and the stage of infection, fungicide options may be available to control milkweed diseases. While there are numerous chemical classes of fungicides (and individual products may contain multiple classes), they are sometimes broadly described as either "preventative" or "curative" in their mode of action, although this simplistic division is in actuality typically inaccurate. An in-depth description of all fungicide classes is beyond the scope of this document. However, the seed producers we work with generally rely upon four fungicide groups to manage milkweed diseases. These four groups include sulfur, copper, strobilurins, and triazoles. Note that individual fungicide products are unlikely to be labeled for milkweeds. While we make no recommendations on the legal interpretation of fungicide labels, it is our opinion that milkweeds meet the broad definition of ornamental nursery plants.

Sulfur represents the oldest known class of plant fungicide. Despite this, its specific mode of action is still poorly understood, although it is recognized to inhibit spore germination. Sulfur is generally considered a "preventative" as opposed to "curative" fungicide. It may be toxic to some plants, especially in warm weather. One of sulfur's important strengths as a fungicide is the low potential for pathogen resistance to develop. Because of sulfur's phytotoxic potential, we recommend applying it at the minimum recommended rate to a small group of test plants before applying it at the field-level scale.

Copper fungicides, like sulfur-based products, are considered preventative, have low potential for pathogen resistance, and can be phytotoxic. They may pose health risks to people and precautionary guidance on the label should be followed. Like sulfur, we recommend applying copper fungicides at the minimum recommended rate to a small group of test plants before applying them at the field-level scale.

The strobilurin class of fungicides includes specific chemicals like trifloxystrobin, fluoxystrobin, azoxystrobin, and others. This class inhibits fungal respiration and spore germination and has limited systemic movement into the plant (although it is still considered primarily to be a preventative fungicide class). Unlike sulfur and copper, the potential for pathogens to develop resistance is relatively high among this chemical group.

The final class of fungicide we routinely see native seed producers employ is the triazole group, which includes active ingredients like propiconazole, cyproconazole, and metaconazole. This fungicide group has limited systemic movement into the plant (primarily upward, in xylem), and unlike the aforementioned groups, is considered mostly curative, stopping active infections. The triazole group, which functions by inhibiting the development of fungal cell walls, has a relatively high potential for creating fungicide resistance among diseases, especially rusts.

While these and other fungicides are reasonably effective for many sac and club fungi, they typically have limited effectiveness against egg fungi. Unfortunately, this is even true of most fungicide classes beyond those described here. A few specific fungicides like metalaxyl and foestyl aluminum may be partially effective, but once established in a specific crop, egg fungi are often impossible to eradicate and infections are likely to reoccur. Where lab tests confirm such pathogens, and where diseases reoccur, the most profitable management option may be removal of the susceptible crop, followed by planting a resistant species, such as a native grass.

To manage sac and club fungi infections, we recommend the regular rotation of different fungicide classes to reduce the development of fungicide-resistant pathogens. Moreover, for all disease-causing organisms, we recommend pesticides only as a last resort. Native seed producers should note that fungicides are broad-spectrum in nature, killing good and bad fungi alike. When milkweeds in home gardens or landscape features display symptoms of fungal infection, we recommend removing and disposing of the diseased tissue to reduce the presence of spores that might infect healthy plants. More proactive disease management strategies are described later in this section.

Bacteria

Bacteria are single-celled organisms that are abundant in most soils. Like fungi, they are largely benign to plants; they play a critical role in nutrient cycling, and a relatively small number of species are identified as plant pathogens. While a few types of bacteria can degrade a host plant's cell walls during the infection process, most bacterial infections occur in physically damaged plant tissues (such as leaves bruised by hail). The symptoms of bacterial infection in plants usually appear as wet or water-soaked foliage, or irregularly-shaped leafspots (often confined by the leaves' vein structure). One bacterial pathogen, *Xanthomonas campestris*, is widespread among many plant species, and has been noted routinely in milkweeds.

In contrast to true bacteria, phytoplasmas are a related group of pathogens that lack cell walls (and consequently cannot live freely outside of a host cell). Phytoplasmas are vectored by insects, especially those with piercing–sucking mouthparts such as aphids. These insects consume the pathogen while feeding on an infected host. They then move to an uninfected plant, where they secrete some of the pathogen into the new host along with the digestive enzymes they inject into the plant to help them feed. Commonly, infected plants suffer a destabilized immune response. This reduces the plant's ability to produce chemicals that may inhibit feeding by insects, thus making the host plant even more susceptible to insects that may help vector the pathogen. Physical impacts include extreme mutations, especially of flowers, which may spontaneously branch where no branching should occur, or which may lack pigment.

There are few chemical control options to manage bacterial infections. Though copper hydroxide fungicides may have some efficacy against bacterial infections, fungicides generally fail to control bacterial plant diseases. In recent years several hydrogen peroxide solutions labeled for crop protection have become available; these may offer some bacterial pathogen control but are broad-spectrum in nature and will kill both good and bad bacteria. Finally, some probiotic bacteria solutions—primarily consisting of *Bacillus subtilis*—are now available to provide competition against pathogenic bacteria. While we have not tested them on milkweeds, we think the overall approach of supporting diverse microbial communities as a disease prevention measure is scientifically sound.

Viruses

Viruses represent a largely under-studied group of plant pathogens, especially among wild plants like milkweeds (whereas virus-resistant technology, including genetic modification, is widely adopted for food crops). Viruses usually consist of single-stranded RNA genomes housed within a protein coat and they may be vectored by insects or transported through cell walls. Viral replication within infected plants is complex, and may result in structural or biochemical changes to the host cell—including mutation or death. At the whole-plant level, symptoms may include yellowing, stunting, leaf or flower deformity, or mosaic color patterns. In some cases, plant pathogenic viruses are also seed-borne.

Unfortunately, there are few virus control strategies available to seed producers. We recommend regular scouting, the immediate removal of symptomatic plants, and proactive insect management—especially of the invasive oleander aphid, which is likely a vector of milkweed viruses.

Other Organisms

Other biological plant pathogens may include nematodes, parasitic plants, protozoa, and algae. Of these, neither nematodes nor parasitic plants have been observed infecting milkweeds, though it is possible that milkweed pathogens among one or both groups may exist but are not yet identified. Nematodes, which are microscopic roundworms, are extremely widespread in soil and while most species are beneficial, some plant-pathogenic species will attack a wide range of plant hosts, causing galls, deformities, and lesions to the roots of susceptible plants. Nematodes are also potential vectors of plant viruses.

Protozoa, which are mobile single-celled organisms, include one known milkweed pathogen that is vectored by the large milkweed bug (*Oncopeltus fasciatus*). The extent of protozoa infections among milkweeds is currently unknown, and no treatments are known or recommended. Similarly, one species of algae is known to grow on the surface of milkweed leaves, causing superficial leafspots. As with protozoa, no treatment is known or recommended.

Abiotic Diseases

Abiotic milkweed diseases result from non-living causes like pollution, soil salinity, nutrient deficiencies, herbicides, radiation, etc. These conditions tend to occur as a distinct field pattern (for example, only the plants growing close to a road where de-icing salt was applied might be affected), and all plants in an area tend to be affected in a similar way—even plants of other species. In most cases, there are no treatment options for abiotic diseases.

Among milkweeds, ground-level ozone damage is a notable example of abiotic disease and is characterized by the appearance of distinct black dots on the upper leaf surfaces (Chappelka et al. 1997; Bennett et al. 2006). In fact, due to common milkweed's sensitivity to elevated ozone levels, it has been used by the U.S. Forest Service as a bioindicator of forest health in the eastern U.S. (Brantley et al. 1994).

Disease Management Strategies

While chemical products can control some specific diseases, they are likely to reoccur unless the underlying conditions promoting infection are addressed. Following the plant disease triangle, susceptible host plants will always be present in the equation, as will pathogens. Even healthy soils and crop systems tend to have an enormous bank of dormant disease spores. Although it may not be obvious, the environmental conditions that make widespread crop infection occur are the one element of the plant disease triangle that growers have the greatest ability to influence.

We believe that most disease outbreaks can be mitigated by maximizing biodiversity at multiple trophic levels within the farm ecosystem. Ideally, this concept of expansive biodiversity begins with the crop itself, by using foundation seed from a large genetic pool to establish the production field. The more diverse the foundation seed, the more likely the population will be to contain disease-resistant individual plants.

Biodiversity can also be incorporated into the production system by intercropping milkweeds with other plant species. For example, a milkweed stand could be limited to six rows (or whatever equipment constraints allow) and alternated with six rows of another, unrelated crop. Reducing individual stand size will reduce the potential for the rapid spread of disease across your entire milkweed population.

Similarly, our preliminary investigations have suggested the promise of seeding various low cost annuals within milkweed production fields. Possible examples include partridge pea (*Chamaecrista fasciculata*) in the eastern U.S., or even canola in northern and western states. Such intercropping may increase the biodiversity of both soil fauna (including fungi antagonistic to milkweed pathogens) and beneficial insects (such as parasitoid wasps) that may feed on disease-vectoring aphids. The benefits of understory cover cropping are now widely recognized for conventional crops and supported by extensive science. Yet, to date, native seed producers have been largely reluctant to explore this same model for their crops.

Where persistent and devastating diseases (such as *Pythium* root rot) occur, biodiversity can be reintroduced to the system via long-term crop rotations that move milkweed production to a new location on the farm while occupying the disease-infested ground with a new plant community (such as a native grass field). However, this should be a last resort for managing milkweed diseases.

Finally, we have received interesting anecdotal reports of largely unmanaged milkweed stands persisting for many years—and in some cases decades—while commercial seed producers who are actively managing pests, disease, water, and nutrient issues often report production field lifespans of only a few years. While there are clearly multiple variables that can influence disease (and we recognize that occasionally, devastating plant diseases can strike even healthy populations), the regularity of these anecdotes suggests a trend worthy of deeper investigation.

Seed Harvesting

Milkweed pods within a given population or production stand mature over a period of a few to several weeks and only a subset of them will likely be ready for collection each day. Due to the wind-aided dispersal of milkweed seeds, the window of opportunity to harvest mature seed pods can be narrow.

Mature pods split open along vertical seams to release their seeds. Seeds are brown when mature. If seeds are green or white, they are immature and not ready for collection. If pods are still closed and the seams do not split open readily when gentle pressure is applied, the pods are not ready for collection.

The most effective strategy for seed collection will depend on the scale of the collection effort, the equipment and labor force available, and the degree to which fruits (pods) mature uniformly versus indeterminately. Here, we describe potential approaches to collecting milkweed seed, ranging from hand-harvesting to using mechanized equipment for large-scale harvesting.

Narrowleaf milkweed pods in a California seed production field. Some pods have already opened to disperse seed while others are still maturing. (Photo: John Anderson, Hedgerow Farms, Inc.)

Hand-Harvesting

Suitable Scale

Up to one acre per person, per day. For production stands larger than one acre, the increased efficiency of mechanized harvesting may be more cost effective.

Advantages

No specialized equipment needed.

Compared to mechanized harvesting, a reduced volume of inert material (e.g., stems, leaves, floral parts) is collected along with the pods. (Note: there will still be inert material present in the collection, in the form of pod shells, floss, and the lightweight spindle structures that span the length of the pods).

Harvests can easily be made on multiple occasions during the seed maturation window. Collecting seed from early-, mid-, and late-maturing plants will likely help to maximize genetic diversity of the seed lot.

Close contact with plants provides opportunities to observe the presence of seed-feeding insects and avoid collecting infested pods as necessary.

Disadvantages

Can be time consuming and labor intensive.

Depending on how uniformly the pods mature within a given stand, seed may need to be collected daily or every other day over a several week period.

Basic Instructions

Entire pods or contents of pods can be harvested directly into a bag or other receptacle.

If the seed lot will be cleaned by hand, it is best to collect pods when the seams have just begun to split and the floss has not yet expanded.

If pods have fully opened and the floss has already expanded, scoop the seeds and floss out of the pods, rather than also collecting the pod shells. This reduces the amount of time and labor needed later to clean the seed lot.

Avoid collecting pods on which red and black milkweed bugs (see the *Identification and Management of Milkweed Herbivores* section of this document for more information) are aggregated. These bugs pierce through pods to feed on seeds and their feeding activity can reduce the seed lot's viability.

Hand Harvesting with Seed Capture Bags

Suitable Scale

Production stands of less than ¼ acre or a wild seed collection effort with a target quantity of grams or ounces.

Advantages

When used in a cultivated milkweed stand, seed capture bags significantly reduce the number of visits required during the seed maturation window. Bags can be applied on a few select days when fruits are reaching maturity and then retrieved all at once, several days later, when fruits have dehisced. The efficiency of this method will depend on the available labor force.

When used for wild seed collection, this method helps ensure that seeds are not dispersed before a return visit can be made.

Depending on how securely the bags are fastened, they may also prevent seed-feeding insects from accessing the pods and seeds.

Seed capture bags are relatively inexpensive and can potentially be reused multiple times.

Potential Disadvantages

Leaving the bags in place until after the pods have fully opened will increase the amount of time and labor required later to separate the seeds from floss (compared to strategically harvesting pods that have not yet dehisced).

When used for wild seed collection, the bags may attract unwanted attention (from either humans or wildlife) that could result in vandalism or browsing.

If seed-feeding insects (egg, nymph, or adult stages) are inadvertently trapped inside the bags when the bags are applied, seeds may be subject to higher levels of damage than if the bags had not been used.

Depending on climate, the bags may concentrate moisture around the pods and encourage mold growth.

Basic Instructions

Ready-assembled bags meant for other purposes can be used for seed capture. Organza wedding favor bags come with drawstrings and are durable enough to reuse. Mesh bags with drawstrings can be purchased from some companies that sell corn shoot bags. When purchased in quantities greater than 500, both of these types of bags will likely cost 30–40 cents each. You can also assemble bags by cutting pieces of lightweight polypropylene garden fabric ("floating row cover") and then stapling or sewing the material along three sides of the square or rectangle with an opening at the bottom. However, the bag assembly approach will require additional materials (e.g., twist-ties, lengths of fine-gauge wire) to affix the bags to plants.

Once pods have matured to full size, place bags over individual pods or pod-bearing stems, securing the bags to stems with drawstrings or twist-ties.

Confirm the absence of red and black seed-feeding bugs before applying the bags.

Mesh seed capture bags affixed to maturing rush milkweed pods. (Photo: Megan Lahti, Arizona Western College.)

Contents of seed capture bags used on rush milkweed. (Photo: Megan Lahti, Arizona Western College.)

Combine Harvesting

Suitable Scale

Using a mechanical combine harvester is most suitable for production stands of ¼ acre or larger. This approach will be most effective on stands with determinate maturation, in which the majority of seed pods mature within a few days of one another.

Advantages

Much more time-efficient than hand-harvesting.

Combines can be very effective at separating seeds from floss, saving significant time on post-harvest seed processing.

Potential Disadvantages

Equipment may not always be available or cost-effective to rent, especially for small production operations. This is especially true for production fields less than 1 acre in size.

Even where equipment is available, some growers report that the cutting action of a combine may damage root crowns, making the plants susceptible to secondary infections.

Finally, if used on stands with indeterminate fruit maturation, this method will potentially reduce the seed lot's genetic diversity by selecting for plants with fruits that are mature at the chosen time of harvest. This will also reduce seed yield since early- and late-maturing fruits will not be harvested.

Basic Instructions

Crops should be combined during the estimated peak of fruit maturation.

A recommended guideline for harvesting common milkweed is that when 10% of the pods in a production stand have dehisced, the majority of fruits will contain mature seed (Winthrop Phippen, pers. comm.). Whether this rule of thumb applies to other milkweed species is unknown.

To maximize genetic diversity of the seed lot and capture early,- mid-, and late-maturing genotypes, some hand harvesting can be done in the early part of the seed maturation period. Have the combine skip a subset of the field so that additional hand-harvesting can be done toward the end of the seed maturation period.

Some producers use a variation on direct combining, first swathing the crop, then laying it in windrows to further dry, and finally feeding it into a stationary combine.

Combining butterfly milkweed with a Hege 125B, 1978 model plot combine. (Photo: Tallgrass Prairie Center, University of Northern Iowa.)

Swathed narrowleaf milkweed material shaped into windrows, to dry and after-ripen before being processed. (Photo: John Anderson, Hedgerow Farms, Inc.)

Butterfly milkweed material after being combine-harvested. (Photo: Tallgrass Prairie Center, University of Northern Iowa.)

Notes on Additional Harvesting Equipment

Some producers report that a Flail-Vac Seed Stripper is of only limited utility for harvesting milkweed seed. A significant portion of the lightweight floss and seed tends to become airborne, rather than being captured by the equipment. However, it may be possible to modify vacuum harvesters to facilitate harvesting fluffy seed. An additional consideration with using a Flail-Vac is that it will significantly increase the time needed for seed processing because the harvested material will be a coarse mixture of seeds, floss, pod shells, leaves, and stems that is difficult to separate with traditional seed cleaning equipment.

Von Bargen et al. (1994) successfully converted a self-propelled corn ear harvester into a milkweed pod harvester. Their description of equipment modifications would be helpful to anyone interested in developing custom equipment for harvesting milkweed pods. However, their objective was to maximize floss recovery (for commercial use as loose fill insulation) and they viewed milkweed seed as a by-product of their operation. They designed their equipment to harvest pods that had not yet opened, and it is possible that seeds would not yet be mature at the time of harvest.

Post-Harvest Instructions

We recommend drying milkweed pods for several days before processing them. If drying bins are unavailable, spread the material out to dry in an area with good air circulation or with electric fans set up to aid the drying process. Leaving the material compacted in bags (particularly plastic ones) or other receptacles will encourage mold growth. Make sure that red and black seed-feeding bugs are not present in plant material that is being dried or stored prior to seed processing.

Flail-Vac harvesting results in a coarse mixture of seeds, floss, and other debris that is difficult to separate using either small-scale improvised cleaning equipment or traditional seed cleaning equipment. (Photo: Brianna Borders, The Xerces Society.)

We attempted to hand-clean the Flail-Vac harvested seed lot by screen-sorting, but it was not possible to clean the lot any more finely than this. Winnowing with the aid of a box fan was also attempted but was ineffective. (Photo: Brianna Borders, The Xerces Society.)

Seed Processing

Harvested milkweed plant material will consist of seeds, pod shells, and floss, and possibly also stems, leaves, dried floral parts, and insects. Seed yield per unit weight of harvested raw material will vary with the amount of inert material harvested along with the seeds, the moisture content of the material, and the efficiency of the seed processing method used. The Ogallala Comfort Company, which processes several thousand pounds of common and showy milkweed pods per year, reports that processing ten units of milkweed pods (dried to 10% moisture) yields two parts of floss, three parts of seed, and five parts of pod shells and other inert material (Knudsen & Zeller 1993). While Berkman (1949) corroborates these relative proportions for common and showy milkweed, their accuracy for other milkweed species is unknown.

Removing floss fibers is the most challenging step in the cleaning process, whether milkweed pods have been harvested mechanically or by hand. The rest of the process is straightforward and uncomplicated. Here, we describe several options for processing milkweed seed, ranging from cleaning small harvests by hand or with easily accessible equipment to processing large volumes of material with specialized harvesting and seed cleaning equipment. Beyond the strategies outlined here, there is significant potential for developing novel approaches and equipment modifications.

Note: we recommend wearing eye protection and a dust mask or particulate respirator while processing milkweed seed.

Raw showy milkweed material that was harvested by hand. The mixture includes intact pods, pod shells, and loose seed and floss fibers. (Photo: Brianna Borders, The Xerces Society.)

Hand-Cleaning Without Tools or Equipment

<u>Suitable Scale:</u>
In our experience, hand-cleaning is only feasible when dealing with less than a couple pounds of pods.

Typically this limits hand-cleaning to pods that have been hand-collected for the purposes of selling, planting, or giving away small quantities of seed (e.g., grams or ounces), or for securing foundation seed that will be used to initiate seed production activities.

When seed is cleaned by hand, harvest pods before they have fully opened because it is easier to remove the seeds before the floss fibers expand. It is important to process the pods as soon as possible. If they are allowed to dry for a few days, the floss will begin to expand. Once the floss has expanded, the seeds will be suspended in a voluminous mass of fibers and the amount of time required to clean the seed lot by hand will have increased exponentially. If the floss fibers in your seed lot have expanded, you may want to use some simple pieces of equipment to increase cleaning efficiency (methods are described later in this section).

A mature showy milkweed pod in which the floss fibers have not yet expanded. This is the ideal stage for hand-stripping seeds from the pod and quickly separating them from the floss. (Photo: Brianna Borders, The Xerces Society.)

<u>Method</u>
Before floss has expanded, firmly grasp the bundle of floss fibers at the tapered end of the pod to prevent them from separating from the lightweight spindle structure that spans the length of the pod. You can then either remove the pod shell from the bundle of floss or leave it attached. While still holding the floss fibers together, gently separate the seeds from the floss with a rubbing or scraping motion and let them fall into a bucket or bowl. The floss and pod shells can then be discarded.

Hand-cleaning of milkweed pods is easiest when the floss has not yet expanded. (Photo: Brianna Borders, The Xerces Society.)

Small-Scale Cleaning with Easy-to-Acquire Tools and Equipment

Hand-cleaning by Screen-Sorting

<u>Suitable Scale</u>

When floss fibers have expanded, hand-screening can save time over picking individual seeds out of the fluff by hand, but the process is still slow and messy. For example, it has taken us approximately three hours to clean one pound of narrowleaf milkweed (*Asclepias fascicularis*) pods using this method. Thus, we recommend it only for small volumes of harvested material that weigh less than a pound. However, this approach may be more efficient per unit weight for species with larger pods.

<u>Method</u>

If the floss has expanded and mechanized seed cleaning equipment is unavailable, plant material can be sorted by hand, using a sheet of hardware cloth placed over a large bin. You will want to choose material with a mesh size that is just large enough to allow the seed to fall through (¼ inch is likely suitable for most species). Rub the material over the screen or between your hands to release the seeds from the floss. The seeds will fall through the screen while most of the floss, pod shells, and other material will remain on top of the screen and can be discarded. A small amount of floss fibers and other inert materials will likely pass through the screen and will have to be removed by hand. Alternatively, the remaining fractions can potentially be separated using a stack of soil sieves of varying screen sizes.

During this process, individual floss fibers will become airborne and float everywhere. Therefore, it is best to do this outside but in a location protected from the wind, to reduce seed loss.

Using simple, easy-to-obtain materials to screen-sort a milkweed harvest. (Photo: Brianna Borders, The Xerces Society.)

Floss Ignition

Suitable Scale

Floss ignition is easiest when handling small amounts of seed (e.g., less than a couple pounds of pods), and should be performed in small batches.

Milkweed floss is highly flammable and some people have reported success with burning relatively small quantities of floss and seed to quickly dispose of the floss. Please note that this is a risky technique with significant potential for seed damage and is not recommended for small seed lots of high value. Also, a fair amount of time and labor is required to remove materials such as leaves, pod shells, and floral parts from the seed lot prior to ignition. Their presence will cause the fire to burn longer and hotter, increasing the potential for seed damage. This technique should only be performed outdoors with a source of water nearby. Eye protection is recommended.

Method

Loosely place a small quantity of floss and seed in a nonflammable container (such as a metal bucket or coffee can) or spread the material out on a nonflammable surface. If the material is too densely packed, the fire will burn longer, possibly damaging the seed. Once a flame is applied (such as from a lighter), the floss will ignite quickly and burn for a few seconds. The fire will rapidly die out, and the majority of the seed should be undamaged by the heat or flame. However, we do not have any professional seed testing results to confirm that this method does not negatively impact seed viability. An informal germination test conducted by the Nature Conservancy indicated that this method resulted in a significant loss of seed viability (The Prairie Ecologist 2012).

Shop Vacuums

Suitable Scale

This is the method we prefer and we have found that practically any quantity can be processed, although in our experience, it takes approximately 75 minutes to clean one pound of showy milkweed pods. We suspect, however, that efficiency increases with practice!

Method

Standard shop vacuums ("shop vacs") with cartridge filters can be very effective at cleaning milkweed seed. As small handfuls of raw material are slowly fed into the vacuum (either through the hose or straight into the tank's inlet port), the floss fibers will collect around the filter while seeds and inert materials such as stems, leaves, pod shells, and floral parts will fall into the bottom receptacle. Minimizing the amount of inert material that enters the vacuum will result in cleaner seed and reduce the need for further cleaning. After feeding material into the vacuum for several minutes, you will need to stop and remove the accumulated floss from the filter. The majority of the floss can be peeled off in a single strip and discarded. Some fibers will also need to be removed from between the folds of the filter. This can be done by hand, with an air compressor, or with a second shop vac.

If the pods have not fully opened and the floss fibers have not expanded, you can minimize the amount of floss that enters the vacuum. The advantage of doing so is that it reduces the frequency with which floss must be removed from the filter. Use the same approach described in the previous section on hand-cleaning, i.e., grasping the bundle of floss fibers with one hand, while working the seeds loose from the floss with the other hand next to the vacuum hose. In this manner, most of the floss can then be discarded rather than fed into the vacuum.

In our experience, a 5.5 HP shop vac with 16-gallon capacity worked extremely well to separate seeds from floss without seed damage. Results may vary as there is considerable range in the design and horsepower of shop vacs, and it is advisable to conduct an initial test run to ensure that seeds do not break. Seed breakage may be the result of abrasion against the ridged hose; feeding the material directly into the inlet port may reduce this. When choosing a vacuum model, consider that it will be easier to remove material from the receptacle if it does not require a collection bag. Similarly, we recommend both carefully cleaning the inside of a vacuum before use, and installing a new filter. Some shop vacs can be quite loud and require ear protection. While the vacuum will capture most of the floss, some of the fibers will become airborne.

In numbered order:

1. You can prevent floss fibers from entering the vacuum by grasping them at their base while dislodging the seeds into the vacuum hose.

2. After seeds have been sucked into the vacuum, the remaining floss fibers can be discarded.

3. Milkweed floss fibers aggregated around the cartridge filter of a shop vacuum.

4. When floss fibers have aggregated around the filter after several minutes of vacuum operation, they can usually be removed in a cohesive strip.

(Photos: Brianna Borders, The Xerces Society.)

Build-Your-Own Small-Scale Cleaning Equipment

Monarch Watch Seed and Floss Separator

Suitable Scale
Unknown.

A milkweed seed and floss separator designed by Monarch Watch consists of a 32-gallon trash can, a shop vac, and other easy-to-obtain building materials (Monarch Watch 2010). The design specifications are available online, along with a video of the cleaner in use. We modified Monarch Watch's design by scaling it down to a 5-gallon paint bucket, but found that functionality was lost. The performance of the full-scale model is likely superior. As part of their seed production work, the USDA-NRCS Plant Materials Center in Manhattan, Kansas built a version of this device using metal components and powered by an electric drill (NRCS 2013). However, construction of this modified version would require basic skills in metal fabrication (e.g., welding and cutting).

USDA-NRCS staff operating a milkweed seed separator at the Manhattan, Kansas Plant Materials Center. (Photo: USDA-NRCS Manhattan Plant Materials Center.)

Both top and bottom: Milkweed seed separator constructed by the USDA-NRCS Plant Materials Center in Manhattan, Kansas. (Photo: USDA-NRCS Manhattan Plant Materials Center.)

Mechanized Seed Cleaning

As mentioned previously, the most challenging step of milkweed seed processing is separating the floss fibers from the rest of the harvested material. First, we will describe equipment that is capable of completing that step: hammermills, brush machines, debearders, and combines. Then we will highlight equipment that can effectively separate seeds from the remaining inert materials (e.g., air-screen cleaners, gravity separators).

Before using mechanized equipment to process milkweed pods, it is helpful to dry the pods for several days, ideally in a forced-air drying bin. Threshing will be more effective when moisture content in the pod shells and floss is reduced. Also, seeds with higher moisture content are more likely to be damaged.

Suitable quantity: All equipment described in this section is suited for cleaning large volumes (e.g., multiple pounds) of harvested plant material.

Equipment for Removing Floss Fibers

Hammermills

A hammermill can very effectively break up pods and separate seeds from floss and pod shells. A ¼ inch screen will likely work for most milkweed species. The main drawback of using a hammermill is that the chamber fills with floss and pod shells fairly quickly and must be opened and cleaned out every few minutes. Hammermills come in a variety of shapes and sizes; those with larger chambers may be more efficient. Depending on the machine's design, it may be possible to set up a vacuum at the discharge end to capture the floss.

Partially processed showy milkweed pods in a hammermill chamber at the USDA-NRCS Plant Materials Center in Corvallis, Oregon. (Photo: Brianna Borders, The Xerces Society.)

Hammermill. The chamber is in front of the grid. (Photo: Brianna Borders, The Xerces Society.)

Seed lot condition after one pass through a hammermill. Some additional fine cleaning is needed but the floss has been almost completely removed and there is little debris remaining. (Photo: Brianna Borders, The Xerces Society.)

Brush machines

In addition to breaking up pods, brush machines alter the texture of milkweed floss fibers, making consecutive phases of the cleaning process easier. However, brush machines are often used to de-wing and polish seeds, and can cause seed damage when operated aggressively. Unprocessed milkweed floss typically has a silky, smooth texture that clings to seeds. Using a table top brush machine, we have found that brushing gives the floss a woolly texture, making it easier to separate from the majority of the seeds, especially when the seed-floss mix is passed through an air-screen cleaner. When using smaller brush machines, the operator will need to stop and open the machine often to remove the pod shells that accumulate within the chamber. Small test runs with different mantles and speeds will be necessary to find the right combination of settings that effectively break up the pods without damaging seeds. We found that using a sandpaper mantle abraded the seed coats to the point that the embryos were exposed. Wire mesh mantles were gentler on the seeds, but significant de-winging and polishing, along with some seed breakage, occurred at higher speeds. At lower speeds, de-winging was greatly reduced but pods were not always broken up after just one pass through the machine. It is unlikely that de-winging has a negative effect on seed viability and it is a non-issue if the seed will be planted for one's own purposes or used to produce transplants. However, if the seeds will be sold, their appearance may be a consideration and due to the reduced mass of the individual seeds, an accurate seed count estimate should be obtained.

Example of a table top brush machine. Much larger models are also available. (Photo: Brianna Borders, The Xerces Society.)

Milkweed floss has a different texture after passing through a brush machine, making it easier to separate seeds from floss during consecutive cleaning phases. (Photo: Brianna Borders, The Xerces Society.)

After brush machine processing, this coarse mixture of pod shells, floss, seeds, and small debris, is ready to be processed using an air-screen cleaner. (Photo: Brianna Borders, The Xerces Society.)

Seed condition after being processed with a brush machine and an air-screen cleaner. Some of the seed wings are broken due to abrasion in the brush machine but the seed lot is very clean. (Photo: Brianna Borders, The Xerces Society.)

Debearders and De-awners

Debearders and de-awners typically contain metal rods positioned at right angles around a turning central shaft that operates within a chamber. They work by churning plant material against itself and are most effective when there is enough material to nearly fill the chamber. If the chamber is more empty than full, the material will not be broken down to the same degree. As pods are fed into a debearder or de-awner, seeds and debris will flow out the bottom end. This is a messy process and less clean-up will be required if this is done outdoors. A slight breeze can help to carry some of the floss away. Setting up a vacuum at the discharge end will also capture some of it. Following this step, the floss fibers will be highly fragmented, which facilitates passing the material through an air-screen cleaner.

Example of a de-awner. (Photo: Tallgrass Prairie Center, University of Northern Iowa.)

Partially processed butterfly milkweed material after being passed through a debearder. (Photo: Tallgrass Prairie Center, University of Northern Iowa.)

Stationary Combines

Combines very effectively break up plant material and remove floss fibers. Even if a combine has not been used for harvesting, pods can be fed into a stationary combine, to complete the initial phase of seed processing.

Milkweed floss is highly flammable. Combining milkweed pods early in the morning, late in the evening, or at other times when there are relatively high levels of moisture in the air can reduce the risk of spontaneous ignition. It is helpful to lay tarps both behind and in front of the combine to catch any unthreshed seed. Then, pods can be deposited in the header while the combine is running. However, this requires extreme caution and steps must be taken to ensure that people can maintain a safe distance from the header. The header can potentially be modified so that a chute or elevator can be used to deliver the pods. The majority of the floss will exit the machine as the material is threshed and winnowed. The process can be messy, so it is advisable to do this in a somewhat isolated area under non-windy conditions.

Top: Milkweed plant material is carefully fed into a stationary combine, with staff wearing dust masks and standing at a safe distance from the equipment. Bottom: Milkweed floss exiting a combine while harvested material is being processed. (Photos: John Anderson, Hedgerow Farms, Inc.)

A wide range of equipment settings can be effectively used to process milkweed pods. However, some recommended settings used by the producers we work with (such as for a Gleaner K combine) consist of cylinder clearance set at around 3/8 inch or wider and the sieve opening set about ¼ of the way between closed and open. A quick poll of established milkweed seed producers on recommended cylinder speeds typically resulted in feedback like "as fast as it will go!" However, to maximize seed recovery, regardless of settings, you may want to run the material that comes across the straw walkers and sieve through the combine at least twice. Then the material can be passed through an air-screen cleaner or gravity separator as necessary to separate seeds from any fine debris.

Note: stationary plot threshers effectively process milkweed pods in essentially the same manner as combines.

Equipment for Separating Seeds from Fine Debris and Other Inert Materials

Air-screen Cleaners and Gravity Separators

Floss fibers make it impossible to effectively clean raw milkweed plant material with traditional equipment like air-screen cleaners and gravity separators. However, this type of equipment is ideal for fine cleaning of milkweed seed lots following floss removal. There are a wide variety of air-screen cleaners on the market, including those made by Westrup, Seedburo Equipment Company, Crippen International, and others.

Once the floss is removed from a seed lot, the remaining material can be processed with these types of cleaners in the same manner as any other seed. While experimentation with various screen sizes, air flow adjustments, and feeding rates will be required for optimization, there are no special instructions for cleaning milkweed seed lots.

Milkweed material moving across the top screen of an air-screen cleaner. Seed will fall through the holes in the screen and the floss and other debris that travels across the screen will be discarded. (Photo: Brianna Borders, The Xerces Society.)

Mechanized Seed Cleaning with Custom Equipment

In the 1940s, when milkweed floss was used to fill life-preservers for World War II, a "milkweed gin" design was patented and multiple gins were built and used to process millions of pounds of milkweed pods at a specialized facility in Petoskey, Michigan (Berkman 1949). While the facility and processing equipment were dismantled (Winthrop Phippen, pers. comm.), the milkweed gin patent application and detailed design specifications are available online. However, the design is exceedingly complex and the machine could likely only be built by someone who has significant fabrication skills.

More recently, to recover large volumes of milkweed floss for commercial use, Von Bargen et al. (1994) developed a pod processing system that included a pod conditioner (for opening pods), drying bins, a pneumatic conveyor, a centrifugal separator, and a spiketooth cylinder processor. Their descriptions of equipment modifications would be helpful to anyone interested in developing custom equipment for processing milkweed pods. However, it should be noted that they viewed milkweed as a by-product of their processing operation. They based their approach on harvesting and processing pods that had not yet opened, and it is possible that seeds are not yet mature at that stage.

Today, the Ogallala Comfort Company in Nebraska uses a modified 1940 John Deere combine to process dry pods at an impressive rate of 200 pounds per hour. For a service fee, Ogallala will process milkweed pods supplied by outside entities.

Manual Threshing

If you lack equipment for breaking up pods and removing floss fibers but have equipment to separate seeds from leaves, pod shells, and other inert materials (e.g., air-screen cleaners, gravity separators), raw, harvested material can be manually threshed to remove the majority of the floss and prepare it for the next stage of cleaning. One way to do this is by placing screens from a large air-screen separator over kiddie pools or other large, shallow receptacles; spreading the material over the screens; and using plastic rakes to lightly break up the material and release the seeds. It is best to do this outdoors, where a light breeze will help carry some of the floss away. Select a screen size that the seeds can pass through; if specialized screens are unavailable, a large sheet of hardware cloth stapled to a wooden frame should suffice. It may take approximately an hour for one person to process two pounds of material in this manner.

Milkweed threshing. (Photo: John Anderson, Hedgerow Farms, Inc.)

Seed Viability, Testing, and Storage

At the time of this writing there are no comprehensive studies on species- or genus-level trends in milkweed seed viability. However, based on seed test results (both germination tests and tetrazolium chloride (TZ) tests to determine viability) available from commercial seed producers, professional seed laboratories, and the Seed Information Database from the Royal Botanic Gardens, there is no indication that milkweed seed lots are characterized by low initial viability. Rather, seed test results indicate that initial viability of the tested species is quite high, often greater than 85%.

Data on milkweed seed longevity while in storage is virtually unavailable, with the exception of a study conducted on showy milkweed (Comes et al. 1978). This study showed that the germination rate of a showy milkweed seed lot stored under dry conditions at room temperature for five years decreased very little over time (initial germination percentage was 72%).

Like most temperate species, milkweed seeds are orthodox in their storage requirements (Royal Botanic Gardens Kew, 2014), which means that they remain viable for longer than one year, can be dried to low moisture content without damage, and can be stored at low temperatures (Luna & Wilkinson 2009). The two most important factors influencing seed longevity in storage are temperature and seed moisture content (Young & Young 1986). Essentially, storing seed at low temperature and with low moisture content will result in longer-term viability. Both factors are important and if one is controlled but not the other, an accelerated loss of viability could occur. Suggested rules of thumb regarding seed storage conditions are: 1) Each 1% reduction in seed moisture doubles the life of the seeds, and 2) Each 10°F (-12°C) reduction in seed temperature doubles the life of the seeds. The first rule applies to seeds with a moisture content ranging from approximately 5–14%. The second rule is applicable down to at least 32°F (0°C) (Young & Young 1986).

Milkweed Marketing Opportunities

In our observations, market demand for milkweed seed has been historically limited in many areas due to multiple factors, including: 1) the relatively high cost of seed per pound, 2) the perceived difficulty of establishing milkweeds from seed, 3) public perception of milkweeds as weedy or undesirable (including concerns about livestock toxicity), and 4) greater consumer demand for milkweed transplants rather than seed. Successful marketing messages (such as seed catalog descriptions) address these consumer factors and highlight milkweeds' critical role in supporting monarchs and other pollinators.

In recent years, several seed producers we work with have devoted space in their print catalogs, company websites, and sales brochures to highlight custom monarch butterfly seed mixes that include regionally native milkweeds and high-value nectar plants (e.g., various asters, goldenrods, native thistles, cardinal flowers, Joe Pye weeds, ironweeds, blazing star, or others). These seed mixes can provide a mechanism for attracting new customers while also helping to raise awareness of milkweeds' broader value.

To support greater inclusion of milkweeds in restoration seed mixes, both the seed industry and the monarch conservation community should consider pressing for state and federal agency revegetation standards that include milkweeds. The Xerces Society maintains ongoing discussions with state transportation agencies to include milkweeds in roadside revegetation seeding standards, and with the Natural Resources Conservation Service (NRCS) to recommend milkweeds as part of pollinator seed mix specifications for agricultural lands, as well as the U.S. Forest Service and Bureau of Land Management to recommend the inclusion of milkweeds in rangeland and post-fire rehabilitation efforts.

There are numerous opportunities for other stakeholders to play a similar role. For example, the NRCS is supported in each state by a State Technical Committee made up of citizen groups, conservation organizations, and farm industry representatives. These committees benefit significantly from the participation of native plant industry specialists and wildlife conservation organizations and are a logical avenue for expanding dialogue around milkweed conservation issues. Similarly, local Conservation Districts and other agencies often have public meetings and citizen advisory groups that can help influence the adoption of specific conservation priorities.

Finally, beyond monarch butterfly conservation specifically, there is clear, documented value of milkweeds supporting both wild and managed bees, and beneficial insects such as predators and parasitoids for pest control. These important characteristics highlight the potential for marketing milkweed seed for insectary plantings through seed companies that specialize in vegetable seed (especially organic gardening seed companies). The fact that milkweed specialist herbivores do not attack food crop plants makes milkweeds especially appealing for use in insectary plantings.

Using Milkweeds in Habitat Restoration Plantings

The ultimate goal of milkweed seed production is to enhance local landscapes by restoring habitat for monarchs and other insects integral to ecosystem function. Here, we provide an overview of ways to use milkweeds in restoration and revegetation efforts, highlight the species for which plant materials are typically available, and provide advice on ecologically sound plant selection. We also provide specific guidance on establishing milkweed from seed with respect to site preparation, seeding rate, and including milkweeds in seed mixes.

At the time of writing (spring 2014), the eastern monarch population that overwinters in Mexico is at an all-time low since population monitoring began 20 years ago. Increasingly, the monarch conservation community is recognizing the landscape-scale loss of milkweeds as a critical factor in the monarch's decline. There are now serious questions being raised about the near-term presence of a viable breeding monarch population in the U.S. To counteract these continuing declines, milkweeds can, and should, be incorporated into residential and institutional landscaping, conservation easements on farmlands, transportation right-of-way revegetation efforts, and designated pollinator gardens (such as through the Xerces Society's Bring Back the Pollinators campaign, www.bringbackthepollinators.org). Habitat restoration is now widely regarded as the single most important measure needed to increase all wild pollinator populations.

Studies demonstrate that roadsides with native plants support more butterflies and bees than roadsides dominated by nonnative grasses and flowers. Including milkweeds in roadside revegetation projects within known monarch breeding areas could significantly contribute to the provision of habitat for monarchs and other pollinators. Additionally, where milkweeds already grow on roadsides, land managers could consider altering the timing of maintenance activities (like mowing and herbicide application) to minimize disturbance to milkweeds during the period of time when monarchs are most active in the region.

In agricultural landscapes where insect-pollinated crops are grown, planting milkweeds and other native wildflowers in noncropped areas will help support bees and other pollinators outside of the crop's bloom period. Examples of on-farm pollinator habitat enhancement plantings include field borders, hedgerows, and wildflower meadows. Due to their ability to attract and support native insects that are predators of crop pests, milkweeds can also bring benefits to producers of non-pollinator-dependent crops.

To support pollinator habitat restoration on working agricultural lands, the USDA Natural Resources Conservation Service (NRCS) offers various financial and technical support incentive programs such as the Environmental Quality Incentives Program (EQIP). Through these voluntary programs, NRCS provides qualifying rural landowners with cost-share assistance that can help offset the expenses of project implementation. Similarly, the USDA Farm Service Agency (FSA) administers several large-scale conservation easements that provide long-term rental payments to landowners willing to maintain environmentally sensitive lands in a noncropped condition. Some of the best known FSA programs are the Conservation Reserve Program (CRP), the Wetlands Reserve Program (WRP), and the Grasslands Reserve Program (GRP). In addition to rental payments for maintaining these lands in a long-term natural condition, FSA programs typically provide financial assistance for the initial revegetation of the land. To determine if you qualify for participation in these programs, please contact your local USDA Service Center: http://goo.gl/wTmp2W.

Narrowleaf milkweed (in foreground) established as part of a pollinator hedgerow adjacent to an almond orchard in the San Joaquin Valley of California. (Photo: Jessa Cruz, The Xerces Society.)

Sourcing Milkweed Plant Materials

The term "plant materials" encompasses seeds, plugs, and container plants. Their availability fluctuates from year to year due to growing conditions, crop yields, production capacity, and market demand. Regardless of the material used, we recommend the ecologically responsible approach of selecting species that are as locally native as possible. Though no studies demonstrate that wild milkweed populations will be negatively impacted by gene flow with non-local plants of the same species, using locally native plant materials, to the extent possible, will help maximize plant adaptation and minimize potentially undesirable gene flow with wild populations.

It is ultimately up to the restoration practitioner—whether an agency, organization, or an individual—to determine criteria for sourcing native plant materials. Some restoration practitioners seek to use materials sourced from the same county or watershed as the project site, while others, working in degraded environments, may be more flexible about their seed sourcing criteria.

Milkweed seed can be purchased from multiple vendors (including many internet sources), but given some species' broad distribution across the U.S., commercially available seed is often of non-local origin.

CASE STUDY: MONARCH-FRIENDLY LANDSCAPING

Sunnylands Center & Gardens, Southern California

The Annenberg Retreat at Sunnylands, located in Rancho Mirage, California, serves as a high level retreat center while also offering tours of the historic estate and new Center & Gardens. Ambassador Walter Annenberg and his wife, Leonore, entertained presidents, royalty, political figures, and cultural icons in their Midcentury Modern home. That tradition continues today with retreats and meetings among world leaders on topics in the areas of institutions of democracy, the greater Pacific Rim, education, health, and arts and culture.

The Sunnylands Center & Gardens are open to the public and host visitors from around the country. The Gardens feature 9 acres of more than 70 native and ornamental desert plants arranged in mass plantings for dramatic visual effect. This expansive garden design includes over 4,000 rush milkweed (*Asclepias subulata*) plants. Because of rush milkweed's aesthetic appeal and low maintenance requirements (it is drought tolerant and produces minimal litter and debris), it is sometimes used in landscaping within its native range (which encompasses southeastern California, southeastern Nevada, and the lower deserts of Arizona), in particular within the Phoenix and Tucson metropolitan areas.

Sunnylands' use of milkweeds in large-scale landscaping provides both essential habitat for monarch and queen butterflies (and other milkweed specialist herbivores) and a valuable tool for butterfly outreach, education, and research. During garden tours, Center staff educates visitors about monarchs and their habitat requirements. Since monarchs are present at Sunnylands several months of the year, visitors can often observe butterflies firsthand. Additionally, Center staff work with the Southwest Monarch Study to document winter aggregations of monarchs on the Sunnylands property; sample monarchs to detect infection by a protozoan parasite (*Ophryocystis elektroscirrha*); and tag butterflies to facilitate their recovery at overwintering sites, which would help reveal monarch migratory pathways. The data collected through this joint effort will provide important insights into monarch population dynamics in the southwestern U.S.

Rush milkweed (at left, in flower) is prominently featured in the landscaping at the Sunnylands Center & Gardens and the plants frequently host monarch and queen caterpillars. (Photo: Scott Hoffman Black, The Xerces Society.)

While some seed companies specialize in locally native seed, many do not advertise seed origin or ecotype, and it cannot be assumed that seeds were collected or produced in the region in which a vendor is located. However, most vendors can provide details about seed origin upon request. To identify sources of regionally appropriate seed, please ask prospective vendors for information about seed origin. If milkweed seed is completely unavailable within your region, but the plants are integral to your project plans, you could consider having seed wild-collected from local populations.

Seed Transfer Zones and Monarch Migration Research

Although research into the ecological importance of localized milkweed adaptation is limited, plant ecologists have two primary concerns about the long distance movement of plant materials: 1) milkweed seeds used for habitat restoration may fail to establish due to a lack of local adaptation and, 2) gene flow among distinct plant populations may ultimately produce offspring that are less well adapted to the local environment than either of the parent populations.

Beyond these concerns related to plant genetics, some monarch scientists question whether the movement of milkweed plant materials may interfere with future studies seeking to document where monarch butterflies developed as caterpillars. For example, various milkweed species have distinctive chemical signatures ("cardenolide fingerprints") that can be detected in butterfly tissues, offering insights into migratory patterns and particular milkweed species' importance as monarch hosts (Brower et al. 1982; Seiber et al. 1986; Malcolm et al. 1993). While the variability of these signatures within a given species is unknown, the movement of plant materials could potentially muddle the results of these chemical analyses.

Geographic guidelines for moving plants and seeds are typically developed based on genetic data and the results of experiments in which plant materials are transferred to various locations and their performance is monitored and compared. Guidelines for transferring milkweed have not been developed; in the absence of that information, provisional "seed zones" developed by the U.S. Forest Service may be helpful in determining how far from the original collection source it is appropriate to plant milkweed seed (http://goo.gl/dw3djd). These seed zones are based on climate data (i.e., mean monthly minimum and maximum temperature and annual precipitation) and can be viewed with a variety of programs, from a web browser to ArcMap. In addition to the temperature and precipitation variables included in the Seed Zone Mapper, it is important to consider elevation and latitude when evaluating the potential adaptability of a particular seed source.

Sourcing Plant Materials Free of Insecticides

In recent years there has been a large-scale adoption of new systemic insecticides by the nursery industry. Unlike older classes of insecticides that were typically sprayed onto the foliage of plants to kill pests on contact, systemic insecticides are absorbed into and dispersed throughout plant tissues, including pollen and nectar.

The most common class of systemic insecticides are the neonicotinoids, available as foliar sprays, root drenches, seed coatings, and various other delivery formulations. Driven by demand for blemish-free nursery stock—and their low risk to human applicators—the horticultural industry has increasingly adopted neonicotinoid insecticides for many ornamental plant applications. Unfortunately, neonicotinoids have broad spectrum toxicity not only to pests, but also to bees, butterflies, and many other beneficial insects. Although there is no focused effort to track neonicotinoid use on milkweeds within the ornamental nursery industry, there have been anecdotal reports of monarch caterpillars being sickened or killed by feeding on nursery-purchased milkweeds. When buying milkweeds, or other pollinator conservation plants, we strongly recommend asking whether the plants have been treated with systemic insecticides.

Introduced Milkweed Species

Using native species in habitat restoration plantings is the ecologically responsible approach, given the potential for non-native, introduced species to become weedy, compete aggressively with native species, or disrupt species interactions. Three *Asclepias* species have been introduced to the U.S: tropical milkweed (*A. curassavica*), African milkweed (*A. fruticosa*), and swan or balloon plant (*A. physocarpa*). Of these, tropical milkweed (also called blood flower, scarlet milkweed, and Mexican milkweed) is the most widely available from commercial sources, and is typically sold as a container plant. Due to its showy red and yellow-orange flowers and its attractiveness to monarchs, tropical milkweed is frequently planted in gardens and has become naturalized in parts of southern Florida (Cohen 1985), presumably having escaped from cultivation. Additionally, the USDA PLANTS database documents tropical milkweed as present in Louisiana, Tennessee, and Texas. The extent of its occurrence in other states, outside of gardens, is unknown.

Beyond concerns around the escape of plants from cultivation and the need to prevent new species of weeds from becoming established and replacing native plant communities, monarch scientists are also concerned about tropical milkweed's potential impacts on monarch health. This concern stems from the fact that most native U.S. milkweeds are deciduous and do not produce flowers or foliage during late fall and winter (Woodson 1954). In contrast, tropical milkweed continues to flower and produce new leaves well into the fall months, providing foliage year-round in areas with mild winters and adequate moisture (such as parts of California, Texas, Louisiana, Florida, and coastal Georgia). Its presence can encourage some monarchs to lay eggs outside of their regular breeding season and disrupt their migratory cycle (Batalden & Oberhauser, in press).

CASE STUDY: POLLINATOR HEDGEROWS IN AGRICULTURAL LANDSCAPES

Sacramento, California

The Muir Glen name is certainly associated with organic tomatoes, but behind the scenes the brand has been steadily working to expand habitat for pollinators in California. Working with the Xerces Society and researchers at the University of California–Davis, Muir Glen has been testing native plant restoration methods near a tomato processing facility in Colusa County. The showcase feature of this effort is a mile-long hedgerow of drought-tolerant native shrubs and forbs that is specifically designed to attract and support native bees (bumble bees in particular) that pollinate tomato flowers.

Primarily selected as a nectar source for bees and for predators and parasitoids of crop pests, showy milkweed (*Asclepias speciosa*) was an essential component of the planting design. However, the inclusion of milkweed provides clear benefits to monarch butterflies as well. Hedgerows represent a particularly viable strategy for increasing milkweed abundance in California's Central Valley since their linear planting configurations do not encroach significantly into the surrounding, intensively farmed crop fields.

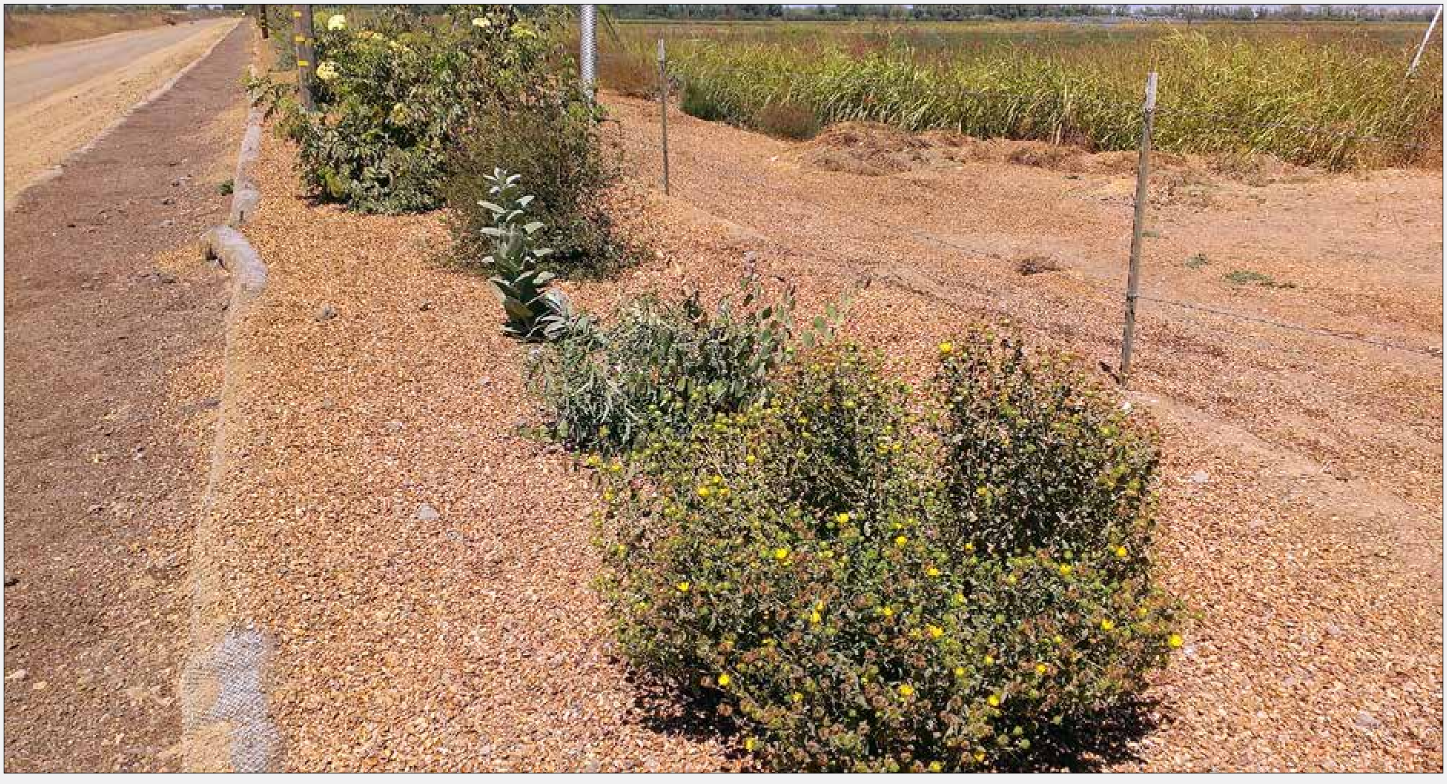
Xerces biologists selected showy milkweed for its tall, upright growth habit (necessary to compete with nearby shrubs), and transplanted the milkweed from deep-pot plugs to ensure a strong root system at the time of planting. The milkweeds were placed within the hedgerow adjacent to smaller-statured shrubs so that they will persist and not become too shaded as the closest shrubs mature. The plants were supported with drip irrigation during the establishment phase, with irrigation ceasing after two years (thus relying on the natural drought tolerance of the native hedgerow plants from that point forward).

Muir Glen is supporting these restoration activities through outreach to both consumers and the farmers they work with, and encouraging others to restore and protect habitat for pollinators. The hope is that high-profile conservation efforts like this will make the establishment of native plants in general, and milkweeds in particular, an increasingly mainstream practice adopted by farmers and gardeners.

Showy milkweed (shown at middle) included in a mile-long pollinator hedgerow. Great Valley gumplant and blue elderberry are also shown. (Photo: Jesa Cruz, The Xerces Society.)

The year-round availability of tropical milkweed foliage in mild climates also raises concerns about the potential increase in monarch diseases like the protozoan, *Ophryocystis elektroscirrha,* commonly known as OE (Bartel & Altizer 2012). OE is a debilitating parasite that infects both monarch and queen butterflies. The parasite is transmitted from adults to larvae when infected females scatter dormant spores onto milkweeds during egg-laying and caterpillars then ingest the spores while feeding (McLaughlin & Meyers 1970). Historically, migratory monarchs experienced low levels of infection (under 8% of wild adults sampled in eastern North America were heavily infected between 1968 and 1997 (Altizer et al. 2000)). This is likely because migration allows monarchs to periodically escape habitats where OE spores accumulate, and because infected monarchs are less likely to successfully migrate and are thus removed from the population (Bartel et al. 2011). In contrast, recent monitoring work from the Altizer Lab at the University of Georgia indicates that the formation of sedentary monarch populations subsisting on tropical milkweed in the southeastern U.S. has increased disease risk among monarchs. Sampling across approximately 30 sites in Texas, Florida, Georgia, and Louisiana showed that monarchs breeding in the southern U.S. during the winter experienced over 5 times greater OE prevalence than migratory monarchs sampled in the same time period, with some locations showing up to 100% prevalence of OE (D. Satterfield, unpublished data).

In regions where winter temperatures frequently fall below freezing, tropical milkweed behaves as an annual plant that is typically frost-killed. When this occurs, milkweed foliage is not available during the winter and there is no potential for parasite spores to build up on plant tissues. To mimic this effect and prevent potential negative impacts to monarch health, people who live in warmer climates where tropical milkweed can produce flowers and foliage into the fall and winter months are advised to cut stalks back to the ground during early fall. However, these recommendations may be less applicable to areas of Florida south of Orlando, where both tropical milkweed and a distinct non-migratory population have long been established. The south Florida monarch population will require additional research to determine best practices for monarch conservation.



Given these concerns, and the fact that the U.S. hosts a striking diversity of native milkweed species, many of which are commercially available and aesthetically pleasing, the Xerces Society recommends only planting milkweeds that are native to the U.S.

Native Milkweed Cultivars

Some selected cultivars of butterfly milkweed (e.g., 'Hello Yellow') and swamp milkweed (e.g., 'Cinderella' and 'Ice Ballet') are commercially available. While the genetic effects of cultivar selection are largely undocumented, plants bred for flower color traits may have lost some of their ability to produce nectar or may have altered chemical composition. Therefore, they may not provide the same resources for wildlife that wild-type plants do. Though cultivars are suitable for planting in gardens or urban areas, it is not advisable to plant them in or near natural areas where they could breed with wild populations.

CASE STUDY: MONARCH-FRIENDLY ROADSIDE MANAGEMENT

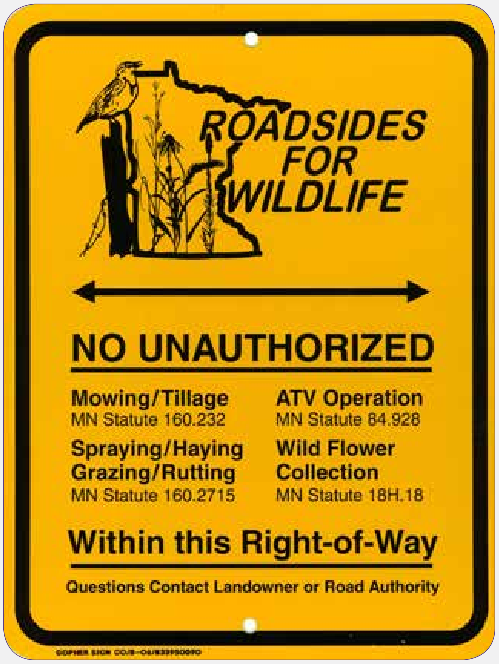
Roadsides for Wildlife Program, Minnesota

With roadside rights-of-way covering more than 10 million acres of land in the United States (Forman et al. 2003), transportation corridors are a significant, yet often overlooked, opportunity for monarch conservation. One effort that has seized this opportunity is the Minnesota Department of Natural Resources' (DNR) Roadsides for Wildlife Program.

Monarchs are typically present in Minnesota from May through early September, and a drive across most rural Minnesota landscapes immediately reveals roadside milkweeds as a prime resource in supporting that population. Recognizing this important resource, the Roadsides program has engaged rural landowners and state and local transportation agencies with a comprehensive set of management recommendations intended to protect plants and wildlife, while also balancing the need for road safety. Among these recommendations are:

- Using native prairie plants for roadside revegetation. In Minnesota, more than 500,000 acres of roadsides are available as wildlife habitat in just the southern two-thirds of the state, a region that includes prime areas of pheasant habitat. The DNR encourages transportation agencies to replant these areas with native grasses and wildflowers whenever they are disturbed for routine maintenance or new road construction. In addition to supporting monarchs and other wildlife, these deep-rooted native plants increase infiltration, capture runoff from nearby farmlands, and improve aesthetics. Working with the Minnesota State Department of Transportation, and county and township highway departments, the DNR has completed hundreds of roadside prairie habitat restoration projects across the state, totaling thousands of acres of restored habitat. Many of these efforts include milkweeds.
- Delaying mowing of roadside ditch bottoms and back slopes until after August 1st. While intended to protect ground-nesting birds, late season mowing also provides a longer period of time for monarch caterpillars to develop and extends the availability of nectar plants later into the summer. From a monarch conservation perspective, mowing would ideally be delayed further into the fall, until migrating monarchs have left the state, but the recommendations recognize the need some transportation managers have to maximize mowing opportunities with limited staff resources. Widespread herbicide spraying, burning, and vehicle encroachment are also not recommended in ditch areas.
- Using shoulder and spot mowing to manage invasive species, to control safety concerns, and to prevent snow drifting. The DNR points out to program participants that widespread mowing and herbicide spraying are not only detrimental to wildlife, but are also expensive and often unnecessary. By focusing on problem spots, transportation agencies can save money and time.

For more information about Minnesota's Roadsides for Wildlife Program, visit http://www.dnr.state.mn.us/roadsidesforwildlife/index.html.



Native Milkweed Seed Availability

In the U.S., there are approximately 20 native milkweed species for which seed is typically available from commercial sources or for which seed production activities have been initiated (Appendix III). Many of these are also usually available for purchase as transplants.

These species can be utilized in restoration and revegetation efforts within their native ranges. There are nearly 50 additional milkweed species native to the U.S. (Appendix I) for which seed is completely unavailable or is intermittently available only in small quantities. Seed production of these species may be commercially viable if there is demonstrated success in their use for habitat restoration plantings and if there is perceived market demand. Some milkweed species (e.g., *A. meadii*, *A. welshii*) are formally designated as threatened or endangered at the state and/or federal level. Where these species are rare and declining, they are in need of protection, habitat management, and focused restoration and

Agencies in a number of Midwestern states have made efforts to conserve and restore native wildflowers along roadways. Restored roadsides across Minnesota, Iowa, and Michigan (pictured here) offer high quality breeding habitat for monarchs, and should serve as models for other states. Butterfly milkweed (orange flowers in foreground) and prairie coneflower are pictured. (Photo: Jennifer Hopwood, The Xerces Society.)

recovery efforts. Yet, due to their special conservation status, they are not presently good candidates for commercial seed production.

Due to available inventory and reasonable cost, species for which seed can be purchased by the pound are the most suitable candidates for use in large-scale habitat plantings. For example, they can be included in diverse seed mixes that are planted on multi-acre sites. If a species' seed is available by the ounce, it can be included in a variety of small-scale plantings or included in large-scale projects at a relatively low seeding rate. Species for which seed production activities are currently underway are denoted in Appendix III. Available inventory for those species is projected to increase over time.

There are additional species, not featured in Appendix III, for which seed is sometimes available in small quantities (e.g., a few grams). Yet, because their seed is typically wild-collected, inventory fluctuates to a greater degree than for species cultivated for the purpose of seed production. While wild-collected seed can meet demand for small-scale plantings such as gardens or demonstration sites, it is rarely available in the quantities needed for large-scale restoration and can be prohibitively expensive compared to commercially produced seed.

To help people locate milkweed seed sources, the Xerces Society has created the Milkweed Seed Finder, a searchable web directory of milkweed seed vendors across the country. Several milkweed seed producers also sell milkweed transplants and many will ship plants. Please ask your regional vendors about transplant availability.

http://www.xerces.org/milkweed-seed-finder

Seed Availability by Region

Milkweed seed is currently available only in some regions of the country (Appendix IV). To date, regionally produced milkweed seed is most readily available in the Midwest and Great Lakes regions, where several seed companies and producers offer seed for which the origin and ecotype are docu-

Selecting Regionally-Appropriate Species

In Appendix IV, we recommend species that are suitable for planting on a regional basis based on their broad distribution and adaptability to a variety of habitat conditions. We also provide general assessments of current seed availability and comments on each region's relative importance as a monarch breeding area. There are many additional milkweed species that are excluded from these recommendations due to seed scarcity or specialized habitat requirements. Appendix I includes a complete list of milkweed species native to the U.S. The following web-based resources are helpful for assessing county-level distribution of milkweed species:

The USDA-NRCS PLANTS database (www.plants.usda.gov)

- Enter the species name into the name search field near the top left of the screen and click 'Go'.
- If your target species is characterized by subspecies, you will have to choose one for which to view results
- On the map that is displayed, click on your state to review the presence (shown in green for native plants and gray for nonnatives) or absence of the species in specific counties. Information on county-level distribution is available for nearly all species.
- Some species profiles will include a tab that says "Legal Status". Click this tab to learn whether the species has special conservation status in some states or is considered a weed by some authorities.

The Biota of North America Program's (BONAP) North American Plant Atlas (http://goo.gl/V1EMSp)

- By following the link above, you can view the county-level distribution of each *Asclepias* species in the lower 48 states. Dark green indicates that a species is present within the state, whereas bright green shows that a species is documented to occur in that specific county. Please refer to BONAP's map color key for detailed information.

Note that an absence of species occurrence records within a particular county does not definitively confirm the absence of the species. Beyond these two resources, more detailed information on species distribution is sometimes available from regional botanical guides and websites that aggregate digitized herbarium records from multiple sources (e.g., the Consortium of California Herbaria and the Southwest Environmental Information Network).

Once you have identified species native to your area, you can review their habitat requirements to determine whether they are well-suited for your target planting site. You may also want to determine whether any species have special conservation status in your state. When this is the case, do not include the species in nontargeted restoration efforts or purchase its seed from another region of the country. Species conservation status at the state and federal level is presented in Appendix I and can also be obtained from the USDA-NRCS PLANTS database, as described above. Additionally, many states have Natural Heritage Programs that assess the rarity of plant species and assign them rankings that are of a lower level designation than threatened or endangered. These state rankings are not captured in Appendix I but can be found online. For example, NatureServe maintains a list of these state programs: http://cheetah.natureserve.org/visitLocal/usa.jsp.

mented. Also, source-identified, regionally produced seed has been reliably available from at least one producer in both the Southeast and Mid-Atlantic regions. Yet, the availability of milkweed seed that is source-identified to the following regions is currently scarce to nonexistent: the Maritime Northwest, the Inland Northwest, the Rocky Mountains, the Northern Plains (with the exception of Nebraska), the Northeast, and the Southeast (with the exception of Kentucky). Milkweed seed's regional scarcity can prevent the inclusion of milkweeds in native plant restoration efforts or result in the sourcing of seed from distant sources.

In 2010, the Xerces Society launched Project Milkweed to increase native milkweed seed availability in key regions of the monarch's breeding range where seed had not been reliably available: California, the Great Basin, the Southwest, Texas, and Florida. As a result of a successful partnership with Hedgerow Farms, Inc. in the Central Valley of California, woollypod milkweed (*A. eriocarpa*), narrowleaf milkweed (*A. fascicularis*), and showy milkweed (*A. speciosa*) seed are now available by the pound. Similarly, antelope horns (*A. asperula* ssp. *capricornu*) and green antelope horns (*A. viridis*) seed is now available from Native American Seed in Texas and spider milkweed (*A. asperula* ssp. *asperula*) seed is increasingly available from Terroir Seeds, LLC in central Arizona. Milkweed seed production activities in the Great Basin, southern Arizona, and Florida are still in progress.

Milkweed Transplant and Container Plant Availability

There are numerous milkweed species for which seed is available but not container plants. Conversely, there may be a few species for which live plants are available yet seed is not. To help connect conservationists with plant materials, Monarch Watch hosts an online "Milkweed Market" where visitors can order source-identified milkweed plugs and search for milkweed plant vendors (http://goo.gl/bQAjww). According to Monarch Watch's vendor listings, milkweed plants are currently available in 28 states. Additionally, the Xerces Society's Pollinator Conservation Resource Center (http://www.xerces.org/pollinator-resource-center/) provides list of native plant nurseries across the country, many of which carry milkweed plants.

Establishing Milkweeds from Seed

In working with conservation practitioners over multiple years to include milkweed in restoration seed mixes, we have received variable feedback on the establishment success of milkweed planted from seed. In particular, establishment varies most when milkweed seed is broadcast directly onto the soil surface (rather than drill-seeded), and in mild climates without predictable freeze-thaw cycles to enhance seed-to-soil contact and provide cold stratification. *The most significant lesson learned in establishing milkweed from seed is that patience is necessary!* Milkweeds are typically slow-to-establish perennial species with small seedling size relative to their mature height. Milkweeds may germinate and persist as small seedling-stage plants among faster growing vegetation for several seasons until they are mature enough to be readily visible. Where larger plants are called for immediately, we recommend installing mature transplants. Here, the following paragraphs provide guidance on increasing establishment success when restoring habitat using milkweed seed.

Site Preparation

To ensure success when establishing any native plant from seed, it is critical to first eliminate existing weed cover and deplete the amount of weed seed in the soil. Prior to planting, weeds can be eliminated with herbicides, smothering, solarization (using UV-stabilized greenhouse plastic to heat the soil below, thus killing seeds), or a combination of those methods. Cultivation is another approach to removing weed cover; however the practice (deep tillage in particular) brings buried weed seeds closer to the soil surface and often facilitates additional weed growth. To minimize this effect, it is best to cultivate only to shallow depths. Cultivation should not be done just prior to seeding; it is important to first control the weed growth that results from cultivation before moving forward with seeding a restoration site. Depending on the abundance of weeds or weed seed at the planting site, one to two full years of weed control may be necessary to deplete the weed seed bank and effectively reduce competition from weeds.

Cotyledons, or "seed leaves" of showy milkweed. Seedlings of most milkweed species will look very similar to these, but likely without the red stems. (Photo: John Anderson, Hedgerow Farms, Inc.)

Timing

In most parts of the U.S., milkweed seed should be planted in the fall. Exposure to cold temperatures and moist conditions during winter will typically stimulate germination in the spring, and winter precipitation can help work seed into the soil. Spring planting may also be possible but artificial cold stratification of the seed is recommended to enhance germination. It is important to note that once stratified seed has been planted, the soil in the planted area must be kept moist for the duration of the germination period. A notable exception to this recommended planting time may be in the monsoon-adapted plant communities of the southwest, where planting should occur before anticipated rains arrive.

Planting Method

Unlike some wildflowers that grow easily when broadcast-seeded onto the soil surface, milkweed seed may establish more effectively when drilled into the soil using either a specialty native seed drill or a vegetable seed drill (such as an Earthway-type seeder using seed plates designed for cucurbits or sunflower). The latter approach allows for milkweed to be planted separately from a multi-species seed mix, and may thus be useful in facilitating follow-up monitoring of seedling establishment (since the milkweed would be seeded in distinct rows across an area planted with a diverse seed mix).

Additional research is required to compare the success rate of drill seeding versus surface broadcasting, but we suspect (based upon initial observations) that drill seeding may be the most effective establishment method. Where drill seeding is used, milkweed should be seeded to a maximum depth of ½ inch. In contrast, if milkweed seed will be broadcast onto the soil surface as part of a diverse seed mix, we recommend cultipacking or rolling the site (such as with a turf roller) to press the seeds into the soil surface.

Seed Mix Formulation

We strongly recommend establishing milkweeds as part of a diverse seed mix made up of the primary functional groups of locally native plants (i.e., a mix that contains native grasses, legumes, and other native forbs). Efforts to establish large-scale, unmanaged, milkweed-only plots will likely have only marginal success because the lack of plant diversity may foster weed encroachment, and an extensive monocultural planting is more susceptible to damage from milkweed diseases and specialist herbivores like oleander aphids. Furthermore, pollinators targeted for conservation, like monarch butterflies, typically require the presence of other adjacent nectar plants. Finally, milkweed seed's relatively high cost typically makes large milkweed-only plots unfeasible. In our experience, we have included milkweed in seed mixes at rates ranging from 0.1% to 14%. When designing a custom seed mix that includes one or more milkweed species, you can use the seed count estimates included in Appendix IV to calculate how much seed will be needed to plant a specific target area at a desired seeding rate. The Xerces Society has developed a seed calculator spreadsheet that is very helpful for designing seed mixes: http://goo.gl/gbezRZ.

Irrigation

Many milkweed species are drought-tolerant *once established*, owing to their often extensive root systems, but most still require or strongly benefit from soil moisture during the first year of establishment. Seeding should be timed to take advantage of regional precipitation patterns. It is unlikely that milkweeds can be established from seed under dryland conditions, if rainfall is scarce and irrigation is not feasible.

Ongoing Weed Management

Milkweeds typically germinate from seed or emerge from perennial rootstock later in the season than cool-season annual plants (either weeds or desirable natives). Thus, where cool season plant competition is extensive, milkweeds may be outcompeted by other species when sown as part of a mix. We recommend planting milkweed separately to reduce competition during the establishment phase, especially in mild climates where most wildflowers are cool-season annual species. Alternatively, milkweed transplants can be installed into areas seeded with cool-season annuals. However, irrigation is typically required for transplant survival.

Seedling Identification

Milkweed cotyledons, or "seed leaves," are typically thick-textured with prominent veins, and in some cases it can be difficult to distinguish one milkweed species from another during early growth stages. Similarly, seedling-stage milkweeds may be difficult to distinguish from *Apocynum* spp., and some other species in the Euphorbiaceae. With the exception of butterfly milkweed (*Asclepias tuberosa*), milkweed seedlings can be identified by the milky, latex sap that is present in even the smallest sprouts. This characteristic may aid in plant identification when monitoring is conducted during the early phases of plant establishment. However, please consider that milkweeds are not the only plants that have milky sap. Also, it is important to avoid any contact of the sap with the skin, eyes, and mouth.

Plant Maturation and Establishment

Even under ideal conditions, milkweeds planted from seed may require more than one growing season to appear and become established. Note that milkweeds look very different upon emerging from established root systems, as compared to newly germinated seedlings. Please compare photos of seedling, second year, and mature plants for comparison.

Emergence of established showy milkweed plants in early spring. (Photo: John Anderson, Hedgerow Farms, Inc.)

Second-year showy milkweed plants established from seed as part of a pollinator seed mix trial at the USDA-NRCS Plant Materials Center in Corvallis, Oregon. (Photo: Brianna Borders, The Xerces Society).

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Conclusion

Amid growing concerns about the decline of monarch butterflies and new calls to conserve that species, milkweeds are gaining renewed attention. While the challenge of restoring milkweeds at the landscape scale in North America may seem daunting, the basic technology and expertise needed to rapidly increase commercial-scale production are readily accessible, as this document hopefully makes clear.

While this document has focused primarily on the role of milkweed seed production in supporting wildlife, additional market potential for milkweed products (including floss, latex, and even biofuels) justifies further investments in the research and development of milkweeds as an alternative crop. In our vision for the future, milkweed farming will continue to expand as a viable business model that concurrently offers financial and ecological rewards.

Achieving this vision calls for one final element beyond the scope of this text: a policy framework that both recognizes the value of native plants and rewards their production accordingly. In the two years we spent planning and writing this guide, almost 2.5 million acres of American grassland were converted to active crop production—often to cornfields for ethanol and livestock feed. This land conversion, which has included steep declines in the Conservation Reserve Program and other voluntary conservation easement programs, represents the largest short-term conversion of permanent grassland to cropland since just before the Dust Bowl. Not surprisingly, monarch butterflies and other pollinators are responding accordingly with continued downturns in their numbers. It would be a mistake to interpret this continentwide habitat loss as anything other than the natural outcome of policies that single out and reward one agricultural model at the expense of others.

Until there is a national policy framework that incentivizes a robust native seed industry and maximizes the conservation of wildlife habitat, we hope that this guide can pick up a small amount of the slack with practical how-to advice, some simple cheerleading, and shared awe at the diverse beauty of milkweeds, monarch butterflies, and our native ecosystems.

Please connect with us, and happy planting!

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Acknowledgements

This guide was written as part of the Xerces Society's Project Milkweed (www.xerces.org/milkweed). We offer an enthusiastic "thank you" to the funders of our milkweed conservation work, our Project Milkweed collaborators, and the individuals who contributed to the development of this document.

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We thank our tireless and brilliant Project Milkweed partners: Hedgerow Farms, Inc.; Native American Seed; the Painted Lady Vineyard; Arizona Western College; Ernst Conservation Seeds; Gunnell Farms; and the USDA-NRCS Plant Materials Centers in Florida, New Mexico, and the Great Basin. We thank the Desert Botanical Garden, Dr. Jeff Norcini, Chris Parisi, Bob Sivinski, Gail Haggard, Linda Kennedy, Eric Roussel, Laura Merrill, Tom Stewart, and Tatia Veltkamp for their indispensable role in collecting foundation seed; Greenheart Farms for producing an essential crop of spider milkweed transplants; the USDA-NRCS Plant Materials Center in Corvallis, Oregon for allowing us to use their seed processing facility; Sitting Duck Studio for fabricating tools needed for our central Arizona transplanting effort; and the Tall Timbers Research Station and the Florida Department of Transportation for granting permission to collect seed on their land.

Over the course of Project Milkweed, several people contributed helpful ideas related to milkweed pod collection and processing. We'd like to credit Dr. Jeff Norcini for the idea of using rubber bands as a strategy for successful milkweed pod collection; Desert Botanical Garden staff for their idea to assemble seed capture bags from floating row cover; Bill Boothe for suggesting the use of organza wedding favor bags to capture seed; and Bob Karrfalt of the USFS National Seed Laboratory for recommending the use of a shop vac to process milkweed pods.

Several individuals reviewed portions of this guide or contributed content. We thank Dr. Kip Panter of the USDA Agricultural Research Service's Poisonous Plant Research Laboratory for providing helpful feedback on content related to milkweed toxicity to livestock; Dr. Jeff Norcini for reviewing and editing content related to wild seed collection; Dr. Anurag Agrawal for sharing the details of his lab's seed treatment technique and for providing information on the clonality of various milkweeds; Dr. Sonia Altizer and Dara Satterfield for reviewing and contributing to the section on tropical milkweed and monarch parasitism; Dr. Eric Eldredge of the USDA-NRCS Great Basin Plant Materials Center for investigating and photo-documenting the feeding activity of milkweed longhorn beetle larvae; John Anderson of Hedgerow Farms, Inc. and Greg Houseal of the Tallgrass Prairie Center for sharing their experiences with milkweed harvesting and seed processing and for reviewing multiple sections of the document; Keith Fredrick of Minnesota Native Landscapes for providing information on seed harvesting and processing techniques; and Ransom Seed Laboratory for sharing their milkweed germination data.

Finally, we thank each photographer that generously granted us permission to use their photos or who made their images available for use through Creative Commons licenses.

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Appendix I:

Milkweed Species Native to the United States and Canada

Milkweed Species Native to the United States and Canada

Scientific name[1]	Common name(s)	Range[2]	Conservation status[3]	Bloom period[4]	Notes
Asclepias albicans[a] S. Watson	whitestem milkweed	CA, AZ		Mar–Jun	One of the few evergreen milkweeds native to the U.S.
Asclepias amplexicaulis[b] Sm.	clasping milkweed blunt-leaved milkweed	AL, AR, CT, DC, DE, FL, GA, IA, IL, IN, KS, KY, LA, MA, MD, MI, MN, MO, MS, NC, NE, NH, NJ, NY, OH, OK, PA, RI, SC, TN, TX, VA, VT, WI, WV	Threatened in NH, VT	Mar–Sep	
Asclepias angustifolia[a] Schweigg.	Arizona milkweed	AZ		Sporadic throughout the year	Evergreen when growing at low elevation
Asclepias arenaria Torr.	sand milkweed	CO, KS, NE, NM, OK, SD, TX, WY		May–Aug	
Asclepias asperula (Decne.) Woodson **ssp. *asperula***[b]	spider milkweed	AZ, CA, CO, ID, NE, NM, NV, TX, UT		Mar–Aug	
Asclepias asperula (Decne.) Woodson **ssp. *capricornu***[b] (Woodson) Woodson	antelope horns	AZ, KS, NE, NM, OK, TX		Mar–Jul	
Asclepias brachystephana Engelm. ex Torr.	bract milkweed	AZ, NM, TX		Apr–Sep	
Asclepias californica Greene **ssp. *californica***[b]	California milkweed	CA		Apr–Jul	
Asclepias californica Greene **ssp. *greenei***[b]	Greene's milkweed	CA		Apr–Jun	
Asclepias cinerea Walter	Carolina milkweed	AL, FL, GA, MS, SC		May–Aug	
Asclepias connivens Baldw.	largeflower milkweed	AL, FL, GA, MS, SC		Jun–Aug	
Asclepias cordifolia[b] (Benth.) Jeps.	heartleaf milkweed	CA, NV, OR		May–Jul	
Asclepias cryptoceras S. Watson ssp. *cryptoceras*	pallid milkweed	AZ, CA, CO, NV, UT, WY		Apr–Jun	

Species with names in **bold font** are documented to be used by monarchs as larval hosts (**a**: Southwest Monarch Study 2013; **b**: Malcolm & Brower 1986; **c**: USFWS 2003; **d**: Dr. Jaret Daniels, pers. comm.). In some cases, it is the authors' extrapolation that each subspecies of a known host is likely to be used by monarchs.

[1]Additional *Asclepias* taxa that are acknowledged by Fishbein et al. (2011) yet are not included in the USDA PLANTS database or the Biota of North America Program's North American Plant Atlas: *Asclepias elata*, *A. macrosperma*, *A. ruthiae*, *A. sanjuanensis*. Some authorities consider these scientific names to be synonyms for species included in the list above.

[2]Information on species' presence and absence in U.S. states and Canadian provinces is derived from the USDA PLANTS database. Some of these species, plus many others not included in this list, occur in Mexico. Canadian provinces are abbreviated as follows: AB = Alberta, BC = British Columbia, MN = Manitoba, NB = New Brunswick, NS = Nova Scotia, ON = Ontario, PE = Prince Edward Island, QC = Quebec, SK = Saskatchewan.

[3]Many states have Natural Heritage Programs that assess the rarity of plant species and assign them rankings that are of a lower level designation than threatened or endangered. Please refer to http://cheetah.natureserve.org/visitLocal/usa.jsp to identify which states maintain such programs and if any *Asclepias* species have special status in your state(s) of interest.

[4]Bloom time information is sourced almost exclusively from Woodson (1954). Additional sources are Hartman (1986) and Sundell (1993).

Milkweed Species Native to the United States and Canada

Scientific name[1]	Common name(s)	Range[2]	Conservation status[3]	Bloom period[4]	Notes
Asclepias cryptoceras S. Watson ssp. *davisii* (Woodson) Woodson	Davis' milkweed	CA, ID, NV, OR, WA, WY		Apr–Jun	
Asclepias curtissii A. Gray	Curtiss' milkweed	FL	Endangered in FL	Apr–Aug	
Asclepias cutleri Woodson	Cutler's milkweed	AZ, UT		Apr–Jun	
Asclepias emoryi (Greene) Vail	Emory's milkweed	NM, TX		Apr–Aug	
Asclepias engelmanniana Woodson	Engelmann's milkweed	AZ, CO, IA, KS, NE, NM, OK, TX, UT, WY	Endangered in IA	Jul–Sep	
Asclepias eriocarpa$_b$ Benth.	woollypod milkweed	CA		May–Oct	
Asclepias erosa$_b$ Torr.	desert milkweed	AZ, CA, NV, UT		Apr–Oct	
Asclepias exaltata$_b$ L.	poke milkweed	AL, CT, DE, GA, IA, IL, IN, KY, MA, MD, ME, MI, MN, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WI, WV, Canada (ON, QC)		May–Aug	
Asclepias fascicularis$_b$ Decne.	Mexican whorled milkweed	CA, ID, NV, OR, UT, WA		May–Oct	
Asclepias feayi Chapm. Ex A. Gray	Florida milkweed	FL		Apr–Jul	
Asclepias glaucescens Kunth	nodding milkweed	AZ, NM, TX		Jul–Sep	
Asclepias hallii A. Gray	Hall's milkweed	AZ, CO, NM, NV, UT, WY		Jun–Aug	
Asclepias hirtella$_b$ (Pennell) Woodson	Tall green milkweed	AL, AR, GA, IA, IL, IN, KS, KY, LA, MI, MO, MN, MS, OH, OK, TN, WI, WV, Canada (ON)	"Threatened in MI, MN "	May–Sep	
Asclepias humistrata$_b$ Walter	Pinewoods milkweed	AL, FL, GA, LA, MS, NC, SC		Apr–Jul	
Asclepias hypoleuca (A. Gray) Woodson	Mahogany milkweed	AZ, NM		Jun–Aug	

Species with names in **bold font** are documented to be used by monarchs as larval hosts (**a**: Southwest Monarch Study 2013; **b**: Malcolm & Brower 1986; **c**: USFWS 2003; **d**: Dr. Jaret Daniels, pers. comm.). In some cases, it is the authors' extrapolation that each subspecies of a known host is likely to be used by monarchs.

[1]Additional *Asclepias* taxa that are acknowledged by Fishbein et al. (2011) yet are not included in the USDA PLANTS database or the Biota of North America Program's North American Plant Atlas: *Asclepias elata*, *A. macrosperma*, *A. ruthiae*, *A. sanjuanensis*. Some authorities consider these scientific names to be synonyms for species included in the list above.

[2]Information on species' presence and absence in U.S. states and Canadian provinces is derived from the USDA PLANTS database. Some of these species, plus many others not included in this list, occur in Mexico. Canadian provinces are abbreviated as follows: AB = Alberta, BC = British Columbia, MN = Manitoba, NB = New Brunswick, NS = Nova Scotia, ON = Ontario, PE = Prince Edward Island, QC = Quebec, SK = Saskatchewan.

[3]Many states have Natural Heritage Programs that assess the rarity of plant species and assign them rankings that are of a lower level designation than threatened or endangered. Please refer to http://cheetah.natureserve.org/visitLocal/usa.jsp to identify which states maintain such programs and if any *Asclepias* species have special status in your state(s) of interest.

[4]Bloom time information is sourced almost exclusively from Woodson (1954). Additional sources are Hartman (1986) and Sundell (1993).

Milkweed Species Native to the United States and Canada

Scientific name[1]	Common name(s)	Range[2]	Conservation status[3]	Bloom period[4]	Notes
Asclepias incarnata L. **ssp. *incarnata***[b]	swamp milkweed	AL, AR, CO, CT, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, PA, SD, TN, TX, UT, VA, VT, WI, WV, WY, Canada (MB, NB, NS, ON, PE, QC)		May–Sep	
Asclepias incarnata L. **ssp. *pulchra***[b] (Ehrh. ex Willd.) Woodson	swamp milkweed	CT, DC, DE, FL, GA, KY, MA, MD, ME, MI, NC, NH, NJ, NY, PA, RI, SC, TN, TX, VA, VT, WV		Jun–Aug	
Asclepias involucrata Engelm. ex Torr.	dwarf milkweed	AZ, CO, KS, NM, OK, TX, UT	Presumed extirpated in Kansas	Mar–Jul	
Asclepias labriformis M.E. Jones	Utah milkweed	UT		May–Aug	
Asclepias lanceolata[b] Walter	Fewflower milkweed	AL, DE, FL, GA, LA, MD, MS, NC, NJ, SC, TN, TX, VA		May–Aug	
Asclepias lanuginosa Nutt.	Sidecluster milkweed	IA, IL, KS, MN, ND, NE, SD, WI, Canada (Manitoba)	Endangered in IL; Threatened in IA, WI	May–Aug	
Asclepias latifolia (Torr.) Raf.	broadleaf milkweed	AZ, CA, CO, KS, NE, NM, OK, SD, TX, UT		May–Sep	
Asclepias lemmonii A. Gray	Lemmon's milkweed	AZ		Jun–Sep	
Asclepias linaria[a] Cav.	Pineneedle milkweed	AZ, CA, NM		Apr–Nov	Evergreen when growing at low elevation
Asclepias linearis Scheele	Slim milkweed	TX, MD		May–Sep	This species' disjunct distribution is curious. Records of its occurrence in MD may be based on introduced individuals.
Asclepias longifolia[b] Michx.	Longleaf milkweed	AL, AR, DE, FL, GA, LA, MD, MS, NC, SC, TX, VA, WV		Apr–Jul	
Asclepias macrotis Torr.	Longhood milkweed	AZ, CO, NM, OK, TX		May–Oct	

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[1]Additional *Asclepias* taxa that are acknowledged by Fishbein et al. (2011) yet are not included in the USDA PLANTS database or the Biota of North America Program's North American Plant Atlas: *Asclepias elata*, *A. macrosperma*, *A. ruthiae*, *A. sanjuanensis*. Some authorities consider these scientific names to be synonyms for species included in the list above.

[2]Information on species' presence and absence in U.S. states and Canadian provinces is derived from the USDA PLANTS database. Some of these species, plus many others not included in this list, occur in Mexico. Canadian provinces are abbreviated as follows: AB = Alberta, BC = British Columbia, MN = Manitoba, NB = New Brunswick, NS = Nova Scotia, ON = Ontario, PE = Prince Edward Island, QC = Quebec, SK = Saskatchewan.

[3]Many states have Natural Heritage Programs that assess the rarity of plant species and assign them rankings that are of a lower level designation than threatened or endangered. Please refer to http://cheetah.natureserve.org/visitLocal/usa.jsp to identify which states maintain such programs and if any *Asclepias* species have special status in your state(s) of interest.

[4]Bloom time information is sourced almost exclusively from Woodson (1954). Additional sources are Hartman (1986) and Sundell (1993).

Milkweed Species Native to the United States and Canada

Scientific name[1]	Common name(s)	Range[2]	Conservation status[3]	Bloom period[4]	Notes
Asclepias meadii $_c$ Torr. ex A. Gray	Mead's milkweed	IA, IL, IN, KS, MO, WI	Threatened nationally; Endangered in IA, IL, MO; Reintroduced in IN	May–Jun	
Asclepias michauxii Decne.	Michaux's milkweed	AL, FL, GA, LA, MS, SC		Apr–Jun	
Asclepias nummularia Torr.	tufted milkweed	AZ, NM, TX		Mar–Aug	
Asclepias nyctaginifolia $_a$ A. Gray	mojave milkweed	AZ, CA, NM, NV		May–Aug	
Asclepias obovata Elliott	pineland milkweed	AL, AR, FL, GA, LA, MS, OK, SC, TX		Jun–Aug	
Asclepias oenotheroides $_b$ Cham. & Schltdl.	zizotes milkweed	AZ, CO, LA, NM, OK, TX		Feb–Oct	
Asclepias ovalifolia Decne.	oval-leaf milkweed	IA, IL, MI, MN, MT, ND, SD, WI, WY, Canada (AB, BC, MB, ON, SK)	Endangered in IL and MI; Threatened in WI	May–Jul	
Asclepias pedicellata Walter	savannah milkweed	FL, GA, NC, SC		May–Jun	
Asclepias perennis $_d$ Walter	aquatic milkweed	AL, AR, FL, GA, IL, IN, KY, LA, MO, MS, SC, TN, TX		Apr–Sep	
Asclepias prostrata Blackwell	prostrate milkweed	TX			
Asclepias pumila (A. Gray) Vail	plains milkweed	CO, IA, KS, MT, ND, NE, NM, OK, SD, TX, WY		Jun–Sep	
Asclepias purpurascens $_b$ L.	purple milkweed	AR, CT, DC, DE, GA, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, NC, NE, NH, NJ, NY, OH, OK, PA, RI, SD, TN, TX, VA, WI, WV, Canada (ON)	Endangered in MA and WI; no extant populations in RI	May–Jul	
Asclepias quadrifolia Jacq.	fourleaf milkweed	AL, AR, CT, DE, GA, IA, IL, IN, KS, KY, MA, MD, MN, MO, MS, NC, NH, NJ, NY, OH, OK, PA, RI, SC, TN, VA, VT, WV, Canada (ON)	Threatened in NH, RI	Apr–Jul	

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[1]Additional *Asclepias* taxa that are acknowledged by Fishbein et al. (2011) yet are not included in the USDA PLANTS database or the Biota of North America Program's North American Plant Atlas: *Asclepias elata*, *A. macrosperma*, *A. ruthiae*, *A. sanjuanensis*. Some authorities consider these scientific names to be synonyms for species included in the list above.

[2]Information on species' presence and absence in U.S. states and Canadian provinces is derived from the USDA PLANTS database. Some of these species, plus many others not included in this list, occur in Mexico. Canadian provinces are abbreviated as follows: AB = Alberta, BC = British Columbia, MN = Manitoba, NB = New Brunswick, NS = Nova Scotia, ON = Ontario, PE = Prince Edward Island, QC = Quebec, SK = Saskatchewan.

[3]Many states have Natural Heritage Programs that assess the rarity of plant species and assign them rankings that are of a lower level designation than threatened or endangered. Please refer to http://cheetah.natureserve.org/visitLocal/usa.jsp to identify which states maintain such programs and if any *Asclepias* species have special status in your state(s) of interest.

[4]Bloom time information is sourced almost exclusively from Woodson (1954). Additional sources are Hartman (1986) and Sundell (1993).

Milkweed Species Native to the United States and Canada

Scientific name[1]	Common name(s)	Range[2]	Conservation status[3]	Bloom period[4]	Notes
Asclepias quinquedentata A. Gray	slimpod milkweed	AZ, NM, TX		Jun–Aug	
Asclepias rubra L.	red milkweed	AL, AR, DC, DE, FL, GA, LA, MD, MS, NC, NJ, NY, PA, SC, TX, VA	Endangered in MD; Extirpated in PA	May–Aug	
Asclepias rusbyi (Vail) Woodson	Rusby's milkweed	AZ, CO, NM, NV, UT		Jun–Jul	
Asclepias scaposa Vail	Bear mountain milkweed	NM, TX		Mar–Oct	
Asclepias solanoana Woodson	serpentine milkweed	CA		Jun	Has been anecdotally observed in Oregon, but a voucher specimen has not yet been submitted to an herbarium
Asclepias speciosa$_b$ Torr.	showy milkweed	AZ, CA, CO, IA, ID, IL, KS, MI, MN, MT, ND, NE, NM, NV, OK, OR, SD, TX, UT, WA, WI, WY, Canada (AB, BC, MB, SK)	Threatened in IA	May–Sep	
Asclepias sperryi Woodson	Sperry's milkweed	TX		Apr–Aug	
Asclepias stenophylla A. Gray	slimleaf milkweed	AR, CO, IA, IL, KS, LA, MN, MO, MT, NE, OK, SD, TX, WY	Endangered in IL, IA, MN	Jun–Aug	
Asclepias subulata$_a$ Decne.	rush milkweed	AZ, CA, NV		Sporadic throughout the year	One of the few evergreen milkweeds native to the U.S.
Asclepias subverticillata$_a$ (A. Gray) Vail	horsetail milkweed	AZ, CO, ID, KS, MO, NE, NM, NV, OK, TX, UT, WY		Jun–Aug	
Asclepias sullivantii$_b$ Engelm. ex A. Gray	prairie milkweed	AR, IA, IL, IN, KS, MI, MN, MO, ND, NE, OH, OK, SD, WI, Canada (ON)	Threatened in MI, MN, WI	Jun–Aug	

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[1]Additional *Asclepias* taxa that are acknowledged by Fishbein et al. (2011) yet are not included in the USDA PLANTS database or the Biota of North America Program's North American Plant Atlas: *Asclepias elata*, *A. macrosperma*, *A. ruthiae*, *A. sanjuanensis*. Some authorities consider these scientific names to be synonyms for species included in the list above.

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[4]Bloom time information is sourced almost exclusively from Woodson (1954). Additional sources are Hartman (1986) and Sundell (1993).

Milkweed Species Native to the United States and Canada

Scientific name[1]	Common name(s)	Range[2]	Conservation status[3]	Bloom period[4]	Notes
Asclepias syriaca[b] L.	common milkweed	AL, AR, CT, DC, DE, GA, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, VA, VT, WI, WV, Canada (MB, NB, NS, ON, PE, QC, SK)		Jun–Aug	Typically regarded as an eastern species. Records of its occurrence in OR and MT may be based on introduced individuals.
Asclepias texana A. Heller	Texas milkweed	TX		Jun–Aug	
Asclepias tomentosa[b] Elliott	tuba milkweed	AL, FL, GA, NC, SC, TX		May–Jun	
Asclepias tuberosa L. ssp. ***interior***[b] Woodson	Butterfly milkweed	AR, AZ, CA, CO, CT, IA, IL, IN, KS, KY, LA, MI, MN, MO, MS, NE, NM, NY, OH, OK, PA, SD, TN, TX, UT, WI, WV, Canada (ON, QC)		May–Sep	Plant nurseries and seed vendors rarely denote which subspecies they are selling.
Asclepias tuberosa L. ssp. ***rolfsii***[b] (Britton ex Vail) Woodson	Rolfs' milkweed	AL, FL, GA, MS, NC, SC		Feb–Aug	
Asclepias tuberosa L. **ssp. *tuberosa***[b]	Butterfly milkweed	AL, CT, DC, DE, FL, GA, IL, IN, KY, MA, MD, ME, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WV	Endangered in NH; Threatened in VT	Apr–Sep	
Asclepias uncialis Greene ssp. *ruthiae* (Maguire) Kartesz & Gandhi	Ruth's milkweed	AZ, NM, NV, UT		Apr–Jun	
Asclepias uncialis Greene ssp. *uncialis*	Wheel milkweed	AZ, CO, NM, OK, TX, UT, WY		Mar–May	
Asclepias variegata[b] L.	redring milkweed	AL, AR, CT, DC, DE, FL, GA, IL, IN, KY, LA, MD, MO, MS, NC, NJ, NY, OH, OK, PA, SC, TN, TX, VA, WV, Canada (ON)	Endangered in CT, NY, PA	May–Jul	

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[1]Additional *Asclepias* taxa that are acknowledged by Fishbein et al. (2011) yet are not included in the USDA PLANTS database or the Biota of North America Program's North American Plant Atlas: *Asclepias elata*, *A. macrosperma*, *A. ruthiae*, *A. sanjuanensis*. Some authorities consider these scientific names to be synonyms for species included in the list above.

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Milkweed Species Native to the United States and Canada

Scientific name[1]	Common name(s)	Range[2]	Conservation status[3]	Bloom period[4]	Notes
Asclepias verticillata[b] L.	whorled milkweed	AL, AR, AZ, CT, DC, DE, FL, GA, IA, IL, IN, KS, KY, LA, MA, MD, MI, MN, MO, MS, MT, NC, ND, NE, NJ, NM, NY, OH, OK, PA, RI, SC, SD, TN, TX, VA, VT, WI, WV, WY, Canada (MB, ON, SK)	Threatened in MA	Apr–Aug	
Asclepias vestita Hook. & Arn. ssp. ***parishii***[b] (Jeps.) Woodson	Parish's woolly milkweed	CA		Apr–May	
Asclepias vestita Hook. & Arn. **ssp.** ***vestita***[b]	woolly milkweed	CA		Apr–Jul	
Asclepias viridiflora[b] Raf.	green comet milkweed	AL, AR, AZ, CO, CT, DC, DE, FL, GA, IA, IL, IN, KS, KY, LA, MD, MI, MN, MO, MS, MT, NC, ND, NE, NJ, NM, NY, OH, OK, PA, SC, SD, TN, TX, VA, WI, WV, WY, Canada (AB, BC, MB, ON, SK)	Endangered in FL; Threatened in NY	Apr–Aug	
Asclepias viridis[b] Walter	Green antelopehorn	AL, AR, FL, GA, IL, IN, KS, KY, LA, MO, MS, NE, OH, OK, SC, TN, TX, WV	Endangered in IN	Apr–Aug	
Asclepias viridula Chapm.	southern milkweed	AL, FL, GA	Threatened in FL	Apr–Jul	
Asclepias welshii N.H. Holmgren & P.K. Holmgren	Welsh's milkweed	AZ, UT	Threatened nationally	Jun–Jul	

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[4]Bloom time information is sourced almost exclusively from Woodson (1954). Additional sources are Hartman (1986) and Sundell (1993).

Appendix II:

Known Milkweed Pathogens

Known Milkweed Pathogens

	Other *Asclepias* spp.	*Asclepias asperula* ssp. *capricornu*	*Asclepias fascicularis*	*Asclepias incarnata*	*Asclepias speciosa*	*Asclepias subverticillata*	*Asclepias syriaca*	*Asclepias tuberosa*	*Asclepias verticillata*	*Asclepias viridis*	References
FUNGAL DISEASES											
Leafspot											
Alternaria spp.	X			X			X				USDA 1960
Alternaria fasciculata										X	USDA 1960
Ascochyta asclepiadis							X				USDA 1960
Cercospora asclepiadorae	X							X		X	USDA 1960
Cercospora clavata				X	X		X	X			USDA 1960; Tiffany and Knaphus 1995 (*A. syriaca*)
Cercospora elaeochroma	X				X		X				USDA 1960
Cercospora hansenii	X						X				USDA 1960
Cercospora illinoensis							X				USDA 1960
Cercospora venturioides[1]	X				X		X				USDA 1960
Passalora californica			X								Koike et al. 2011
Passalora clavata var. *hansenii*							X				Koike et al. 2011
Phyllosticta cornuti							X				USDA 1960
Phyllosticta tuberosa		X		X				X			USDA 1960
Septoria asclepiadicola	X			X			X				USDA 1960
Septoria cryptotaeniae	X			X			X				USDA 1960
Septoria incarnata				X			X				USDA 1960
Stagonospora zonata							X				USDA 1960
Anthracnose & Canker (discolored lesions restricted in size and spread, occurring on stems and/or foliage)											
Colletotrichum fusarioides[2]					X		X				O'Gara 1915 (*A. speciosa*); USDA 1960; Tiffany and Knaphus 1995 (*A. syriaca*)
Didymella cornuta							X				USDA 1960
Scolecotrichum asclepiadias	X						X				USDA 1960
Leaf & Stem Blight (sometimes characterized by dark colored pycnidia fruiting bodies on dead tissue)											
Colletotrichum fusarioides					X		X				USDA 1960
Diaporthe arctii	X						X	X			USDA 1960
Diplodia asclepiadea							X				USDA 1960
Phoma asclepiadea	X				X		X				USDA 1960
Phoma rostrata					X						O'Gara 1915
Phomopsis missouriensis	X										USDA 1960
Pleospora diplospora				X							USDA 1960

[1]Considered by some to be a synonym of *Cercospora clavata*; [2]Possible synonym of *Glomerella fusarioides*; [3]Diagnosed by Tom Creswell at Purdue University Plant and Pest Diagnostic Lab (*Chalara elegans* is a synonym); [4]*Bouteloua* spp. are alternative hosts; [5]*Spartina* spp. are alternative hosts

Known Milkweed Pathogens

	Other *Asclepias* spp.	*Asclepias asperula* ssp. *capricornu*	*Asclepias fascicularis*	*Asclepias incarnata*	*Asclepias speciosa*	*Asclepias subverticillata*	*Asclepias syriaca*	*Asclepias tuberosa*	*Asclepias verticillata*	*Asclepias viridis*	References
Pyrenophora depressa	X										USDA 1960
Sphaeropsis sphaerospora							X				USDA 1960
Powdery Mildew											
Erysiphe circhoracearum	X						X				USDA 1960
Phyllactinia corylea							X				USDA 1960
Root Rot											
Phymatotrichum omnivorum	X						X	X			USDA 1960
Pythium spp.				X				X			Blake et al. [year unknown]; Tsror et al. 1997
Rhizoctonia solani	X						X				USDA 1960
Rosellinia aquila	X										USDA 1960
Thielaviopsis basicola[3]								X			
Rust											
Puccinia bartholomaei[4]	X	X			X	X	X	X	X	X	USDA 1960; Popp and Lundquist 2006 (*A. verticillata*)
Puccinia chloridis							X				Tiffany and Knaphus 1995
Puccinia concrescens	X										USDA 1960
Puccinia seymouriana[5]	X				X		X				USDA 1960
Puccinia vexans[4]								X			USDA 1960
Uromyces asclepiadis	X	X		X	X	X	X	X		X	USDA 1960
BACTERIAL DISEASES											
Xanthomonas campestris var. *asclepiadis*				X							Flynn and Vidaver 1995
VIRUSES											
Cucumber mosaic virus	X						X				USDA 1960
Asclepias asymptomatic virus										X	Min et al. 2012
PHYTOPLASMA											
Milkweed yellows phytoplasma	X										Griffiths et al. 1994
Aster yellows phytoplasma							X				USDA 1960
PROTOZOAN PARASITE											
Phytomonas elmassiani	X										McGhee and McGhee 1971 (numerous species mentioned)
PARASITIC ALGAE											
Rhodochytrium spilanthidis var. *asclepiadis*	X										USDA 1960

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Appendix III:

Seed Availability, Seed Count Data, and Growth Characteristics of Several Milkweed Species

Seed Availability, Seed Count Data, and Growth Characteristics of Several Milkweed Species

Scientific name	Common name	Seed available by the pound	Seed available by the ounce	Seed available in small packets	Available as transplants	Bulk seeds per pound[1]	Number of data points for seed count estimates
Asclepias asperula ssp. *asperula*	spider milkweed		+	√	√	62,320	2
Asclepias asperula ssp. *capricornu*	antelope horns		+	√	√	87,440	3
Asclepias cordifolia	heartleaf milkweed		+		√	20,700	2
Asclepias eriocarpa	woollypod milkweed	√	√		√	24,990	1
Asclepias exaltata	poke milkweed		√	√		48,000	1
Asclepias fascicularis	narrowleaf milkweed	√	√	√	√	105,240	7
Asclepias hirtella	tall green milkweed		√	√	√	64,280	2
Asclepias humistrata	pinewoods milkweed		+	+		67,280	2
Asclepias incarnata	swamp milkweed	√	√	√	√	84,160	7
Asclepias latifolia	broadleaf milkweed		+	+		56,640	1
Asclepias purpurascens	purple milkweed		√	√		77,130	2
Asclepias speciosa	showy milkweed	√	√	√	√	70,250	10
Asclepias subulata	rush milkweed		+	+	√	88,560	2
Asclepias sullivantii	prairie milkweed		√	√	√	84,440	3
Asclepias syriaca	common milkweed	√	√	√	√	64,540	4
Asclepias tuberosa	butterfly milkweed	√	√	√	√	69,590	6
Asclepias verticillata	whorled milkweed	√	√	√		182,060	3
Asclepias viridiflora	green comet milkweed			√	√	78,110	2
Asclepias viridis	green milkweed		√	√	√	69,370	3

(√) Indicates availability; (+) Seed production activities are being conducted as part of the Xerces Society's Project Milkweed; availability is projected to increase.

[1]Data on seeds per pound was compiled from the Royal Botanic Gardens Kew Seed Information Database (Royal Botanic Gardens Kew 2014), native seed companies (Cardno JFNew, Everwilde Farms, Hedgerow Farms, Inc., Native American Seed, Prairie Moon Nursery, Roundstone Seed, S&S Seeds, Western Native Seed), and seed counts conducted by Xerces Society staff. When multiple data points per species were available, the value shown represents an average rounded to the nearest ten. For a few species, seed count data is scarce and it was not possible to calculate an average value.

[2]Plant height information is largely sourced from Woodson (1954) and also from Hartman (1986) and the authors' personal observations.

Growth habit	Maximum height (feet)[2]
Sparse clusters of few-to-several erect or ascending stems	3
Low-growing with multiple stems; sometimes forms large, dense clusters	2
Small clusters of erect or nodding stems	2
Stout, erect stems; can form small dense clusters	3
Tall, slender stems with drooping inflorescences	6
Slender, erect stems; can spread by lateral roots to form dense, localized stands	3
Stout, erect stems; does not form clusters	3
Decumbent with multiple stems and large arrow-shaped leaves	1.5
Dense multi-stemmed clusters; erect stems, each with multiple terminal inflorescences	5
Compact stature with stout, erect stems and broad, thick leaves	2
Stout, erect stems; may spread via lateral roots	4
Stout, erect stems; can spread by lateral roots to form large colonies	4
Dense clusters of gray-green, nearly leafless, photosynthetic stems, all originating from a woody root crown	6
Stout, erect stems; can spread by lateral roots to form large colonies	4
Stout, erect stems; can spread by lateral roots to form large colonies	6
Dense multi-stemmed clusters; erect stems, each with multiple terminal inflorescences	3
Typically short-statured with thin, whorled leaves; can spread by lateral roots to form large colonies	3
Short-statured, broad-leaved, usually a single stem	2
Small to medium-sized clusters of erect or ascending stems	2

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Appendix IV:

Region-by-region Summary of Milkweed Seed Availability, Priority Species for Use in Habitat Restoration, and an Overview of Monarch Population Dynamics

Region-by-region Summary of Milkweed Seed Availability, Priority Species for Use in Habitat Restoration, and an Overview of Monarch Population Dynamics				
Region	Availability of regionally-sourced seed	Priority species for habitat restoration efforts	Monarch population dynamics	Notes
Western U.S.				
Maritime Northwest (w. WA, w. OR, nw. CA)	Very limited.	*Asclepias fascicularis* (narrowleaf milkweed) *Asclepias speciosa** (showy milkweed)	From late spring through fall, monarchs occur throughout Oregon and east of the Cascades in Washington, usually near major rivers (James & Nunnallee 2011). In Oregon, they may be most abundant in the southern Willamette Valley and the Klamath Mountains.	*Asclepias cordifolia* (heartleaf milkweed) is also a good candidate for planting in southwestern Oregon. Northwestern Oregon and western Washington (west of the Cascades) are some of the only areas of the country where milkweeds are not documented to occur.
Inland Northwest (e. OR, e. WA, w. ID)	Very limited.	*Asclepias fascicularis* (narrowleaf milkweed) *Asclepias speciosa* (showy milkweed)	Monarchs are present during the summer months but are relatively uncommon in the region (Journey North 2014). Monarchs sometimes also breed in south-central and southeastern British Columbia.	Showy milkweed is by far the most naturally abundant milkweed in this region.
California	Good. Available in northern CA and the Central Valley. Availability of southern CA-sourced seed may increase in coming years.	*Asclepias cordifolia* (heartleaf milkweed) *Asclepias eriocarpa** (woollypod milkweed) *Asclepias fascicularis** (narrowleaf milkweed) *Asclepias speciosa** (showy milkweed)	A very important breeding area for western monarchs. In the spring, when monarchs disperse from coastal overwintering sites, some breed along the coastline (Wenner & Harris 1993) but many fly inland in search of milkweed (Nagano et al. 1993). Monarchs are present in California year-round; several generations are likely produced within the state.	Narrowleaf milkweed is very broadly distributed across California, whereas showy milkweed and heartleaf milkweed do not occur in the southern third of the state. Woollypod milkweed has a patchy distribution; please refer to the USDA PLANTS database for more information.

*Denotes species for which regionally-sourced seed is available, as of Spring 2014.

Region-by-region Summary of Milkweed Seed Availability, Priority Species for Use in Habitat Restoration, and an Overview of Monarch Population Dynamics				
Region	Availability of regionally-sourced seed	Priority species for habitat restoration efforts	Monarch population dynamics	Notes
Rocky Mountains (e. ID, w. MT, WY, e. UT, w. CO)	Very limited.	*Asclepias speciosa* (showy milkweed) *Asclepias tuberosa* (butterfly milkweed)	Monarchs are present during the summer months and sometimes into the fall, but are relatively uncommon in the region (Journey North 2014).	Showy milkweed is by far the most naturally abundant milkweed in this region. Butterfly milkweed is appropriate for planting in the southern Rocky Mountains, but is not native to the northern Rocky Mountains.
Great Basin (se. OR, NV, w. UT)	Currently limited, but seed production activities are underway.	*Asclepias asperula* ssp. *asperula* (spider milkweed) *Asclepias fascicularis* (narrowleaf milkweed) *Asclepias speciosa* (showy milkweed)	Monarchs occur in southeastern Oregon, Nevada, and western Utah during the summer months and into the fall (Dingle et al. 2005). Nevada is potentially a very important breeding area for western monarchs.	Showy milkweed is suitable for planting where soil moisture is available for most of the growing season (e.g., stream banks, wetlands, channel banks, riparian areas). Once established, narrowleaf milkweed and spider milkweed are more tolerant of dry growing conditions but they still require adequate soil moisture in their first year of growth.
Southwest (se. CA, AZ, NM, w. TX)	Currently limited, but seed production activities are underway.	*Asclepias asperula* ssp. *asperula** (spider milkweed) *Asclepias latifolia* (broadleaf milkweed) *Asclepias speciosa* (showy milkweed) *Asclepias subulata* (rush milkweed)	Monarchs are present in Arizona throughout most of the year, with peak numbers observed during fall (Southwest Monarch Study, unpublished data). Fall may also be a peak time for monarch activity in New Mexico, though monarchs are more abundant in Arizona. Little is known about monarch breeding activity in southeastern California and there are few monarch occurrence records from the Trans-Pecos region of Texas.	*Asclepias subverticillata* (horsetail milkweed) is one of the most abundant wild milkweed species in the Southwest. It is widely perceived as a weed and its seed is not likely to become commercially available, but the species likely plays an important role in supporting monarchs. *Asclepias subulata* is suitable for planting in southeastern California, western Arizona, and southern Nevada, but is not native to eastern Arizona or western Texas.

*Denotes species for which regionally-sourced seed is available, as of Spring 2014.

Region-by-region Summary of Milkweed Seed Availability, Priority Species for Use in Habitat Restoration, and an Overview of Monarch Population Dynamics				
Region	Availability of regionally-sourced seed	Priority species for habitat restoration efforts	Monarch population dynamics	Notes
Central U.S.				
Northern Plains (e. MT, e. WY, ND, SD, NE, w. MN)	Limited. Available from a few vendors in Nebraska and Minnesota.	*Asclepias incarnata** (swamp milkweed) *Asclepias speciosa** (showy milkweed) *Asclepias syriaca** (common milkweed) *Asclepias verticillata** (whorled milkweed)	There are relatively few monarch observations reported from Montana and Wyoming. Sightings are more common in the eastern portions of North Dakota, South Dakota, and Nebraska than in the western part of this region (Journey North 2014). Western Minnesota is within the eastern monarch's core breeding range; monarchs are abundant during spring and summer. Monarchs also breed in parts of Manitoba, Saskatchewan, and Alberta (east of the Rockies).	*Asclepias incarnata* occurs infrequently in Montana, Wyoming, and North Dakota, and is more common in the southern part of South Dakota than the northern. In general, milkweed seed availability is much greater in Minnesota than in the other parts of this region.
Southern Plains (e. CO, KS, OK, AR, TX)	Good. Available from a few vendors.	*Asclepias asperula* ssp. *capricornu** (antelope horns) *Asclepias tuberosa** (butterfly milkweed) *Asclepias viridis** (green milkweed) *Asclepias verticillata* (whorled milkweed)	Monarch sightings in eastern Colorado are relatively uncommon but the rest of the Southern Plains, Texas in particular, is an extremely important spring breeding area. Breeding can also occur in late summer and early fall if milkweed foliage is available (Baum & Sharber 2012; Calvert 1999).	*Asclepias incarnata* (swamp milkweed) is also suitable for planting in Kansas, but is far less common in the other states.
Great Lakes (e. MN, WI, MI, OH, w. PA, w. NY)	Very good. Available from multiple vendors.	*Asclepias exaltata** (poke milkweed) *Asclepias incarnata** (swamp milkweed) *Asclepias syriaca** (common milkweed) *Asclepias tuberosa** (butterfly milkweed) *Asclepias verticillata** (whorled milkweed)	A very important summer breeding area. Monarchs are present and abundant from May through approximately early September (Journey North 2014). Monarchs also breed in southern Ontario.	*Asclepias sullivantii* (prairie milkweed) is listed as threatened in Michigan, Minnesota, and Wisconsin. To avoid interfering with research or recovery efforts, it is advisable to abstain from planting the species in those states.

*Denotes species for which regionally-sourced seed is available, as of Spring 2014.

Region-by-region Summary of Milkweed Seed Availability, Priority Species for Use in Habitat Restoration, and an Overview of Monarch Population Dynamics				
Region	Availability of regionally-sourced seed	Priority species for habitat restoration efforts	Monarch population dynamics	Notes
Midwest (IA, MO, IL, IN)	Very good. Available from multiple vendors.	*Asclepias incarnata** (swamp milkweed) *Asclepias sullivantii** (prairie milkweed) *Asclepias syriaca** (common milkweed) *Asclepias tuberosa** (butterfly milkweed) *Asclepias verticillata** (whorled milkweed)	A very important monarch breeding area. Research suggests that a large percentage of monarchs that overwinter in Mexico are produced in the Midwest (Wassenaar & Hobson 1998). The widespread adoption of herbicide resistant crops is a significant driver of milkweed loss in the region (Pleasants & Oberhauser 2012).	*Asclepias purpurascens* (purple milkweed) is broadly distributed across the Midwest, and is an additional candidate for restoration efforts, though seed sources are more scarce than for the other recommended species.
Eastern U.S.				
Northeast (e. NY, CT, RI, MA, VT, NH, ME)	Very limited. Seed is available from the Mid-Atlantic region, but those sources are less than ideal for planting in New England.	*Asclepias incarnata* (swamp milkweed) *Asclepias syriaca* (common milkweed) *Asclepias tuberosa* (butterfly milkweed)	Monarchs are present from May through approximately early September (Journey North 2014). Monarchs also breed in southern Quebec and the Canadian Maritimes.	*Asclepias tuberosa* (butterfly milkweed) is endangered in New Hampshire and threatened in Vermont. To avoid interfering with research or recovery efforts, it is advisable to abstain from planting the species in those states.
Mid-Atlantic (NC, VA, WV, Wash DC, MD, DE, NJ, e. PA)	Good. Available from at least one vendor.	*Asclepias incarnata** (swamp milkweed) *Asclepias syriaca** (common milkweed) *Asclepias tuberosa** (butterfly milkweed)	Monarchs are present as early as April and potentially as late as October (Journey North 2014). The Atlantic coast is an important fall migration corridor.	*Asclepias syriaca* (common milkweed) should be considered a priority species for habitat restoration efforts, despite its perception as a weed.

*Denotes species for which regionally-sourced seed is available, as of Spring 2014.

Region-by-region Summary of Milkweed Seed Availability, Priority Species for Use in Habitat Restoration, and an Overview of Monarch Population Dynamics

Region	Availability of regionally-sourced seed	Priority species for habitat restoration efforts	Monarch population dynamics	Notes
Southeast (LA, MS, AL, GA, SC, TN, KY)	Limited. Available from Kentucky, but not currently from the Southeastern coastal plain.	*Asclepias tuberosa* (butterfly milkweed) *Asclepias verticillata* (whorled milkweed)	An important spring breeding area, with peak activity during March and April (Journey North 2014).	Additionally, *Asclepias syriaca* (common milkweed) and *A. incarnata* (swamp milkweed) are suitable for planting in Kentucky or Tennessee but would be far less adaptable to the Southeastern coastal plain. *Asclepias humistrata* (pinewoods milkweed) occurs in the southern portions of Mississippi, Alabama, South Carolina, and Georgia and is a good candidate for planting in those areas.
Florida	Currently limited, but seed production activities are underway.	*Asclepias humistrata* (pinewoods milkweed) *Asclepias perennis* (aquatic milkweed) *Asclepias tuberosa** (butterfly milkweed)	Spring breeding in north-central Florida is well documented (Cockrell et al. 1993; Malcolm et al. 1993; Knight et al. 1999). Also, some non-migratory monarchs remain in Florida and breed year-round (Knight & Brower 2009).	Based on range, *Asclepias incarnata* (swamp milkweed), *Asclepias lanceolata* (fewflower milkweed), *Asclepias pedicellata* (savannah milkweed), and *Asclepias verticillata* (whorled milkweed) are excellent candidates for planting in Florida, yet to the authors' knowledge there are currently no seed production efforts underway for these species.

*Denotes species for which regionally-sourced seed is available, as of Spring 2014.

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