Native Thistles

A Conservation Practitioner's Guide

Plant Ecology, Seed Production Methods, and Habitat Restoration Opportunities

James Eckberg, Eric Lee-Mäder, Jennifer Hopwood, Sarah Foltz Jordan, and Brianna Borders

XERCES SOCIETY
for Invertebrate Conservation

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The Xerces Society for Invertebrate Conservation

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Photographs & Artwork

Cover: front—Monarch butterfly (*Danaus plexippus*) nectaring on native tall thistle (*Cirsium altissimum*); back—brown-belted bumble bee (*Bombus griseocollis*) foraging on field thistle (*Cirsium discolor*). (Photographs by Jennifer Hopwood and Sarah Foltz Jordan, The Xerces Society.)

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Introduction

Native thistles are a largely misunderstood and wrongly maligned group of wildflowers. These diverse plants fill a variety of significant niches along more esteemed wildflowers including the coneflowers, prairie clovers, camas, and compass plant. While so many of those native wildflowers have been embraced by restoration practitioners, ultimately finding a place in our gardens and restored natural areas, appreciation for our native thistles never really caught on. This is too bad. With sublime blue-green foliage, interesting stem and leaf architecture, and pink blossoms, our native thistles are every bit as resplendent as countless other native plants.

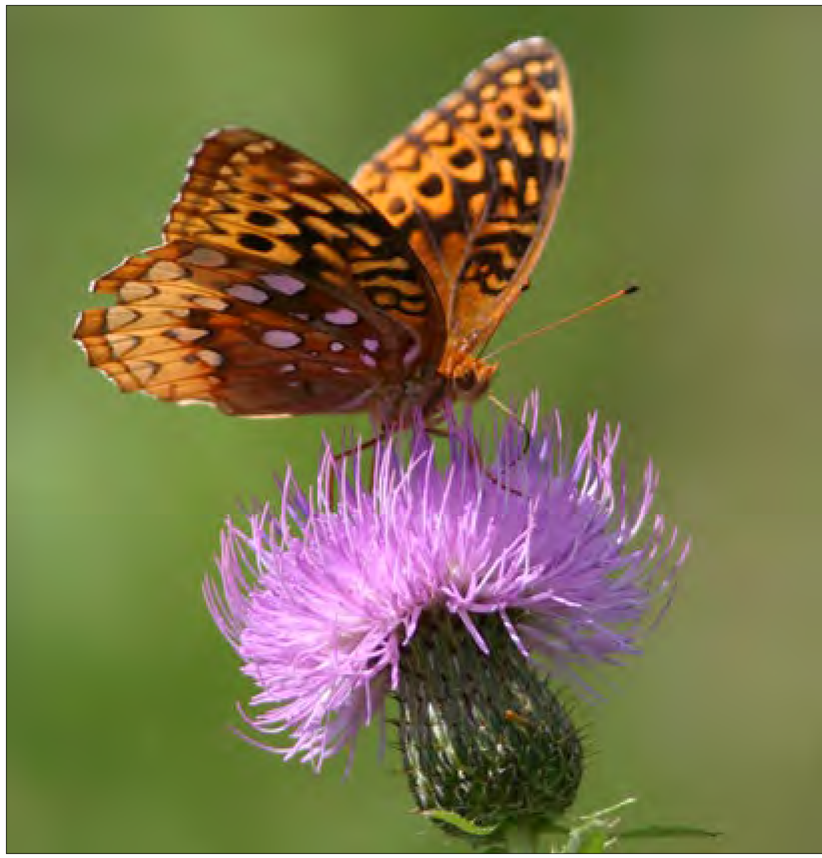

Figure 1.1: Great spangled fritillary butteflies (*Speyeria cybele*) have been documented to visit several native thistle species, including tall thistle (*C. altissimum*), shown above.

More significantly, these plants play important roles in our ecosystems. In great grasslands and prairies, alpine meadows and silty Midwestern river bottoms, the seeds of our native thistles help sustain enormous flocks of songbirds such as goldfinches and indigo buntings. The nectar of these plants fills the stomachs of countless flower visitors, including the enormous black and gold bumble bee (*Bombus auricomus*), while the foliage of thistles feeds both people and rare butterflies alike. Edible thistle (*Cirsium edule*), for example, is a staple food of the Salish people of the Pacific Northwest, while swamp thistle (*C. muticum*) is a caterpillar host plant for the endangered swamp metalmark butterfly (*Calephelis muticum*).

As with so many of our other native prairie and meadow species, thistles have been a direct casualty of habitat loss, first beginning with the conversion of native plant communities to intensive plow-based agriculture, then continuing with urbanization and the development of cities and roads. Most significantly, the later invasion of non-native thistles and the lack of discernment between superficially similar native and invasive species is heralding the potential end of these beautiful and important plants. A number of native thistles are now threatened with extinction.

In fact, in response to the spread of exotic invasives such as Canada thistle (*C. arvense*), expansive biocontrol programs have released alien thistle-eating insects that devour invasive and native thistles alike. These biological control efforts have had only limited impacts on some invasive thistles, but likely devastating impacts on our native ones. This pressure has been compounded by farm-level thistle eradication efforts, including the ever-increasing use of herbicides. And, finally, some broad-reaching weed control policies treat all members of the genus as noxious weeds, ignoring the potential to push historically common native thistles toward local extinction.

We think it's time to bring back native thistles.

This book is our first step in that process. Here you will find one of the most comprehensive discussions of the value of native thistles for pollinators and other wildlife, as well as a detailed account of the conservation status of native thistles, many of which are well studied. Given the significance of non-native thistle invasions and the ramifications this has had for their native counterparts, we provide a brief history of invasion by Canada thistle. Finally, we have developed a practical section on the production of native thistle seed for use in restoration projects. This section is based on multiple years of actual native thistle seed production by the Xerces Society Pollinator Conservation Program in partnership with a fantastic group of native seed companies.

Ultimately we hope this document provides the inspiration and the tools necessary for you to take the next step and make native thistle conservation a routine part of your work—whether you are a public land manager, a native seed producer, or a landowner working to create a conservation legacy.

Native plants are the foundation of a resilient and healthy world. These plants have co-evolved with our pollinators and herbivores, and adapted to their unique corner of the world over tens-of-thousands of years. Native plants provide food for wildlife, sequester carbon in soils, protect water quality, and add color and beauty to our lives.

Ultimately, the inclusion of native thistles in this equation will require a larger paradigm shift on the part of the public and policy makers. You can be a part of that paradigm shift. Along the way there will be much work to do, but also incredible opportunities, not the least of which is the potential to create a new place in our landscapes for the countless wildlife species that are intertwined with this interesting group of plants. For your contribution to this noble cause, we are profoundly grateful.

FIGURE 1.2: Native thistles are important resources to countless species—from providing pollen and nectar to pollinators and beneficial insects like monarch butterflies (*Danaus plexippus*), goldenrod soldier beetles (*Chauliognathus pensylvanicus*), and bumble bees (*Bombus* spp.).

2

The Natural History of Thistles

What Are Thistles?

Thistles are members of the aster or sunflower family (Asteraceae), one of the most diverse groups of flowering plants with over 24,000 species (Funk et al. 2009). The common name "thistle" has been applied to a number of genera within the Aster family—as well as several that occur in other plant families (see Table 2.1)—from the tribe Cardueae (also called Cynareae). In North America, there are many native and introduced thistles from this tribe, which include the true thistles (*Cirsium* spp.), plumeless thistles (*Carduus* spp.), distaff thistles (*Carthamus* spp.), star thistles (*Centaurea* spp.), carline thistles (*Carlina* spp.), milk thistles (*Silybum marianum*), scotch thistles (*Onopordum* spp.), and globe thistles (*Echinops* spp.) (Keil 2006, Gleason and Cronquist 1963, GPFA 1991). This guide focuses primarily on true thistles (*Cirsium* spp.) in North America, the most diverse and widespread of our native thistles.

Table 2.1: Genera Often Referred to As "Thistles"

Many plants with spines are called "thistles" regardless of taxonomic relatedness to true thistles (*Cirsium* spp.).

Family	Tribe	Genera/Species	Common Name
ASTERACEAE	Cardueae (syn. Cynareae)	*Carduus* spp.	Plumeless thistles
		Carthamus spp.	Distaff thistles
		Carlina spp.	Carline thistle
		Centaurea spp.	Star-thistles, knapweeds
		Cirsium spp.	True thistles
		Cynara spp.	Artichoke thistle
		Echinops spp.	Globe thistles
		Onopordum spp.	Scotch thistles
		Silybum spp.	Milk thistles
	Cichorieae	*Sonchus* spp.	Sow thistles
		Cicerbita spp.	Blue sow thistles
APIACEAE	Saniculeae	*Eryngium heterophyllum*	Mexican thistles
AMARANTHACEAE	Salsoleae	*Kali* spp.	Russian thistles, tartar thistles
PAPAVERACEAE	Papavereae	*Argemone mexicana*	Flowering thistles

Thistles of North America

Native Thistles, *Cirsium* (ca. 62 species)

There are several characteristics that generally unify true thistles. As members of the aster family, true thistles have flowerheads (composite) with many small florets (flowers). While other aster groups contain disk florets in the center of the flowerhead and ray flowers as the outer petals, true thistles only have disk florets. This characteristic is useful in distinguishing true thistles from other spiny species in the aster family. For example, sow thistles (*Sonchus* spp.) have only ray florets or petals (GPFA 1991). Thistle flowers are typically pink, purple or white and some species have yellow (e.g., yellow thistle [*C. horridulum*]) or red flowers (e.g., cobweb thistle [*C. occidentale*]).

Spines are one of the most widely recognized characteristics of true thistles. Most true thistles have noticeable spines on their leaves and flowerheads. However, spines are not a reliable diagnostic for distinguishing *Cirsium* from other plants. Spiny plants like sow thistles (Asteraceae: Cichorieae) and Mexican thistle (Apiaceae: Saniculeae), are often referred to as "thistles" despite having no direct taxonomic relationship with true thistles in the tribe Cardueae. In fact, "thistles" within the tribe Cardueae are often distinguished by spines. For example, plants in the knapweed group (Cardueae: Centaureinae) with spines are called star-thistles. These include several introduced and invasive species in North America: yellow star-thistle (*Centaurea solstitialis*), red star-thistle (*C. calcitrapa*) and Iberian star-thistle (*C. iberica*).

The genera *Cirsium* and *Carduus* are the most diverse, abundant and widespread groups of thistles in North America. These genera include both the most significant invasive thistles as well as the rarest native thistles in North America. Several characteristics can be used to distinguish among thistle genera (*Cirsium*, *Carduus*) and other spiny plants in the aster family. The non-native *Carduus*, and the related *Onopordum* (scotch thistle), have spiny-winged stems that distinguish them from *Cirsium*, which lack these structures. Also, *Cirsium* has feathery side branches on the seed dispersal structures while the seed dispersal structures of *Carduus* are single stranded.

Classification of a *Cirsium* sp.

KINGDOM: Plants
PHYLUM: Tracheophyta (vascular plants)
CLASS: Magnoliopsida (dicotyledons or broadleafs)
ORDER: Asterales
FAMILY: Asteraceae (Aster)
TRIBE: Cardueae
GENUS: *Cirsium*
SPECIES: *Cirsium altissimum* (tall thistle)

Figure 2.1: From left to right: tall thistle (*C. altissimum*), elk thistle (*C. scariosum*), and Pitcher's thistle (*C. pitcheri*).

Distinguishing between native and non-native *Cirsium* can be tricky. To our knowledge, there are no fully reliable physical features that can be used to distinguish all native from non-native *Cirsium*. That said, many native *Cirsium* are less spiny than the widespread non-native thistles. For example, spines on several native thistle species (e.g., field thistle [*C. discolor*] and tall thistle [*C. altissimum*]) are mostly localized on leaf margins and sparser in comparison to their co-occuring non-native species (Canada thistle [*C. arvense*] and bull thistle [*C. vulgare*]). There are, however, several native thistle that are intensely spiny, such as Eaton's thistle (*C. eatonii*). Another characteristic that can differ between native and non-native thistles is the thick, white pubescence found on the leaf underside of many native thistles (e.g., the widely distributed tall thistle and field thistle) which contrasts the hairless or gray haired leaf undersides of the widespread non-native thistles (Canada thistle and bull thistle).

Figure 2.2: White hairs on underside of field thistle (*C. discolor*) leaves.

Native Thistle Diversity and Distribution

There are approximately 62 native *Cirsium* species, making this the most diverse thistle genus in North America (Keil 2006). The majority, approximately 78%, of native thistle species are distributed throughout the American West (Great Plains, Intermountain, desert and coast); eastern North America is home to far fewer species. The cause of greater species diversification in the West is not well understood, but may reflect adaptation to a wider range of environments in the West. Few thistle species are widely distributed and many are endemic, restricted to a specific ecological region. Approximately ⅙ of native species have only been documented in a single state or province (Keil 2006). For example, seven species are only found in California. Furthermore, approximately 59% of thistle species are rare throughout much of their distribution (The Biota of North America: North American Plant Atlas, 2014).

The diversity of native *Cirsium* in North America is striking especially compared to other native genera of Cardueae which have far fewer species. For example, the related saw-wort (*Saussurea*) has only seven species, and there are just two species of native knapweed (*Centaurea*). Researchers have

Figure 2.3: Sacramento Mountains thistle (*C. vinaceum*) is only found in the Sacramento Mountains of Otero County, New Mexico.

The Complexity of Native Thistle Diversity

The diversity of native thistles and hybridization among many species has made it difficult for botanists to define and describe thistle species. Numerous botanists have studied and revised the genus *Cirsium* over the past century. While as many as 76 species were recognized at one time (Ownbey et al. 1975), subsequent descriptions suggest there are 62 species—several of which include multiple varieties (Keil 2006). In Appendix A we summarize the most recent comprehensive description of native *Cirsium* spp. provided by Dr. David Keil (California Polytechnic State University) and available through the Flora of North America, eFlora.org (Keil 2006).

explored the evolution of this diversity in the *Cirsium* genus (Kelch and Baldwin 2003), and preliminary evidence from California suggests that *Cirsium* species may have rapidly radiated (a few species split into many) across North America from Europe and formed high levels of diversity during the late Tertiary period, as recently as two million years ago (Kelch and Baldwin 2003). Thistles are likely still evolving rapidly, given the high prevalence of hybridization among geographically overlapping species (Kelch and Baldwin 2003). This hybridization can lead to the grouping of plants into 'species complexes' as opposed to singular recognizable species, which can complicate efforts to identify and define specific species (Dabydeen 1997). While hybridization is prevalent among native thistles, there are no known examples of hybrids formed between native and non-native species (Keil 2006). The diversification among *Cirsium* species has allowed members of the genus to currently occupy an incredibly wide range of habitats across North America.

Habitats

Native thistles occur in an extraordinarily wide range of habitats including prairies, brackish marshes, streamsides, coastal and lacustrine dunes, subalpine meadows, forests, chaparral, cliffsides, and even deserts. Across North America, native thistles occur from sea level to high altitudes of alpine ridges and from northern Canada to tropical Central America. While thistles occupy a broad range of habitats, even

Figure 2.4: Clockwise from top left: elk thistle (*C. scariosum*) in Big Sky Meadow, field thistle (*C. discolor*) in upper Midwest grasslands, Pitcher's thistle (*C. pitcheri*) on the sand dunes of Lake Michigan, wavyleaf thistle (*C. undulatum*) on the Black Hills shortgrass prairie, edible thistle (*C. edule*) in Mount Rainier National Park, and Nuttall's thistle (*C. nuttallii*) in Orlando Wetlands Park.

within particular species, as a group thistles tend to occur in open or sparsely wooded environments.

Life Cycle and Growth Forms of Native Thistles

Native thistles exhibit a wide variety of life history traits. Many thistle species are described as monocarpic, meaning that they flower once in their lifetime and die (Appendix A). Many monocarpic species are biennial, flowering in the second year, but other species can flower in their first year (e.g., Texas thistle [*C. texanum*]) or take two to eight years to flower (e.g., Pitcher's thistle [Loveless 1984]). In monocarpic species, all reproduction is based on seed production, making these seeds critical to the persistence of the species. Habitat conditions, insect herbivory and weather may all influence the timing of this single flowering event. There are also several polycarpic native thistles, meaning that flowering occurs multiple times in their life, and the species are perennial. These species also tend to send out runner roots that produce new flowering stems (e.g., wavyleaf thistle [*C. undulatum*]).

Native thistles also vary widely in their growth form. Some species are densely fuzzy with thick cobweb-like hairs on the flowerheads or stems, whereas other species have few hairs. Species vary in height from less than 2' tall to as high as 10' (tall thistle, minnesotawildflowers.info; field thistle, see figure 2.5). The morphology and size of the flowerhead also varies greatly between species, with some species like Hill's thistle[*C. pumilum* var. *hillii*] displaying flowerheads up to 3" in diameter.

Figure 2.5: Author James Eckberg beside a field thistle (*C. discolor*) measuring ~10' in height.

Identifying Common Native Thistles of North America

We describe the identifying characteristics of some of the most common thistles native to North America, including key features important in distinguishing each species from similar thistles. The complete botanical descriptions of all North American species and their varieties are available at Flora of North America, eflora.org (Keil 2006). See Appendix A for complete habitat and range distributions of each species.

FIGURE 2.6: From left to right: tall thistle in bloom, close-up of tall thistle leaves, and close-up of tall thistle flowerhead.

Tall Thistle (*C. altissimum*)

- **RANGE:** Throughout most of the eastern half of United States to North Dakota and Texas.
- **HEIGHT:** ~3–10' (in bloom).
- **LEAVES:** Coarsely toothed along the edge. Usually not lobed (divided), or have broad triangular lobes. Vegetative basal leaves (rosettes) or lower leaves of flowering stalks may sometimes be lobed. Thick white hairs cover the underside of the leaves.
- **STEMS:** Covered in bristly hairs, lacking dense white hair.
- **FLOWERS:** Purple to pink, sometimes white. Flower heads have scales (bracts) with white line down the center.
- **SIMILAR SPECIES:** Field thistle is similar in appearance, but distinguished by having leaves that are deeply divided throughout the plant. References: Davidson 1963; Keil 2006; Chayka and Dziuk 2011.

FIGURE 2.7: Like tall thistle, field thistle flowers can be pink, lavender, or white. But field thistle leaves have deep lobes.

Field Thistle (*C. discolor*)

- **RANGE:** Throughout much of the eastern half of United States and Canada from Texas to Georgia north to Saskatchewan and Quebec.
- **HEIGHT:** ~3–10' (in bloom).
- **LEAVES:** Can have deep, narrow lobes during vegetative and flowering stages. Thick white hairs cover the underside of the leaves.
- **STEMS:** Bristly hairs to hairless.
- **FLOWERS:** Pink to lavender, sometimes white. Flower heads have scales (bracts) with white line down the center.
- **SIMILAR SPECIES:** Tall thistle is similar in appearance, but most to all tall thistle leaves are not lobed and have coarse teeth along edge. Field thistle leaves are deeply divided throughout plant with smoother edges. References: Davidson 1963; Keil 2006; Chayka and Dziuk 2013a.

Flodman's Thistle (*C. flodmanii*)

Figure 2.8: A distinctive feature of Flodman's thistle (left) is the thick white hair covering the stems and undersides of the leaves (right).

- **RANGE:** Throughout Northern Great Plains and upper Midwest from Colorado through central Canada to British Columbia and Quebec.
- **HEIGHT:** ~1–3' (in bloom).
- **LEAVES:** Variable from non-lobed to lobed (lobes can be wavy). Underside of leaves have thick white hairs while the upperside is mostly green with sparse hair.
- **STEMS:** Thick cobwebby hairs cover the stem.
- **FLOWERS:** Purple. Flowerheads have prominent scales with whitish center.
- **SIMILAR SPECIES:** Wavyleaf thistle may be confused with this species where they co-occur in the northern Great Plains. Flodman's is usually found in wetter habitat than wavyleaf thistle. The upperside of Flodman's leaves are usually greener with less hair than the highly pubescent upperside of wavyleaf leaves. Leaf lobes of wavyleaf rosettes are more strongly lobed and pointed forward ("wavy") in contrast to the shallowly lobed or non-lobed and non-wavy rosette leaves of Flodman's. These species are known to hybridize in the wild; hybrids combine traits of both species. References: Keil 2006; Chayka and Dziuk 2013b; Lym and Christianson 1996; Kaul et al. 2006.

Wavyleaf Thistle (*C. undulatum*)

Figure 2.9: Wavyleaf thistle can be found across most of North America (clockwise from top left): flowerhead, whole plant, and a close-up of the thistle's undulating leaves.

- **RANGE:** Throughout Great Plains from Texas to Manitoba, intermountain west, southwest to California and Mexico, and the Pacific Northwest to British Columbia. Introduced populations found as far east as New York.
- **HEIGHT:** <1–4' (in bloom).
- **LEAVES:** Margins of leaves are usually wavy (note scientific name refers to undulating or wavy leaves) and sometimes toothed. Leaf underside has thick white hair, upperside has thinner white hairs.
- **STEMS:** Dense, white hairs cover stem.
- **FLOWERS:** Generally large flowers up to 2 inches wide with loose, cobwebby hairs on the flowerhead scales.
- **SIMILAR SPECIES:** Flodman's thistle (see above). References: Keil 2006; Lym and Christianson 1996; Kaul et al 2006.

Figure 2.10: Swamp thistle may be nearly hairless and lacking in spines.

Figure 2.11: Elk thistle is highly variable; clockwise from top left: dinnerplate thistle (*C. s.* var. *americanum*), rosette thistle (*C. s.* var. *congdonii*), and meadow thistle (*C. s.* var. *scariosum*).

Swamp Thistle (*C. muticum*)

- **RANGE:** Throughout most of the eastern half of United States and Canada from Saskatchewan to Newfoundland and as far south as Texas and Florida.
- **HEIGHT:** ~3–8' (in bloom).
- **LEAVES:** Deeply lobed and nearly spineless. Undersides of leaves are green with sparse hairs to nearly hairless.
- **STEMS:** Lanky, with sparse hairs to nearly hairless.
- **FLOWERS:** Purple to pink. Cobwebby hairs are present between scales on the flowerhead. Flowerhead scales have a white longitudinal stripe along center. References: Keil 2006; Chayka and Dziuk 2010.

Elk Thistle (*C. scariosum*)

- **RANGE:** Intermountain to coastal West from British Columbia and Alberta south to Mexico. Introduced in Quebec.
- **HEIGHT:** Ground level to 6.5' (in bloom). *Note:* forms vary from stemless clusters of flowers on the ground to stemmed flowering stalks.
- **LEAVES:** Variable in lobing and hairiness.
- **STEMS:** When present, stems are thick with no hairs to thin gray hairs.
- **FLOWERS:** Often in clusters and, if flowering stalk is present, flower heads often directly attached, no side branches.
- **NOTES:** This species represents a complex of eight recognized varieties. These races vary from stemless clusters of flowerheads, to branchless flowering stalks to branched flowering stalks. Unbranched or stemless flowerheads make this species complex distinct from most other native thistles. Reference: Keil 2006.

Figure 2.12: From left to right: cobwebby thistle, California thistle, and Venus thistle.

Cobweb Thistle (*C. occidentale*)

- **RANGE:** California, Oregon and Nevada.
- **HEIGHT:** ~2–5' (in bloom).
- **LEAVES:** Densely hairy, especially on the underside.
- **STEMS:** Densely hairy. Flowerheads: Flowers are purple to red with dense, cobweb hairs.
- **NOTES:** There are seven varieties within this species, including compact cobwebby thistle (*C. o.* var. *compactum*), which forms stemless flower clusters on the ground. California thistle (*C. o.* var. *californicum*) has white- to light purple-colored flowers which differs from all other varieties which have deep purple to bright pink or red flowers. Among the other rich pink- to purple-to red-colored varieties, snowy thistle (*C. o.* var. *candidissimum*), cobwebby thistle (*C. o.* var. *occidentale*), and Coulter's thistle (*C. o.* var. *coulteri*) have fuzzy flowerheads; whereas the pink- to red-flowered Cuesta Rudge thistle (*C. o.* var. *lucianum*) and Venus thistle (*C. o.* var. *venustum*) have less fuzzy flowerheads. Reference: Keil 2006.

Edible Thistle (*C. edule*)

- **RANGE:** Pacific Northwest from Washington to British Columbia and Alaska.
- **HEIGHT:** ~2–6' (in bloom).
- **LEAVES:** Mostly green with sparse hairs on both surfaces mostly along the major leaf vein. Leaf edges are lobed.
- **STEMS:** Hairy to nearly hairless.
- **FLOWERS:** Purple, sometimes pink or white. Dense cobwebby hairs. Slender, soft spines on the flowerheads, not scaly. Clump of flowerheads found at the very top of the plant.
- **SIMILAR SPECIES:** There are multiple varieties of edible thistle (see Appendix A). Varieties occurring in montane and coastal areas display compact clusters of flowerheads at the top of the plant and much hairier flowerheads than those in the interior, lowland regions. Edible

Figure 2.13: Edible thistles have flowerheads covered with thick, cobwebby hairs and sparse hair on the leaves and stem.

Figure 2.14: A distinguishing characteristic of Carolina (or "soft") thistle from other native thistles in the southeast, is its long, spindly stems that have sparse hair, leaves, and spines.

thistle can be confused with clustered thistle (*C. brevistylum*) which also develops tightly compact clusters of hairy flowerheads and is found in the Northwest. Distinguishing these two species can be challenging and is best done by examining the flowers with a hand lens. There are knob-like tips on the ends of the corolla tubes for clustered thistle not found in edible thistle. Also, the style (female structure) usually does not extend beyond the corolla tube in clustered thistle (also known as the short-style thistle) but extends far beyond the corolla tube of edible thistle. References: Keil 2006; Knoke 2006; Knoke 2013; Calflora 2014.

Carolina or Soft Thistle (*C. carolinianum*)

- **RANGE:** Southeast from Texas to Georgia north to Virginia and Illinois.
- **HEIGHT:** ~2–4' (in bloom).
- **LEAVES:** Shallowly lobed with spines at the points. White hairs on leaf underside.
- **STEMS:** Sparse hairs.
- **FLOWERS:** Pink to purple to white. Flowerheads are spiny and scaly with a white stripe along each scale.
- **SIMILAR SPECIES:** Wide floral tubes, diminishingly smaller leaves at increasing plant size, and minutely spiny and spindly stems distinguish this species from other native thistles in the southeast. References: Keil 2006; Tenaglia 2007; Hamilton 2012.

3

The Conservation Value of Native Thistles

Flowering Characteristics and Value to Pollinators

Native thistles provide a unique and attractive resource for insect pollinators. Because many native thistles only flower once before dying, they tend to allocate significant resources toward producing larger flowerheads than many other members of the sunflower family (Fenner et al. 2002). One notable example of large-flowered native thistles is the Hill's thistle (*C. pumilum* var. *hillii*) which can reach nearly 3" in length and 2" in diameter. It has been widely observed that large flowers, including thistle flowers, can encourage greater visitation by bees and flies (Eckhart 1991, Ohara and Higashi 1994, Conner and Rush 1996, Ohashi and Yahara 1998). In addition to the large flower size exhibited by some thistles, many species also produce a high density of flowers to provide a large floral display. For example, in the rare Franciscan thistle (*C. andrewsii*), flowerheads may be nearly 2" in diameter and number 80 or more per plant (Powell et al. 2011). One of the most common, widespread native thistles, tall thistle (*C. altissimum*), can produce 25–45 flowerheads per plant, depending on soil conditions (Andersen & Louda 2008, F. L. Russell, unpublished data). These factors, along with the high density patches typical of many thistle populations, can make for impressive floral displays for pollinators.

Nectar and pollen are key resources for insect visitors to flowers. Floral nectar primarily is composed of water and carbohydrates, as well as some other chemicals, while pollen contains proteins, minerals, vitamins, and carbohydrates. Although the nutritional value and quantity of pollen and nectar produced by thistles is not explicitly known, limited research suggests that these plants provide significant floral rewards to foraging insects. For example, one study found that native thistles (e.g., California thistle [*C. occidentale* var. *californicum*] and Brewer's thistle [*C. douglasii* var. *breweri*], following the updated species descriptions by Keil 2006) have higher concentrations of sugar in their nectar compared to other flowering species (Gut et al. 1977). Additionally, some rare native thistles, such as fountain thistle (*C. fontinale*) and Franciscan thistle (*C. andrewsii*), are highly reliant on insect pollination; without pollinators, less than 10% of seeds develop (Powell et al. 2011). The intimate interdependence of native thistles and pollinators suggests that the floral rewards to pollinators are high. Conversely, self-fertilizing non-native thistles can have low pollen quality and thus may attract fewer visitors (Hanley et al. 2008, Somme et al. 2015).

Importance of Native Thistles to Pollinators

Native thistles in North America are visited and pollinated by a diverse range of insects. We found and compiled records for over 200 species of bees, butterflies and other pollinators visiting native thistles in North America (Appendix B). In Northern California, visitors to thistles include honey bees, bumble bees, solitary bees, beetles, and flies (Powell et al. 2011). In the Midwest, native thistle flowers support

Figure 3.2: From left to right: Delaware skipper (*Anatrytone logan*) and American lady (*Vanessa virginiensis*) on Nuttall's thistle (*C. nuttallii*); and tiger swallowtail (*Papilio glaucus*) on field thistle (*C. discolor*).

Figure 3.3: Thistle long-horned bee (*Melissodes desponsa*) foraging on tall thistle (*C. altissimum*).

Figure 3.4: American bumble bee (*Bombus pensylvanicus*) foraging on field thistle (*C. discolor*).

at least 11 species of bumble bees (including the imperiled rusty patched bumble bee [*Bombus affinis*]), long horned bees, leafcutter bees, sweat bees, syrphid flies, butterflies (including regal fritillaries, monarchs, swallowtails, skippers), hawk moths, soldier beetles, leaf beetles, scarab beetles, and parasitoid wasps (Graenicher 1909, Robertson 1929, Macior 1967). In Illinois alone, 47 species of bees and 18 species of butterflies have been observed feeding on the flowers of six native thistle species (Robertson 1929, Hilty 2015). There is at least one bee that specializes on the pollen of thistles, the thistle long-horned bee (*Melissodes desponsa*); which has a distribution that extends from Maine west to North Dakota and south through North Carolina and Oklahoma. The bee's flight season across its range is June to October, and overlaps with the bloom period of thistles (Mitchell 1962).

Bumble bees are highly attracted to thistle flowers (Lye et al. 2010). For example, in a study conducted in the United Kingdom (U.K.), up to 25% of late season flower visits were made to *Cirsium* or *Carduus* species (Fussell and Corbet 1992). Similarly, in a long-term review of flower visitation records by bumble bees in California, the *Cirsium* genus was found to be the most commonly visited flower group (Thorp et al. 1983). The authors recorded 23 of California's 24 bumble bee species on *Cirsium*, and nearly twice as many individuals as on the next most visited genus (870 individuals on *Cirsium*, 434 on *Chrysothamnus*). Preference for thistles varies among bumble bee species. Given the long and narrow corolla of some thistle florets, long-tongued species of bumble bees have been found to use *Cirsium* more than short tongue bumble bees (Harder 1985). Other thistles have shorter corollas (Inouye 1980), and are accessible to both short and long-tongued bumble

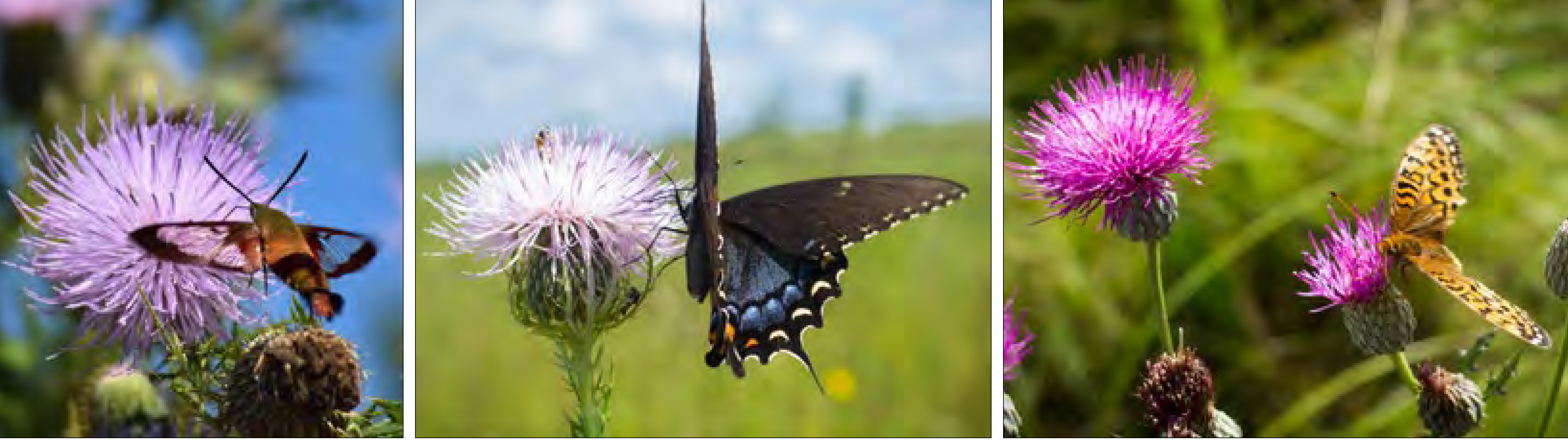

Figure 3.5: From left to right: clearwing hawk moth (*Hemaris* sp.) and tiger swallowtail dark morph (*P. glaucus*) on field thistle (*C. discolor*); and greater fritillary (*Speyeria* sp.) butterfly on swamp thistle (*C. muticum*).

bees. Observations of foraging on *Cirsium* are often not accompanied by flower density data, making it difficult to know if the greater number of visits to flowers reflects a higher abundance of flowers or a specific preference of *Cirsium* by pollinators. However, one of the few studies we know of that recorded floral abundance showed that bull thistle (*C. vulgare*) was one of the six most commonly fed on flowers by bumble bees, despite it being quite sparse (Lye et al. 2010).

Native thistles are one of the most frequently visited flowers by butterflies (Tudor et al. 2004). In a U.K. study of floral visitation by butterflies, 24% of flower visits by 30 different butterfly species were to *Cirsium* flowers (Tudor et al. 2004). Skippers and fritillaries were among the butterfly groups frequently nectaring on thistles. Similar findings have been made in North America. For example, over a nine year observational period of floral use by butterflies in tallgrass prairies in eastern Nebraska, tall thistle was the most visited flower by half of the 10 most common butterfly species (i.e., silver-spotted skipper [*Epargyreus clarus*], monarch [*Danaus plexippus*], painted lady [*Vanessa cardui*], Peck's skipper [*Polites peckius*], and Delaware skipper [*Anatrytone logan*]). Tall thistle composed 75% of flower visitations by species such as Peck's skipper and Delaware skipper. Approximately 51% of flower visits by monarch butterflies were to tall thistle (T. Burk 2016, unpublished data). Tall thistle was less common than several of the other wildflowers present in the Nebraska grasslands (T. Burk 2016, unpublished data) suggesting the high visitation rates on this flower likely reflect a strong preference by monarchs and other butterflies (rather than simply exploitation of a common resource).

The value of a flower to a pollinator can be much more complex than the number of visits to a flowerhead; scientists also consider the nutritional quality of the pollen and nectar, timing of flowering related to the life cycle of the pollinator, and the habitats in which the plant grows and flowers. While governing factors such as these are not yet fully understood for thistles, the exceptionally high use of these flowers by a wide variety of flower visitors clearly demonstrates the important role these plants play in providing highly valuable food resources for pollinators.

Figure 3.6: Clockwise from left: in eastern Nebraska, tall thistle comprised approximately ½ of all floral visits made by monarch butterflies (*Danaus plexippus*) and ¾ of all floral visits by Delaware skippers (*Anatrytone logan*) and Peck's skippers (*Polites peckius*).

In addition to providing floral resources for pollinators, native thistle plants also provide important nesting resources for cavity nesting bees. In a Kansas study examining the nesting biology of the common little leafcutter bee (*M. brevis*), *Cirsium* stalks were found to be the most popular plant for nesting—of the 90 nests that were found in plant stems, over 35%

were in *Cirsium* stalks (Michener 1953). *Cirsium* stalks also supported the greatest number of cells per nest (between 8–11), thus supporting higher numbers of offspring per nest compared to other plants (Michener 1953).

In Appendix B we describe some of the many pollinators, predators, and parasitoids known to be attracted to thistle flowers. This compiled list is not comprehensive and represents a potentially small sample of the pollinators visiting native thistles. See Appendix B for further details on specific plant-animal associations, including plant species, animal species, and citations.

Importance of Native Thistles to Insect Herbivores

A wide diversity of native herbivorous insects feed on the leaves, stems, seeds and flower tissue of native thistles. These include fruit flies (Tephritidae), weevils (Curculionidae), snout moths (Pyralidae), plume moths (Pterophoridae), brush-footed butterflies (Nymphalidae), and true bugs—including stink bugs (Pentatomidae) and treehoppers (Membracidae). Many of these insects are specialists, restricting their diet to *Cirsium* thistles. For example, the tephritid fly *Paracantha culta* oviposits on the flowerhead of tall thistle and the resulting larvae consume the base of the flowerhead before pupating. This fly has also been reported feeding on the highly invasive Canada thistle as well as the invasive bull thistle (Ryckman 1951, Louda and Rand 2003). Snout moths (e.g., *Homeosoma* spp.) and plume moths (e.g., artichoke plume moth [*Platyptilia carduidactyla*]) similarly oviposit on flowerheads, with the larvae feeding on the developing seeds within the flowerheads. Other herbivores, such as owlet moths (e.g., the figwort stem borer moth [*Papaipema sauzalitae*] and northern burdock borer moth [*P. arctivorens*]) bore into and consume the interior of the flowering stems. Many other native insects chew and mine the leaves as well as feed on phloem using piercing mouthparts. These include grasshoppers (e.g., spur-throated grasshoppers [*Melanoplus* spp.]), leaf beetles (e.g., black-headed flea beetle [*Systena hudsonias*]), butterfly larvae (e.g., painted lady [*Vanessa cardui*]), weevils (e.g., crown root weevil [*Baris subsimilis*]), treehoppers (e.g., keeled treehopper [*Entylia carinata*]), leaf-miner flies (e.g., *Metopomyza scutellata*), and others (Takahashi 2006, Hilty 2015a). Spittlebugs (Aphrophoridae) oviposit on the growing tip and deform emerging leaves (Higman and Penskar 1999). Native thistles also support symbiotic relationships between herbivores including ants and treehoppers; in exchange for sugars extracted from the thistle stem by the treehoppers piercing mouthpart, tending ants protect treehoppers from predators. This growing list of plant-insect interactions suggests native thistles support a wide diversity of native specialist and generalist insects. This importance is underscored by a two-year observational study in eastern Nebraska suggesting at least 74 species of insects feed on the native tall thistle (Takahashi 2006).

Figure 3.7: This owlet moth larva (*Papaipema* sp.) was discovered boring through the stem of field thistle (*C. discolor*).

Figure 3.8: The differential grasshopper (*Melanoplus differentialis*) is known to feed on field thistle (*C. discolor*), including the blossoms.

Table 3.1: Known Native Insect Herbivores of Native Thistle Species

Type	Family	Herbivore Species & Associated Thistle Species
FLOWERHEAD FEEDERS	Pterophoridae	Artichoke plume moth (*Platyptilia carduidactyla*)—*Cirsium altissimum*[5], *C. discolor*[8], *C. pitcheri*[14]
	Pyralidae	Snout moths (*Homoeosoma* spp.)—*C. discolor*[9]
		H. ammonastes—*C. repandum*[1]
		H. ardaloniphas—*C. canescens*[1,14], *C. undulatum*[14]
		Sunflower moth (*H. electella*)—*C. horridulum*[1]*, *C. repandum*[1]
		H. eremophasma—*C. altissimum*[5], *C. canescens*[1]
		H. impressale—*C. canescens*[14], *C. occidentale* var. *candidissimum*[1], *C. pitcheri*[14], *C. undulatum*[14]
		H. pedionnastes—*C. horridulum*[1]*
		H. stypticellum—*C. canescens*[1], *C. texanum*[1]
		Phycitodes mucidella—*C. andersonii*[12], *C. brevistylum*[12], *C. cymosum*[12]*, *C. horridulum*[1]*, *C. occidentale*[12]*, *C. o.* var. *candidissimum*[12], *C. o.* var. *venustum*[12]
		Pyrausta insequalis—*C. canescens*[14], *C. undulatum*[14]
	Tephritidae	Peacock fly (*Paracantha culta*)—*C. altissimum*[5], *C. canescens*[14], *C. horridulum*[11]*, *C. nuttallii*[11], *C. undulatum*[14]
		P. gentilis—*C. cymosum*[10]*, *C. o.* var. *californicum*[10], *C. o.* var. *venustum*[10], *C. scariosum* var. *congdonii*[10]
		Terellia occidentalis—*C. andersonii*[13], *C. canescens*[14], *C. undulatum*[14]
		T. palposa—*C. horridulum*[13]*, *C. pumilum*[13]*, *C. texanum*[13], *C. undulatum*[13]
	Tortricidae	Leafroller moth (*Lobesia carduana*)⁑—*C. altissimum*[5]
LEAF FEEDERS	Acrididae	Short-horned grasshoppers (*Melanoplus* spp.)—*C. altissimum*[5], *C. undulatum*[8]
	Chrysomelidae	Lema leaf beetle (*Oulema palustris*)—*C. altissimum*[8], *C. discolor*[8]
		Black-headed flea beetle (*Systena hudsonia*)—*C. altissimum*[5]
	Nymphalidae	Mylitta crescent butterfly (*Phyciodes mylitta*)—*C. douglasii*[1]*, *C. hydrophilum*[1], *C. occidentale*[1]*
		Painted lady butterfly (*Vanessa cardui*)—*C. altissimum*[2,5], *C. discolor*[1,8], *C. douglasii*[3]*, *C. hydrophilum*[1]*, *C. muticum*[4], *C. neomexicanum*[1], *C. occidentale*[1]*, *C. texanum*[1]
	Pyralidae	Celery/greenhouse leaftier moth (*Udea rubigalis*)—*C. horridulum*[1]*
	Riodinidae	Swamp metalmark butterfly (*Calephelis muticum*)—*C. altissimum*[1,8], *C. muticum*[1,8]
		Little metalmark butterfly (*C. virginiensis*)—*C. horridulum*[1]*
LEAF MINER	Agromyzidae	Leaf-miner fly (*Metopomyza scutellata*)—*C. horridulum*[8]*
PHLOEM-SAP FEEDERS	Membracidae	Keeled treehopper (*Entylia carinata*)—*C. altissimum*[5], *C. discolor*[9]
		Buffalo treehopper (*Stictocephala bisonia*)—*C. altissimum*[5]
	Pentatomidae	One-spotted stink bug (*Euschistus variolarius*)—*C. altissimum*[5]
STEM BORERS	Choreutidae	Metalmark moth (*Tebenna carduiella*)—*C. horridulum*[1]*
	Curculionidae	"True" weevil (*Baris subsimilis*)—*C. altissimum*[5†], *C. canescens*[14‡], *C. pitcheri*[14‡], *C. undulatum*[14‡]
	Agromyzidae	Green leaf-miner fly (*Melanagromyza virens*)—*C. discolor*[8]
	Noctuidae	*Papaipema* spp.—*C. discolor*[7]
		Figwort stem borer moth (*Papaipema sauzalitae*)—*C. occidentale*[1]*
UNSPECIFIED	Pyralidae	Julia's dicymolomia moth (*Dicymolomia julianalis*)¤—*C. lecontei*[1]

Notes

- * Variety not specified
- ⁑ Also documented to feed on the *top* leaves[1]
- † Also documented to feed on the leaves of *C. altissimum*[5]
- ‡ Also documented to feed on the roots of *C. canescens*, *C. pitcheri*, and *C. undulatum*[16]
- ¤ *D. julianalis* has been documented to feed externally on *C. lecontei*[1]

Sources:

1. Robinson et al. 2010
2. Baker 2017a
3. Baker 2017b
4. Baker 2017c
5. Takahashi 2006
6. Louda and Rand 2003
7. Eric Lee-Mäder, *pers. obs.*
8. Hilty 2015
9. Sarah Foltz Jordan & Jim Sogaard, *pers. observation*
10. Headrick and Goeden 1990
11. Benjamin 1934
12. Frick and Hawkes 1970
13. Norrbom 2004-2010
14. Gassmann and Louda 2001

Figure 3.9: In addition to supporting pollinators and other wildlife, thistles provide another important resource for songbirds—nesting materials. Many species use thistle down in their nests, from left to right: an American goldfinch (*Spinus tristis*) on field thistle (*C. discolor*), a completed American goldfinch nest constructed with thistle down, and blue-grey gnatcatcher (*Polioptila caerulea*) nest lined with thistle down.

Importance of Native Thistles to Songbirds and Other Wildlife

Native thistles also provide food for songbirds and small mammals. Native thistles are an important food source for European goldfinches (*Carduelis carduelis*) (Holland et al. 2006) and have been found to provide 50% of the diet of these birds late in the season in some regions (Gluck 1985). Goldfinches can forage on thistle seeds (e.g., cabbage thistle [*C. oleraceum*] and bull thistle) more efficiently than most other flowering species. Moreover, the seeds of many thistles are highly nutritious, making these plants critical during the breeding season for song birds. For example, given its higher nutrient content and forage efficiency, bull thistle may be a critical plant during the breeding season of goldfinches (Gluck 1985), allowing more time and energy to be spent rearing young. Seed of the cabbage thistle is high in water content and is preferred during molting when finches require more water in their diet.

A wide diversity of birds feed on native thistle seeds in North America including American goldfinch (*Spinus tristis*), clay-colored sparrow (*Spizella pallida*), pine siskin (*Spinus pinus*), slate-colored junco (*Junco hyemalis*), sparrows (family Passeridae), and indigo bunting (*Passerina cyanea*) (Higman and Penskar 1999, Hilty 2015b). Native thistle seed make up a major part of the diet of American goldfinches and the fluffy thistle down is used to line the nests (Stokes 1950, Hilty 2015b). Even threatened thistles such as the Pitcher's thistle (*C. pitcheri*) have seeds upon which American goldfinches, thirteen-lined ground squirrels (*Ictidomys tridecemlineatus*) and sparrows feed voraciously (Loveless 1980, Higman and Penskar 1999). Notably, up to 50% of pitcher's thistle seeds can be fed on by American goldfinches (Loveless 1980).

Hummingbirds are also known to frequently visit native thistles and may prefer native thistles for the high sugar content of their nectar. In the Midwest, ruby-throated hummingbirds (*Archilochus colubris*) commonly visit native field thistle for nectar. In a California study of floral visitation and nectar characteristics of Great Basin plants, two native thistles (California thistle and Brewer's thistle) were found to be the most highly visited flowers by hummingbirds and hawk moths—a finding that was explained by the very high sugar content in the nectar of these plants (59% and 54%, respectively), as compared with the 31% average sugar content (ranging 10–63%) exhibited by the other species examined (Gut et al. 1977).

Fossorial mammals, such as plains pocket gopher (*Geomys bursarius*), have been found to eat the roots of the Platte thistle (*C. canescens*), and can cause significant mortality during the rosette stage (Lamp and McCarty 1981) and other thistles including field thistle are likely fed on by pocket gophers (J. Eckberg & S. Foltz Jordan, per observation). Similarly, in California, brush rabbits (*Sylvilagus*

Figure 3.10: Many species of hummingbirds are known to prefer the nectar from native thistles, below (from left to right) a rufous hummingbird (*Selasphorus rufus*) and broad-tailed hummingbird (*S. platycercus*) share a wavyleaf thistle, an Anna's hummingbird (*Calypte anna*) visiting a California thistle, and an Anna's hummingbird feeding on a Venus thistle.

bachmani), Botta's pocket gopher (*Thomomys bottae*), and broad-footed moles (*Scapanus latimanus*) feed on cobweb thistle (Palmisano and Fox 1997).

Native Thistles Role in Suppressing Invasive Thistles

Many of the native herbivorous insects described above can spill over to non-native thistles and suppress thistle invasions by feeding on leaves, stems, flowers, or seeds to the point of significantly damaging the plant and reducing or preventing reproduction. As discussed for native thistles, herbivory by native insects on invasive thistles can have several different impacts on the plant. Native insect herbivores of *Cirsium* may lay eggs on the flowerheads and the resulting larvae feed on the pre-dispersed seeds and flower capitulum (e.g., snout moths, fruit flies, and plume moths), bore into the flowering stems (e.g., owlet moths), or feed on the leaves and rosettes (e.g., grasshoppers, butterfly larvae, leaf beetles, and weevils).

The damage to invasive thistle populations is greatest when there is a significant community of insect herbivores that are phenologically synchronized with the non-native thistle. One of the most studied examples of this is the native tall thistle and non-native bull thistle in the western tallgrass prairie region (Louda and Rand 2003). Both species of thistles flower late in the season, August through September. By some estimates, these thistles share over 80% of their herbivore community (Takahashi 2006). The impacts of herbivory to invasive bull thistle are significant. One experiment suggests that herbivory is strongly limiting bull thistle population growth, and without herbivory some bull thistle populations could increase an estimated 88% annually (Eckberg et al. 2014).

Figure 3.11: Conservation of certain native thistle species like tall thistle (*C. altissimum*), left, may help contribute to controlling non-native species, such as bull thistle (*C. vulgare*), right. Tall thistle supports a reservoir of native insect herbivores that spillover onto bull thistle and cause severe feeding damage which can limit invasion by the non-native thistle.

Pitcher's thistle (*C. pitcheri*) is a federally threatened species found along sand dune beaches on the upper Great Lakes.

4

Native Thistle Decline & Conservation

In recent years, there have been an increasing number of documented declines in native thistle populations and several species are now threatened with extinction. Many of these vulnerable species have limited geographic distributions, and populations that are threatened by invasive plants and insects, as well as habitat loss. Even more concerning is the likelihood that once widely distributed and more common native thistles are in decline as a result of human activity. Understanding the population dynamics and human impacts that are significantly affecting native thistles is critical to reversing declines and safeguarding against local extirpations, and even, for some species, extinction.

Rare and At-Risk Species

Globally, 10 *Cirsium* species are listed as near threatened to critically endangered by the International Union of the Conservation of Nature (IUCN 2017), and in the United States, five thistles are now on the Endangered Species List (see table). Of the approximately 20 recognized species in California by the Biota of North America Program (Kartesz 2015), nine species are considered rare and one species, called the “lost thistle" (*C. praeteriens*), is believed to be extinct (Keil 2006, CNPS 2010). Among the most critical risk factors influencing thistle decline is the endemic nature of many thistles (i.e., restricted to a specific region, or ecosystem within a given region). Approximately ⅙ of native species have only been documented in a single state or province (Keil 2006). Many of the species found in multiple states occur only in highly specific habitats (e.g., sand dunes around the Great Lakes). By one estimate 60% of thistle species occur only sparsely throughout much of their range (Kartesz 2015).

Table 4.1: Threatened and Endangered Thistles in North America

Species	Common Name	Range	ESA Status*
C. fontinale* var. *fontinale	Fountain thistle	CA	Endangered
C. fontinale* var. *obispoense	Chorro creek bog thistle	CA	Endangered
C. hydrophilum* var. *hydrophilum	Suisun thistle	CA	Endangered
***C. scariosum* var. *citrinum*⁑**	La Graciosa thistle	CA, Mexico	Endangered
C. pitcheri	Pitcher's thistle	IN, IL, MI, WI	Threatened
C. vinaceum	Sacramento mountains thistle	NM	Threatened
C. wrightii	Wright’s marsh thistle	AZ, NM, TX, Mexico	Under consideration

Notes

* * Endangered Species Act legal status, for more information visit https://ecos.fws.gov/ecp/
* ⁑ La Graciosa thistle was originally listed under the scientific name *C. loncholepis* (ITIS 2010), a synonym that is no longer considered valid due to recent taxonomic changes.

Impact of Non-Native Invasive Plants on Native Thistles

The introduction of invasive plant species is one of the primary threats to native plants, including native thistles. The federally threatened Pitcher's thistle is a striking example of a highly sensitive and naturally uncommon plant threatened by invasive weeds. Pitcher's thistle populations are limited to the open sand dunes and beaches of Lake Michigan, Superior and Huron, where it occurs in early and mid-successional habitat. Since reproduction in this species is only by seed, seedling establishment is critical to Pitcher's thistle (Jolls et al. 2015). The species depends on disturbance of vegetation to create openings where seeds can germinate and grow. During the natural succession of dunes, several factors limit the success and persistence of this species: native vegetation takes root in the dunes, excluding the thistle, and litter accumulation reduces establishment of thistle seedlings. The narrow specialization on early successional dunes makes Pitcher's thistle especially susceptible to invasion of its habitat by several non-native species (e.g., baby's breath [*Gypsophila paniculata*], spotted knapweed [*Centaurea stoebe* ssp. *micranthos*], and oriental bittersweet [*Celastrus orbiculatus*]), all of which further limit open areas for seeds to germinate, grow and flower (Rand et al. 2015). Population models suggest this species could go extinct in the next 17 years (Jolls et al. 2015). In response, a series of new conservation measures are being proposed to save this rare plant, including increased removal of invasive plants, the creation of new dune soil disturbances, and re-introduction of the plant to areas where it has been lost (Jolls et al. 2015).

Impact of Non-Native Invasive Insects on Imperiled Thistles

Figure 4.1: Threatened Pitcher's thistle (*C. pitcheri*) with a northern amber bumble bee (*Bombus borealis*).

In an effort to control invasive thistles, scientists have deliberately released several non-native herbivorous insects as biological control agents. These efforts date back to the early 1960's, when Canadian entomologists began surveying the plant feeding insects of thistles in Western Europe to select appropriate insects for release in North America (Zwölfer 1965). Although extensive screening is usually performed to ensure biological control agents do not feed on related native plants, this process is still fraught with risk. In the case of thistle biocontrol agents, the initial feeding trials were only done in the lab, with virtually no field trials conducted. Perhaps more concerning, many biological control agents for thistles have been released into the wild despite evidence that their diet includes native thistle hosts (Arnett and Louda 2002, Louda et al. 2003). In fact, from the beginning, there was significant evidence that many of the candidate herbivores fed widely among several species of thistles (Cripps et al. 2011b). The presumption was that because biocontrol agents did not *prefer* native thistles over the non-native thistles, they would have negligible effects on the native species (Arnett and Louda 2002). Instead, non-native biocontrol insects have been found to feed extensively on native thistles in natural areas, and are having serious consequences. In particular, many of the biological control agents reduce seed production, which is particularly devastating as many of the impacted native thistles reproduce exclusively by seed (in contrast to the invasive Canada thistle which can also spread vegetatively by rhizomes).

Introduced biological control agents, such as the thistle head weevil (*Rhinocyllus conicus*), Canada thistle bud weevil (*Larinus planus*), and thistle crown weevil (*Trichosirocalus horridus*), have been widely documented feeding on native thistles (Louda et al. 1997, Louda and O'Brien 2002, Takahashi et al. 2009). For example, the thistle head weevil was released and redistributed widely in North America to control the non-native musk thistle (*Carduus nutans*) but unfortunately this insect quickly spread to several native thistles including Rocky Mountain fringed thistle (*C. clavatum* var. *americanum*), wavyleaf thistle (*C. undulatum*), northern mountain thistle (*C. eatonii* var. *murdockii*), Hill's thistle (*C. pumilum* var. *hillii*), shale thistle (*C. pulchellum*), and Platte thistle (*C. canescens*) (Louda et al. 1997, Sauer and Bradley 2008). The most negatively impacted native thistles are those that co-occur with, and flower at the same times as musk thistle. Moreover, the closer native thistles are in proximity to their invasive counterparts, the more weevil eggs are observed in flowerheads of the native species (Russell et al. 2007). The flowerhead weevil has gradually expanded onto native thistles outside the range of musk thistle. Most notably, these weevils have invaded the Sandhills prairie of the Great Plains, where musk thistle is absent but the native Platte thistle is readily consumed. Damage by the flowerhead weevil reduces viable seeds by over 80% in Platte thistle, another species that relies exclusively on regeneration from seed (Louda and Potvin 1995, Louda et al. 1997). Unlike the native insects that feed on and co-exist with Platte thistle, the invasive weevil has been driving the decline of the Platte thistle (Rose et al. 2005). In recent years, the weevil has spread to as many as 23 new native hosts, including other sensitive and rare thistles such as Hill's thistle (Pemberton 2000, Sauer and Bradley 2008, Havens et al. 2012), and has established on musk thistle near the federally threatened Pitcher's thistle (Havens et al. 2012). If it were to spill over to the Pitcher's thistle, it would likely drive the species to extinction (Louda et al. 2005).

FIGURE 4.2: Platte thistle (*C. canescens*) blooming in the Upper Arkansas River Valley, Colorado.

FIGURE 4.3: Hill's thistle (*C. pumilum* var. *hillii*).

Figure 4.4: Canada thistle bud weevil (*L. planus*) damage to wavyleaf thistle (*C. undulatum*) population in southern Oregon.

Figure 4.5: Extensive damage to peregrine thistle (*C. cymosum* var. *cymosum*) caused by a thistle head weevil (*R. conicus*) infestation.

The impacts of biological control agents are not limited to those imposed by the flowerhead weevil and musk thistle. A number of other non-native insects from biological control programs have become invasive on native thistles. For example, the Canada thistle bud weevil was intentionally mass produced and released across the U.S. after biological control advocates discovered that it had already been accidentally introduced into the northeast U.S. (Louda and O'Brien 2002). Unfortunately this species, which was intended to suppress Canada thistle, has spread to the native Tracy's thistle (*C. tracyi*), reducing seed production by over 51% (Louda and O'Brien 2002). Even worse, the weevil has spread to some populations of the Pitcher's thistle and is now expected to hasten the plant's extinction (Havens et al. 2012). Biological control agents are also attacking more common native thistles. For example, the thistle crown weevil, released to control musk thistle, feeds on native tall thistle (*C. altissimum*), field thistle (*C. discolor*), Carolina thistle (*C. carolinianum*), yellow thistle (*C. horridulum*), and swamp thistle (*C. muticum*) (Takahashi et al. 2009, Wiggins et al. 2009).

Conservation of Widespread Native Thistles

Even the most common and widely distributed native thistles often remain at low density in the habitats where they occur. For example, ecologists at the Konza Prairie Biological Station, an 8600+ ac. remnant tallgrass prairie in the Flint Hills of Kansas managed by Kansas State University, have observed low abundance of wavyleaf thistle and tall thistle over the past 30+ years (1983–2015). Percent cover of these plants has on average been less than 0.04% for wavyleaf thistle and 0.24% for tall thistle (Konza Prairie Long-term Ecological Research data, see http://lter.konza.ksu.edu/).

Several natural and human-caused factors limit even widely distributed thistles. Native insect herbivores are widespread across many of the environments where native thistles occur. As discussed previously, insect herbivores feed on the pre-dispersed seeds and flower capitulum, flowering stems, and leaves and rosettes of thistles (see Thistle Importance to Insect Herbivores above). Numerous native herbivore insects are common in the tallgrass prairie where they feed on native tall thistle (Louda and Rand 2003, Takahashi 2006). Across much of the tallgrass prairie landscape, herbivory is severe enough to cause decline of tall thistle reducing their their population size by as much 77% (Russell et al. 2010, Rose et al. 2011), and invasive biocontrol agents may be adding to the pressure from native insects. While the geographic extent and impacts of alien biocontrol insects on native thistles is not fully understood, it is likely that these interactions not only threaten thistles directly, but also cause thistle populations to be more susceptible to other human pressures including habitat loss and invasive plants.

Human land management may be limiting native thistle populations even within ecosystems where these plants may have historically thrived. Many widespread native thistles are early successional disturbance-adapted species. Disturbance creates open spaces where native thistle seedlings germinate and grow more readily than in dense grass cover (Suwa and Louda 2012, Tenhumberg et al. 2015). Fire creates open habitats for native thistles in grassland and woodlands by preventing invasion and overgrowth of shrubs and trees. In addition, fire may increase the number of new native thistle plants by reducing leaf litter (F. L. Russell 2016, unpublished data). In our modern landscape, ecosystems are generally not managed with adequate levels of disturbance. Fire has been suppressed across ecosystems for decades and has only recently been reintegrated into prairie and forest management regimes.

Grazing is another form of disturbance likely important for creating low competition environments where thistles may thrive. Thistles are often avoided by grazers. At the same time, grazers tend to disturb the plant community, creating small areas (microsites) with low competition and litter from other plants as well as enhanced nutrient availability (i.e., urine and dung). In the United States, grazing systems and the grazers themselves have largely changed over the last century; for example, in the Great Plains, millions of freely grazing bison were replaced by cattle with various grazing regimes. While cattle grazing can have similar outcomes for the prairie community as bison (Towne et al. 2005), both grazers have become potentially less common in some regions of North America (e.g., tallgrass prairie ecosystems of the upper Midwest). The potential effect on native thistle populations of removing or altering grazing regimes remains unclear but potentially significant. Research shows that reduced competition from other plants, typical in a periodically grazed landscape, often enhances thistle seedling recruitment, flowering, and population growth for both native and non-native thistles (Suwa and Louda 2012, Tenhumberg et al. 2015). At Konza, ecologists have observed six times greater percent cover of wavyleaf thistle with bison grazing in upland prairie (0.20% wavy leaf percent cover with bison, 0.03% cover without bison). Similarly, heavy cattle grazing of shortgrass steppe led to more wavyleaf biomass in the plant community, from 0.003% to 0.22% (Hart 2001). In the U.K., where bull thistle (*C. vulgare*) is native, sheep grazing enhanced thistle seedling emergence and survival (Bullock et al. 1994). That said,

Figure 4.6: While some native thistle species, like wavyleaf thistle (*C. undulatum*, left) and tall thistle (*C. altissimum*, right), might be classified as "common" species due to their wide geographical distribution, they can often be found in low densities that leave local and regional populations vulnerable to environmental changes.

it is important to note that grazing may not benefit all native thistle species in all grasslands and the abundance of native thistles may remain low even with grazing. For example, tall thistle is less spiny than other thistles and was less abundant on the grazed treatment at Konza Prairie Biological Station, probably due to feeding by bison because tall thistle is one of the first green plants to emerge in the spring, and bison are stocked year-round (Jeff Taylor 2016, personal communication).

Figure 4.7: There are pervasive concerns over invasive thistles that have contributed to native thistles being targeted for eradication.

Another factor threatening native thistles is their similar appearance to invasive thistles. Native thistles are often confused with their invasive relatives and frequently targeted for eradication. The misperceived threat of native thistles among some land managers and policy makers is understandable given the history of invasive thistles in North America. Yet, the evidence we described above overwhelmingly suggests many species of native thistles are in decline. To our knowledge, no native thistle species show potential to become invasive yet some species of native thistles (e.g., yellowspine thistle [*C. ochrocentrum* var. *ochrocentrum*]) have been introduced outside of their native range (Keil 2006). The extent of the control measures and impacts from land managers on native thistles is unclear. Native thistles are frequently mowed prior to seed set on roadsides (S. Foltz Jordan and J. Eckberg 2016, personal observation), and likely routinely sprayed during application of herbicides targeting invasive thistles and other weeds. The State of Iowa has even listed all native thistles as noxious weeds. This mandates the control of up to six native thistles species that have been recorded in Iowa (tall thistle, field thistle, swamp thistle, wavyleaf thistle, Hill's thistle, and Flodman's thistle [*C. flodmani*]), some of which are fairly rare. Even conscientious land managers are required under state law to eradicate native thistles from their property—including restored habitats. This law also prevents native seed growers from cultivating native thistle production plots.

5

Invasive Thistles

In the United States it is estimated that invasive animals and plants cause almost $120 billion in economic losses annually. Non-native thistles are among the worst invasive species in North America, where we now have approximately six non-native thistles in the genus *Carduus*, and five non-native thistles in the genus *Cirsium*. Other invasive "thistles" include the Russian thistle (*Kali tragus*), which is not related to true thistles but members of the Amaranth family. Invasive species typically have very high rates of reproduction and dispersal, and often generate copious amounts of seed that can easily spread into natural habitats, roadsides, and crop fields. Indeed, several non-native thistles have become highly invasive including Canada thistle (*C. arvense*), musk thistle (*Carduus nutans*), bull thistle (*C. vulgare*), marsh thistle (*C. palustre*), and plumeless thistle (*Ca. acanthoides*). Canada thistle is perhaps the most significant of the invasive thistles in terms of impacted area, rate of spread, required control efforts and notorious reputation in the agricultural and conservation communities. Musk thistle is a significant pest in rangelands, pastures, grasslands, roadsides, and meadows across much of the United States. Musk thistle is unpalatable to livestock and tends to increase with overgrazing, invading degraded rangeland and suppressing the recovery of grasses. In this section, we describe the history, impacts and management strategies for Canada thistle because it is perhaps the most persistent and difficult to control among the invasive thistles. We also describe the management of invasive biennial or short-lived thistles (musk, bull, marsh, and plumeless thistle) at the end of this section.

FIGURE 5.1: Canada thistle (*C. arvense*) invading a Minnesota native wildflower planting.

Canada Thistle Invasion: History and Impacts

Despite its name, Canada thistle originated in Europe and western Asia. The name "Canada thistle" came from the belief that the French intentionally introduced the plant into Canada to feed swine (Hodgson 1968). However, the plant was accidentally introduced, likely in the 17th century, to Ontario and Quebec as a contaminant of crop seeds (Guggisberg et al. 2012). English and Dutch settlers may have introduced Canada thistle into the United States; it was first recognized in New England in 1795 (Hansen 1918). Canada thistle then spread rapidly to the south and west as a contaminant in hay and small grains. Agronomists in the U.S. were quick to recognize the invasive nature of Canada thistle; by 1896, 21 of 25 U.S. states with weed laws listed Canada thistle as a noxious weed (Guggisberg et al. 2012). In contrast to many thistles which reproduce only by seed, Canada thistle spreads both by seed and roots; single populations or individual plants can rapidly invade a site. Estimates of population spread vary, but all suggest a rapid growth relative to other thistles and invasive plants. Roots can expand by 6–10' annually, and a single plant can be expected to spread across a half acre in three years (Gover et al. 2007). Canada thistle is also recognized as allelopathic, exuding toxic chemicals that suppress other plants (Stachon and Zimdahl 1980, Wilson 1981). Competition from other plants, natural barriers and control measures can all influence the rate of spread across the landscape. There are significant acreages nationwide infested with Canada thistle. For example, in Colorado, a 2002 survey showed over 100,000 acres infested with Canada thistle (Beck 2013) and an estimated two million acres in South Dakota are infested (Neff 1996). Today, Canada thistle appears on more noxious weed lists than any other plant in North America, including Alaska, Arizona, Kansas, Minnesota, North Carolina, and Pennsylvania.

The economic and environmental impacts of Canada thistle are significant, especially for organic and non-GMO crops where glyphosate is not routinely applied. Canada thistle readily invades row crops and small grains including wheat, corn, peas, beans, sugarbeets, potatoes and more (Moore 1975), as well as diversified vegetable operations. Perennial fruit crops and pasture are also impacted. Heavy infestations can cause losses of alfalfa seed (70% less), spring wheat (90% less) and grass forage (30% less) (Moyer et al. 1991, Donald and Khan 1992, Grekul and Bork 2004).

Figure 5.2: Canada thistle (*C. arvense*) features, clockwise from left: mature plants, flowerheads, and leaves.

Figure 5.3: An infestation of Canada thistle in this Connecticut natural area has pushed out many native plants.

Managing Canada Thistle Invasion

Canada thistle is one of the most studied invasive plants in the world, and is the target of extensive biological control and weed management programs. A growing body of research continues to focus on Canada thistle, resulting in approximately 3000 publications on the management of this weed (Cripps et al. 2011b). Several strategies have been employed to manage Canada thistle including herbicides, mechanical destruction, biological control agents, selection of competitive native plants, and pathogens. The following sections summarize the management strategies for Canada thistle.

Chemical Control

Herbicides are one of the most common approaches to controlling Canada thistle. Herbicides such as glyphosate or aminopyralid effectively suppress Canada thistle (Gramig and Ganguli 2015). Yet in many cases, herbicides alone are not a viable long-term control strategy, and are more effective when used in combination with other control measures including biological control and pathogens (Sciegienka et al. 2011). Herbicides can also negatively impact the diversity of surrounding plant communities especially when used improperly.

Figure 5.4: Exotic Plant Management Team spot-spraying Canada thistle and other invasive plants at Theodore Roosevelt National Park in North Dakota.

Biological Control

There has been a significant effort to establish biological control agents for Canada thistle within their introduced range. The premise of biological control programs is that invasive plants have escaped predation and population regulation from their native predators allowing them to explosively grow and spread in the introduced range. In the case of Canada thistle, biological control programs have imported and released specialist seed and foliage feeding beetles (e.g., the thistle head weevil [*Rhinocyllus conicus*], Canada thistle bud weevil [*Larinus planus*]) to help regulate this plant in North America. Despite significant resources dedicated to strategically releasing and redistributing these non-native herbivores, the insects have failed to control Canada thistle (Cripps et al. 2011b). A cross-continental study comparing the growth, performance and herbivores of Canada thistle in New Zealand (where it is an introduced weed) with native populations in Europe suggested that environmental conditions, not herbivorous insects were probably

Figure 5.5: Efforts to release non-native species like Canada thistle bud weevils (*L. planus*, left) and thistle head weevils (*R. conicus*, right, shown: larvae inside a flowerhead) as biological control agents have been unsuccessful at limiting the spread of Canada thistle in North America.

more significant in contributing to the New Zealand invasion (Cripps et al. 2010). Despite this finding, follow-up research showed that insect herbivory exerts somewhat greater control over Canada thistle populations in the native (Europe) versus introduced (New Zealand) range, suggesting the introduction of specialized herbivores has some potential to limit Canada thistle invasion (Cripps et al. 2011a). In North America, however, biological control agents have proven ineffective at controlling Canada thistle, and in many cases these insects have become invasive species themselves, feeding on and reducing populations of native thistles (Louda et al. 1997, Louda and O'Brien 2002). Canada thistle biocontrol in North America has been one of the least successful, most criticized examples of a biological control program.

Competitive Perennials, Smother Crops, and Diverse Plant Mixtures

Vigorous competitive plants can be used to outcompete and suppress Canada thistle in both agricultural systems and semi-natural and natural areas. Species that can quickly establish in grasslands such as native cool season grasses (e.g., Canada wildrye [*Elymus canadensis*]) may suppress Canada thistle. In a restored prairie, early establishment of highly vigorous plants such as wild bergamot (*Monarda fistulosa*), purple prairie clover (*Dalea purpurea*), golden alexander (*Zizia aurea*), Canada wildrye and slender wheatgrass (*Elymus trachycaulus*) may more significantly suppress Canada thistle than more diverse prairie or prairies with a greater amount of plants functionally similar to Canada thistle (e.g., asters) (Larson et al. 2013). Short-lived species like Canada wildrye may not provide long-term suppression of Canada thistle (Larson et al. 2013). Including other native cool season grasses such as fescues (*Festuca* spp.) or junegrass (*Koeleria macrantha*) in restorations may bolster resistance to Canada thistle invasion.

Within fallow crop fields, smother cropping is a strategy employed by some organic growers. For example, sudangrass (S*orghum bicolor*) is a fast growing, vigorous grass used in smother cropping. In a greenhouse study, sudangrass grass reduced Canada thistle shoot mass by 93% (Bicksler et al. 2012). In field studies Canada thistle biomass was suppressed by 50–87% by a sorghum-sudangrass mixture and by 58–67% by a mixture of oats. The suppressive effect of sorghum-sudangrass was partly due to the soybean and sunflower crops that followed the smother crops (Wedryk and Cardina 2012).

Figure 5.6: Using highly vigorous native plants like wild bergamot in prairie restoration projects may help suppress Canada thistle.

Pathogens

The use of plant pathogens to control Canada thistle has been intensely debated. Some investigators have suggested that pathogens are not appropriate or effective for controlling non-native thistles (Müller and Nentwig 2011), while others have suggested that high concentrations of applied pathogens could effectively suppress Canada thistle in the short term (Cripps et al. 2012). For successful use of pathogens on Canada thistle, it is important to understand the life cycle of the fungi and conditions under which infection was greatest. For example, the fungi *Puccinia punctiformis* has been found to reliably infect and control Canada thistle when applied to newly forming rosettes in the fall (Berner et al. 2013).

Figure 5.7: The host-specific rust *Puccinia punctiformis* has been identified as a promising biological control agent for Canada thistle.

Managing Invasion of Biennial Thistles

The plumeless thistle, musk thistle, and bull thistle are all highly invasive species that can be problematic in agricultural landscapes and disturbed areas (e.g., overgrazed pasture), and are listed as "noxious" in several states. Note that biennial species are not as difficult to control as the invasive perennial thistle species, since biennial thistles spread only by seed, while perennial thistles spread by long-lived rhizomes in addition to seeds. Still, biennial thistles spread very rapidly and can become severe problems in both cropland and natural areas. Invasive thistle seeds are generally produced in great number, averaging around 8,400 seeds per plant for the plumeless thistle (Lym 2013).

Figure 5.8: Musk thistle (*Carduus nutans*) features, clockwise from top left: flowerheads, mature plant, and leaves.

Figure 5.9: Field infested with plumeless thistle (*Carduus acanthoides*) in Minnesota. This invasive species is quick to spread by seed.

Mechanical Control

For effective control of biennial thistles, the focus should be on eliminating seed production. This can be done effectively using a mower, or spade. Close mowing or cutting of second-year plants twice per growing season just before flowering will usually prevent seed production (Czarapata 2005). This can be achieved by cutting thistles at the early bud stage and again when resprouts reach the early bud stage. If plants are cut above the terminal bud before the stems elongate, they likely will regrow (Lym 2013). Mowing before the flowers start showing color is important because plants that have developed flowers will produce some viable seed. Mowing after flowering is not recommended, as it may spread viable seeds. Mower blades should be set as close to the surface as possible (Lym 2013).

In cultivated land, tillage can be an effective method of controlling biennial thistles. According to Lym (2013), tillage followed by planting annual crops can eliminate biennial thistles (such as the plumeless thistle), and reduce/control perennial thistles. Cover crops that also provide good forage for pollinators include clover (*Trifolium* spp.), cowpea (*Vigna unguiculata*), hairy vetch (*Vicia villosa*), oilseed radish (*Raphanus sativus*), lacy phacelia (*Phacelia tanacetifolia*), various mustards (*Brassica* spp.), and buckwheat (*Fagopyrum esculentum*). Cover-crops should be mown following bloom (avoid tillage, since tilling will promote germination of thistle seed remaining in the soil). Assuming thistle numbers are sufficiently reduced, the area should be reseeded with desired species (e.g., native perennial mix) in the fall. Immediate re-seeding with desired plants is necessary to out-compete any thistles that continue germinating from the seed bank.

6

Native Thistle Propagation & Seed Production

Over the past decade, there have been small successive steps to increase the production and availability of native thistle seed for habitat restoration projects. In the Pacific Northwest, a few seed production efforts by federal agencies have focused on edible thistle (*C. edule*), a plant with significant wildlife value and cultural history as a former staple food among Native Americans. In the Midwest, author E. Lee-Mäder consulted for the Agrecol Corporation on seed production of field thistle (*C. discolor*) as early as 2005, with that seed being marketed primarily to private landowners, prairie restoration practitioners, and local agencies.

More recently, responding to a growing awareness of the value of native thistles, the Xerces Society launched a four-year project in partnership with native seed producers in Minnesota and Indiana to establish production plots of field thistle (*C. discolor*), tall thistle (*C. altissimum*), Hill's thistle (*C. pumilum* var. *hillii*), Flodman's thistle (*C. flodmanii*), and swamp thistle (*C. muticum*). Through this partnership, we collected seed from wild populations, and conducted ongoing research and development of production challenges. That work has informed much of the content included in this section.

As awareness of these valuable plants increases, we anticipate a slow, but ongoing increase in demand for these plants. Our hope is that the propagation and seed production guidelines here will empower additional native plant nurseries and seed growers to join in the production of native thistles. Propagating native thistles is both an emerging opportunity for seed growers to expand their species offerings, as well as an opportunity for restoration practitioners to improve the quality of restored habitat for pollinators across farms, state and federal lands, schools, and home gardens.

Seed Collection: Locating Source Populations

Native seed production typically begins with the collection of source material from wild populations. In many cases experienced seed producers and restoration professionals will know of existing wild populations. In some cases, however, the location of remnant plant populations may be a mystery. In launching many native seed production projects at Xerces, we initially narrowed our search areas by using a few investigative approaches, including:

- Searching plant survey and herbarium records available through state conservation agencies and universities;
- Contacting regional native plant societies, and asking them to query their members through their listservs, website, or social media;
- Consulting with ecologists, conservation agency partners, and native seed growers working in areas where the plants are likely to occur;
- Dashboard scouting' consisting of driving and looking along roadsides for remnant populations in specific counties or ecoregions within the native range.

In addition to understanding the habitat and geographic distribution of your target thistle, it is important to familiarize yourself with the key identification characteristics of the species and any similar species in your region, so that you can accurately identify your species. Leaf shape, spininess, hairiness, and flowerhead characteristics (e.g., phyllaries, size, color, spines) can all be helpful diagnostics for identifying native thistles. A complete botanical description of North American thistles can be found at Flora of North America (Keil 2006); we summarize the list of species in our table of all known native species in North America (Appendix A). We have also compiled regional guides and resources identifying native thistles in Appendix C, and provide a table of identifying characteristics for widespread native species.

When identifying, growing, and marketing native thistles species, it is important to realize that several species of native thistle readily hybridize in the wild. Hybrids often show characteristics intermediate to each species. This is a natural phenomenon and adds potentially important genetic diversity to native thistle populations. For example, field thistle (*C. discolor*) readily hybridizes with tall thistle (*C. altissimum*) to form *C. discolor* × *C. altissimum* (Dabydeen 1997). In many cases (including *C. discolor* × *C. altissimum*), the hybrids can have low fertility and may not propagate in production plots (Ownbey 1951, Bloom 1977, Dabydeen 1997). However, sometimes the hybrid is fertile, as is the case for the widely distributed hybrid populations of *C. discolor* × *C. altissimum* known as *Cirsium* × *iowense* (Keil 2006). Since hybrid species may complicate efforts to identify, propagate and commercially market thistle species, we provide a summary of species and varieties known or suspected of hybridizing in the wild based on Dr. David Keil's extensive review of herbaria specimens and literature (Appendix A).

Figure 6.1: Wild harvesting seed of field thistle (*C. discolor*) in Minnesota.

When selecting a thistle species to propagate, first verify that your species is not a protected species, and seeds can be legally collected. Before collecting any seed, ensure that you have all necessary permissions and permits through the landowner. It is important to collect from as large of a thistle population as possible (ideally >1000 mature plants). Large populations usually have greater genetic diversity and can adapt to local conditions better than smaller populations (Leimu et al. 2006, Leimu and Fischer 2008). High genetic diversity is important to ensuring the long-term persistence of restored thistle populations. Even if you are collecting from a large population, remember that many native thistles are monocarpic, flowering once in their life and then dying. Research shows that populations of native plants with short lifespans that depend on reproduction only from seed are particularly sensitive to overharvesting (Meissen et al. 2015). As a general rule of thumb it is important to limit your seed collection to less than 20% of the available seed, and do not harvest the same population multiple times in the same year or consecutive years. Finally, seed viability is often low in native thistle populations; removing unviable seeds is important for precise planting rates (see seed cleaning and planting sections).

Germination

Native thistle seeds typically do not germinate immediately after dispersing in the late summer or fall. Rather, they remain dormant and begin germinating the following season. Few studies have evaluated dormancy rates in native thistles, the amount of live thistle seeds that do not germinate for one to several years. But among those that have, dormancy can be quite high for species like pitcher's thistle (Hamze and Jolls 2000). Seed dormancy is an important adaptation of native plants. It allows native thistles to stagger their germination and for thistle populations to hedge against years with harsh conditions (e.g., drought, high herbivory).

Dormancy can be quite variable across species and seed lots. If time allows, we recommend testing seed for germination through a seed testing laboratory and/or planting a small amount of seed in the greenhouse. This information will help you develop a planting plan, and minimize potential missteps. Native thistles may need to be planted outdoors in the fall to expose them to cold, moist winter conditions, or be exposed to an artificial cold-moist stratification if planting in spring or indoors in seed trays. Planting seeds without stratification may result in limited germination. In addition, not using stratified seed may select for plants with low dormancy, and the subsequent progeny may be less adapted to persist in natural areas. That being said, we have also found unstratified seed to germinate well without cold-moist stratification. This variability underscores the need to learn the germination properties of your species before investing significant resources into planting.

Cold-moist seed stratification is intended to simulate natural winter conditions and break dormancy of seeds. Exposure to cold-moist conditions (i.e., cold-moist stratification) often causes changes in the hormonal chemistry of seeds, triggering their germination. For thistles, the minimum time for cold moist stratification is not well understood, although a cold-moist period of 50–85 days is likely sufficient to break dormancy based on the germination requirement of many other native species in the aster family (Smith et al. 2010). For example, storage of Pitcher's thistle seeds under moist, cold (36˚F) conditions for 14 weeks (98 days) led to germination of 45–73% of seed (Hamze and Jolls 2000). Other

FIGURE 6.2: Field thistle (*C. discolor*) seedling production at native seed farm in Minnesota.

FIGURE 6.3: Field thistle (*C. discolor*) seedlings.

treatments to the seed, such as application of gibberellic acid, can effectively enhance germination of thistles (Kirmizi et al. 2011). Freezing stratification seed treatments may also be necessary for breaking seed dormancy as suggested by one study that showed Pitcher's thistle would only germinate under stratification from freezing winter conditions (Chen and Maun 1998), a finding that offers further support for planting this species outdoors in the fall.

Figure 6.4: Hill's thistle (*C. pumilum* var. *hillii*) seedlings germinating on native seed farm.

Studies on Pitcher's thistle suggest fall planting is important yet it remains unclear how important fall planting is for most other native thistles. As we suggested earlier, seed treatments may not be needed for other species with low dormancy. For example, tall thistle seeded in the winter showed high germination yet spring-planted seeds also germinated across several grasslands in eastern Nebraska (Russell et al. 2010, Suwa and Louda 2012). Our native seed producer partner in Minnesota cold-moist stratified tall thistle seed in planted trays, but did not observe any noticeable difference in germination between stratified and unstratified seed (K. Fredrick 2016, pers. comm.). For field thistle, another species native to the region, populations seemed to vary in the need for cold-moist stratification; one population readily germinated without cold-moist stratification whereas another population showed low germination without stratification (K. Fredrick 2016, pers. comm.). Furthermore, three other native thistles (Hill's thistle, Flodman's thistle, and Swamp thistle) showed low germination without cold-moist stratification, the potential result of high dormancy and/or low seed viability. While cold moist stratification may not be necessary in every species and population, we recommend the safest route is to apply cold-moist stratification of at least 50 days for seedling trays grown in the greenhouse whenever working with a newly collected wild population of native thistle. Or, if direct seeding into production fields, we recommend planting in the fall to expose seed to cold, moist conditions. If spring planting, plant before the last frost or in warm regions well before the rain ends.

Insect damage and poor maturation can also limit the viability of seeds. A viable seed should appear filled out (not flattened) and have no holes or chewing from insects. The color of seeds is also variable, even within a species. In general viable seeds do not have a faded or pale coloration.

Native thistle seeds should be stored in dry, airtight containers at similar temperatures and relative humidity as other native seed. It is generally accepted that the summation of temperature (°F) and humidity (%) for long term storage (beyond one year) not exceed 100 (Smith et al. 2010). If stored properly, thistle seed should maintain high viability for at least two years based on our experience. We have not tested viability in seed stored beyond two years and like all native seeds, seed viability decreases with time.

Field Establishment

Multiple approaches are available for establishing native thistle fields for mass seed production. Consider your available equipment, supplies, and land, as well as the biology of the native thistle species you are working with, to develop a practical plan for thistle establishment and management. Many species of native thistles flower once in their lifetime, often in the second year. We provide a summary of life cycle information in Appendix A.

Site Selection

Grow native thistles in the same region and under similar soil conditions to the wild population where you collected the seed. This will help ensure your native population plot is adapted to phenological conditions and hardy to soil and climatic extremes. If there is any concern that native thistles may establish outside of the production plot, position the plot next to established grasses. Native thistles are strongly limited by competiton from grasses (Suwa and Louda 2012).

Figure 6.5: Production plot of field thistle (*C. discolor*). Two thousand seedlings were planted into this 0.08 ac. area.

Plant Density

Setting an appropriate planting density can help establish a robust stand that suppresses weeds, efficiently utilize plant material, and achieves high yield. Working with our partner grower in central Minnesota we found that an established a density of 1.7 field thistle per sq. ft. (2000 plants as plugs in a 0.08 ac. plot) resulted in a highly robust stand and a full canopy of rosettes in the first year and bolting plants in the second year. Dense stands of native thistles appear to better suppress weeds, especially as they mature and flower. There is some flexibility in the planting density as the growth of some native thistles is remarkably responsive to planting density, producing more shoots and heads under low planting density. While we generally do not recommend planting fewer than 0.8 plants per sq. ft., if there are minor gaps in the planting, or the density is too low, some species (e.g., field thistle and tall thistle) may grow more vigorously, filling in open spaces including planting gaps. To efficiently utilize plant material and achieve robust thistle stands, we recommend establishing 0.8–2 plants per sq. ft.

Figure 6.6: Seed of field thistle (*C. discolor*). Viable seeds are grey colored and filled while potentially unviable seed is pale and flattened.

Planting Methods

There are several methods for establishing production plots of native thistles, including seed drilling, transplanting, and broadcasting seeds. We compare the requirements and benefits of each method in the following table, and then discuss the step-by-step methods of each approach in the sections that follow.

Table 6.3: Planting Method—Drill Seeding

HOW IT WORKS:

Drill seeding can be an efficient method to establish a large thistle seed increase field. You will need to calculate the seeding rate based on target plant density, germination rate, and planting area. For information on calculating seeding rates to achieve a desired plant density see "Calculating your potential seeding rate and plot size" on page 40.

Seed drilling is most appropriate when seed quantity is not limiting the size of your thistle plot and your seed lot has a high germination (70% or greater). If these conditions are not met, consider planting thistles in trays where you can achieve better germination and seedling survival, and then transplant seedlings to the field.

REQUIREMENTS:

- No-till seed drills can plant thistle seeds including Truax drills, Great Plains, grain drill, or vegetable drills. Most drills with a small seed ("slick seed") box can be used to seed thistle. For example, seed drills configured for small seeded crops (e.g. canola), native legumes, or native sunflowers may effectively handle thistle seed.
- Adequate site preparation to reduce weed cover and the amount of weed seeds in the soil. Ongoing management to maintain low weed cover especially during the rosette stage.
- Sufficient amount of seed (e.g., you would need about 11 lb. (bulk) to seed a single ac. at 19 seeds per sq. ft., assuming at least 70% germination and approximately 7,000 seeds/oz).
- Seed lot with relatively high germination (70% or greater). A seed lot with low germination can result in a planting with numerous gaps.

BENEFITS:

- Efficient seeding process for large areas (≥¼ ac.). Seeding can be done quickly in the fall. This is important for establishing large fields and if overwintering cold-moist stratification is required to break dormancy.
- Adequate seed-to-soil contact. Planting depth can be configured to ensure seed-to-soil contact and minimal predation. Seeds should be planted just below the soil surface (approximately ⅛–¼"); deeper depth can reduce seedling emergence.
- Seeds can be planted at a chosen rate, in evenly spaced rows.

ADDITIONAL CONSIDERATIONS

- Renting or utilizing a seed drill is likely only cost-efficient for fields with a minimum size of ¼ ac.
- Irrigation may become critical to plant survival under severe dry periods, and can increase yields
- If seed is planted in the fall, the cold, moist conditions during winter can enhance germination in the spring. If you are planning on a spring planting, test germination rates of seed with and without cold-moist stratification to determine if stratification will be needed. If time does not allow for testing this, plant early in the spring before the last frost or before the end of the rainy period in warm regions.
- A brillion seeder may be used as an alternative to a drill seeder. Brillion seeders broadcast seed and cultipack seed on the surface. The primary difference from a seed drill is that a seed bed should be prepared before using a brillion seeder.

Figure 6.7: From left to right: drill seeding, transplanting, and hand-sowing seeds.

TABLE 6.4: Planting Method—Transplanting

HOW IT WORKS:

When seed drills are not available or seed is limited, a production stand can be established by propagating seedlings in a greenhouse over the winter and transplanting seedlings to the field in the spring.

REQUIREMENTS:

- 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 for a grow-out contract with a professional plant nursery.
- Adequate site preparation and ongoing management to maintain low weed cover especially during the vegetative stage. As the native thistle stand matures, taller thistle species can competitively suppress weeds.
- Optional weed guard (e.g., Weed Guard Plus® which is biodegradable and comes in pre-punched cardboard roles) can provide adequate alternative weed control, yet will limit regeneration of plots from self-seeding.
- Large areas (>¼ ac.) are best planted using a mechanical planter.
- Available labor force that matches the scale of the transplanting and management effort.
- Equipment and labor force for irrigating transplants during the first growing season.
- Irrigation immediately following transplanting and throughout plant establishment (i.e., several weeks to several months depending on rainfall).

BENEFITS:

- Greater seed yields. Using transplants extends the growing season, leading to larger plants and potentially greater seed yields.
- Potentially earlier flowering. Most *Cirsium* species likely require a vernalization period-exposure of rosettes to cold conditions—in order to flower, preventing them from flowering any earlier than year 2 (Wesselingh et al. 1994). Yet jump starting them as plugs may help ensure all plants flower by year 2, instead of year 3 or later.
- Transplants will have a head-start advantage over weeds, provided there is adequate pre-planting weed control.
- Requires less seed than drill-seeding. Better germination can be achieved in the greenhouse under controlled moisture and temperature.
- Greater precision in planting density. Easier control over plant establishment allows fewer planting gaps.
- Feasible on small (<¼ ac.) scale or large scale (>¼ ac.), provided that a sufficient labor force or mechanical planter is available for larger efforts.

ADDITIONAL CONSIDERATIONS

- Transplanting should be timed, as much as possible, to avoid prolonged periods of hot, dry, or windy weather, especially if access to supplemental water is limited. Use of dibble sticks or mechanical vegetable transplanters is recommended for ease of establishing transplants. In addition, deep pot transplant trays can provide enhanced root growth and likely increase transplant survival.

TABLE 6.5: Planting Method—Hand-sowing

HOW IT WORKS:

If the goal is to establish a small plot with minimal inputs of time and resources, we recommend hand sowing. Since the plants will not emerge in rows, it is important to ensure the plot is narrow enough to allow for management activities in all parts of the plot.

REQUIREMENTS:

- Adequate site preparation and management to maintain low weed cover.
- Requires no specialized equipment.

BENEFITS:

- Lowest input of time, effort, planning, and personnel.
- Quickly planting in the fall allows for cold-moist stratification over the winter.

ADDITIONAL CONSIDERATIONS

- If planting seed in the fall, cold, moist conditions during winter can enhance germination in the spring. For spring planting, we recommend planting before the last frost or before the end of the rainy period in warm regions.
- Supplemental water may be necessary to facilitate establishment if rainfall is limited.

Calculating Your Seeding Rate and Production Field Size

We recommend planting 10–12 germinable seeds every linear ft. for a no-till drill with 8" spacing. Up to 30 seeds per linear ft. may be required in arid environments or areas with high weed pressure. It can be challenging to achieve consistent plant density in the field when seed germination is low due to unviable or dormant seed. As such, we recommend seeding fields only when seed viability is greater than 70%, otherwise transplanting is best.

To account for non-germinable seed and inert material in your seed lot, you can calculate your seeding rate, plant density, and field size based on a professional seed purity and germination test of your seed. The test will provide you with an estimate of pure live seed (PLS). PLS is the amount of seed in a bulk seed lot that is viable and can germinate. You can also conduct your own seed count and germination test to estimate PLS and calculate seeding rates.

Figure 6.8: Germination test of tall thistle (*C. altissimum*) seeds.

Pure Live Seed (PLS) Calculations

The formula for calculating PLS is:

(% seed purity × % total germination)
÷ 100
= % PLS (percent live seed)

Sample Pure Live Seed Calculation:

If you have a seed lot with 95% seed purity and 85% total germination:

(95 × 85)
÷ 100
= 80.75% PLS (or 0.8075)

Sample Seeding Rate Calculation:

If your seed lot weighs 2 lbs and there are an estimated 75,000 bulk seeds/lb, you have 150,000 seeds on hand. Since you know the PLS for the lot, you can calculate that 121,125 of the seeds are viable and will potentially germinate:

150,000 seeds on hand
× 80.75% PLS (*or 0.8075*)
= 121,125 viable seeds on hand

If your target seeding rate is 10–12 live seeds per linear ft., you can determine the rate at which bulk seed needs to be sown by dividing the target seeding rate (11 seeds, the midpoint) by the % PLS:

11 seeds per liner ft.
÷ 80.75% PLS (*or 0.8075*)
= 13.6 seeds per linear ft.

Rounding up, if you will sow 14 bulk seeds per linear ft., you can plant 10,714 linear ft.:

	150,000 seeds on hand
÷	14 bulk seeds per linear ft.
=	10,714 linear ft.

At a typical row spacing of 8", an eight row seed drill could establish a 0.145 ac. field (Width of seeder × linear planting feet: 4.7' × 1,339') in a single pass.

	4.7' wide seeder
×	1,339' linear planting
=	6293.3 sq. ft (*or 0.145 ac.*)

It is also important to consider the percentage of dormant seeds (often called hard seed). A highly viable yet highly dormant seed lot will have low germination; treating the seed with cold-moist stratification or exposure to winter conditions can reduce dormancy. Many native species will have a high level of seed dormancy. So, calculating PLS based on the % germination, in addition to % viability, can provide a more reliable estimate of the seeds likely to germinate in the field.

Sample Bulk Seed Calculation

Continuing the PLS calculation example from above, if a two-pound seed lot has an estimated 75,000 bulk seeds/lb, 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 20 bulk seeds per linear ft., for example:

	150,000 bulk seeds
÷	20 bulk seeds per linear ft.
=	7,500 linear ft. (or 0.10 ac.) could be planted

This example illustrates the benefits of having a professional seed test conducted on wild-collected seed so that purity and germination data is available for performing these planting calculations.

Conducting In-House Counts of Viable Seeds

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 g. Counts will be most accurate for seed lots that have been finely cleaned and include minimal amounts of inert material. Since there will be thousands of thistle seed per ounce, it would be unreasonable to manually count a one-ounce quantity. Thus, to estimate the number of viable seeds per unit weight for any given seed lot, you can weigh at least five replicate samples of 0.1 oz, count the total number of seeds in each sample, calculate the average seeds per sample, and then extrapolate the number of seeds per ounce based on the total mass of seed.

Discerning viable from non-viable seeds in your seed count will provide you with a more accurate estimate of real seed weight. Viable seeds appear full, not flattened or sunken in. They are free of small holes or chewing marks from insects. Color of viable seed can vary by species and within species, and is a less reliable indicator of viability. While this is not universally true, very pale tan seeds may be more likely to be non-viable.

Additional Considerations of Planting Methods

Once you have considered the pros and cons of each of the seeding methods (pages 38–39), the sections below will give you additional information and specific considerations for each method.

Drill Seeding

Suitable Equipment

Several types of seed drills can be used to drill seed native thistles. The drill must have a small or "slick" seed box intended for small seeded crops (e.g., alfalfa) to allow for a slower planting rate appropriate for planting native thistle seeds. Grain drills meant for relative large-seeded crops (e.g., wheat) will generally do a poor job of handling the smaller seeds of thistles, and under most circumstances, the small seed of thistles will run too quickly through the planting tubes of these drills. The drill will also need to be adjustable to shallow planting depths. Most native thistle seeds should be planted just below the soil surface (⅛–¼").

Timing of Seeding

Seed of wild thistle populations generally disperses in the late summer and fall. As previously discussed, when native thistle seed disperses it is typically dormant and may not germinate until it has been exposed to cold, moist conditions of winter and early spring (Hamze and Jolls 2000). This environmental cue is advantageous, signaling to the plant that the wet moist conditions typical of spring and ideal for seedling growth are on the way.

Fall and spring plantings of native thistle both have the potential to be successful. For fall plantings, it is important to plant late in the fall when soil temperatures are cool which helps ensure seedlings do not germinate prematurely (Smith et al. 2010). For spring planting, seed should be planted before the last frost or for warmer regions before the rain ends. Spring seeding can be advantageous in that it provides an opportunity for broad-spectrum weed control (e.g., cultivation, broad-spectrum herbicides) and it may reduce seed mortality from predation and diseases because seeds spend less time in the ground before germination. Despite those potential benefits, spring seeding may require artificial stratification for seed to overcome potential dormancy. To do this, you can mix seed with sand and moisten the sand-seed mixture in a sealed container cooled to 36–40° F for approximately seven weeks. To make sure the sand-seed mixture runs through the drill, dry the sand-seed mixture using a box fan immediately before planting. Drying seed may cause dormancy to return so minimize the time from drying to planting and, if possible, water dry planting beds after planting. Seeds swell and become pliable when they are moist making them vulnerable to being damaged during planting, germinating prematurely, or dessicating in dry soil (Smith et al. 2010). Given the extra time and risk involved with artificial stratification, we recommend testing seed for dormancy to determine if stratification is necessary or planting in the fall.

Planting Depth

A planting depth of ⅛–¼" is ideal for most native plants and should be suitable for most native thistles. While deeper planting depths are generally not recommended for most thistle species, the Pitcher's thistle (*C. pitcheri*) is endemic to dunes where seeds appear adapted to moving sand and can germinate and emerge from burial depths over three inches (Hamze and Jolls 2000).

Hand-Sowing

Hand-sowing can be an appropriate, low-input approach if the planting area is too small to justify renting/using a seed drill, and resources are not available to grow and transplant seedlings. Hand-sowing requires significant seed per unit area, so this method is most appropriate for small-scale seed production plots (e.g., from a few hundred sq. ft. up to ⅛ ac.). It is critical that the plot dimensions are narrow, no more than 6" wide, so you can easily manage and harvest seed from plants in the plot interior.

To determine seeding rate, estimate your total number of viable seeds (see "Calculating your seeding rate and production field size") and measure the planting area. Distribute seed approximately 20 viable seeds per sq. ft. as evenly as possible by hand or using a hand-operated broadcast seeder (e.g., "belly grinder"). Mixing seed with a bulking agent (e.g., peat, sand, rice hulls, corn meal) and seeding the area multiple times can improve the evenness of the seeding. Lightly rake seed into the top ¼" of soil using a rake. To achieve good seed-to-soil contact, tamp the soil down with a turf roller or walk over the planting. Similar to drill seeding, spring and fall plantings are both acceptable when hand-sowing (see "Timing of Seeding" section above). Covering seed with soil will also help minimize predation; thistle seeds are relished by birds and invertebrates.

Transplanting

Timing of Transplanting

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 bottom of their containers and begin to air-prune; this stimulates lateral root formation (Smith et al. 2010).

We have observed seedlings of some thistle species ready to transplant within as little as eight weeks, but some species may require five months or more. As mentioned previously, cold-moist stratification can be important in expediting germination in some thistle species. A convenient way to stratify seeds is by sowing seeds in prepared flats and placing them in a refrigerator for the desired amount of time. Cover the flats in plastic to prevent moisture loss. After stratification, move the flats to the growing area and remove the plastic cover. It is difficult to offer specific guidance on how far in advance seed should be sown in order to meet a transplanting date;

Figure 6.9: Sow seeds in flats containing moist media and place in a walk-in refrigerator to be cold-moist stratified.

for species that are new to production in your region, this might require a "trial-and-error" period. Most native plants are sown in a greenhouse two months (eight weeks) before the last frost date (Smith et al. 2010). Thus, if seed is to be stratified for seven weeks and seedlings are to be propagated in a greenhouse for eight weeks, the stratification process should start approximately four months prior to the intended transplanting date. In coastal regions without frost but extended winter rains, consider starting this process early enough so that thistle transplants can take advantage of much of the winter rains.

Reducing Transplant Shock: Container Type and Hardening-Off Seedlings

Native thistles devote a significant amount of energy to root development. It is important to use as deep of a container as practical to accommodate their root growth. That being said, our partners have successfully propagated native thistles using relatively shallow containers: 2.25" deep, 1.5" square container cells. Certain container types can help reduce transplant shock by minimizing root disturbance and allowing for deeper rooting depth. This may be particularly important in environments with limited access to water. For example, peat pots are biodegradable and can be planted directly in the ground, and Ellepots feature a degradable paper membrane that holds soil around the root mass during transplanting.

Seedlings grown in the greenhouse often have softer leaf and stem tissue resulting from the lack of windy, bright outdoor conditions. If seedlings were grown indoors, it is advisable to move them to a semi-protected outdoor location for several days prior to planting to allow them to acclimate to the conditions they will experience in the production field. Transplant shock can also be more intense for thistles with significant leaf growth supported by a small root system, which often occurs when plants outgrow smaller plant container. Additional watering immediately after transplanting may be especially important for such plants.

Planting into Weed Barrier Fabric

Where weed pressure is high and herbicide applications are not permitted, weed barrier fabric, plastic mulch layer, or cardboard can be installed prior to transplanting. There are a range of products available that vary in durability and longevity, which is important given that many thistle species are short lived. Some weed barriers can be mechanically installed using a bed-shaper equipped with a plastic mulch layer or 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.

Installing Transplants

Native thistle plugs can be transplanted to the field using mechanical transplanters (e.g., water wheel-type or other vegetable plug transplanters) or by hand. Ensure transplants have well- formed root balls, otherwise, they can fall apart when moving through a mechanical planter.

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 through the combination of rainfall and irrigation. Mulching can reduce weed competition and 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.

Row Spacing and Plant Spacing

The distance between rows and plants within 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, spraying). Native thistles, especially the larger species (e.g., field thistle, tall thistle), can exhibit larger growth and higher seed count per plant when they are planted at a lower density. If planting density is too low, however, thistles may not effectively suppress weeds. Our experience to date with field thistle suggests that a planting density of one plant per 6–12" on and between rows provides both adequate weed suppression and plant growth.

Avoid Using Insecticides

Do not use systemic insecticides (e.g., clothianidin) when growing thistle transplants, as many of these chemicals have high potential to harm or kill foliage- and nectar-feeding insects including butterflies, caterpillars, bees, and other beneficial insects.

Maintaining Production Fields

Flowering and Stand Longevity

Most native thistles flower in their second year, while many require several years to flower, and a few can flower in the first year (Appendix A). Flowering typically only happens after the second year for thistles that require vernalization, especially those originating from northern latitudes (Wesselingh et al. 1994). The winter conditions are needed to trigger flowering in the second year. Because many thistles die after flowering, most thistle plots will likely produce significant seed early on, but may not persist beyond three to four years.

Figure 6.10: Production plot of tall thistle (*C. altissimum*) established from plugs.

Calculating Target Number of Transplants and 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' centers (e.g., 4 sq. ft. allocated for each plant), you will need to prepare an area of 4,000 sq. ft. (or ~0.1 ac.).

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 0.25 ac. field stand and install transplants on 2' centers, you would require 2,722 transplants, given that there are 10,890 sq. ft. per 0.25 ac.

Figure 6.11: Production plot of field thistle (*C. discolor*).

Rotation

The relatively short lifespan of these plots compared to most native species allows for flexible rotation of thistles with other native species. Rotating crops with diverse root structure and quality improves soil health, including water holding capacity and infiltration, as well as microbial activity important for fertility. In addition, soil pathogens can build up under perennial monocultures, causing a depression in yield over time. Rotating native thistles with native grasses can add significant diversity to cropping rotations given the starkly different roots of these plants, as well as likely differences in soil pathogens, plant tissue quality, and nutrient cycling. Rotating native thistles both in time and in space can also help disrupt insect herbivores of native thistles which can become significant pests (see Pests of Native Thistles).

Weed Management

It is critical to establish thistles in fields with low weed pressure, since competition could reduce seed yield (Suwa and Louda 2012). Canada thistle and other perennial weeds are challenging to manage in established native thistle plots. Every effort should be made to control existing weeds prior to planting. Although the taller species of native thistles (e.g., field thistle, tall thistle) can compete with weeds when planted in a dense stand, slower growing, short-statured species may not provide this same benefit and may need greater weed management.

There are several options for controlling weeds. We recommend controlling weeds before planting, and then mowing, hoeing, or handweeding plantings for further weed control. Weed barrier fabric may be used but can limit self-seeding by thistles in plots that are intended to be self-perpetuating. An annual cover crop (e.g., oats) could also be used to limit weed growth and facilitate establishment of the native thistles. In addition, there are several grass selective herbicides (e.g., sethoxydim) that may be applied to control grasses. As with any selective herbicide, check the label to ensure that it does not affect plants in the aster family (e.g., sunflower or artichoke) and test the herbicide on a small area of your plot before applying to the entire plot. Finally, glyphosate is often applied to weeds when native plants are dormant. However, be aware that many native thistles emerge early in the season which can limit opportunities for a dormant herbicide application.

Native thistles have low potential to become weedy and impact production of other native plants. Yet like most native plants, native thistle seed could disperse into nearby production fields. If you market seed to states where native *Cirsium* are considered noxious weeds, you can add another layer of insurance by planting native thistles next to a grass production field. Dominant grasses both suppress native thistle growth and are conducive to weed management (e.g., selective herbicides).

Soil Fertility

There is little information on the relationship between soil nutrients and seed production. Ecologists have observed major differences in thistle growth related to site characteristics (Russell et al. 2010), much of which is likely due to soil fertility. For example, wild populations of the native tall thistle typically have 25 flowerheads (Andersen and Louda 2006) but some plants can produce up to 45 blooming flowerheads with nitrogen addition (F. L. Russell 2016, unpublished data). Apply fertilizer conservatively (20–40 lb N/ ac.) to avoid lodging and do not apply fertilizers if there is high weed pressure, as it will likely exacerbate weed pressure. While fertilizers can improve yields in the short term, maintaining high yields in the long term requires a focus on soil health practices. Avoiding tillage, and rotating thistles with other crops such as native legumes, native grasses, and annual cover crops can enhance soil health and boost yields.

Pests of Native Thistles

The important role of native thistles as food plants for wildlife is a large part of our motivation for growing and promoting these plants in ecological restorations. These same insects and birds may reach pest-level densities in plots where native thistles are being grown for seed. We now turn our attention to the necessary issue of managing herbivores and plant pathogens in thistle seed production.

Insect Herbivores

Insect herbivory can be a major source of seed loss for native thistles. Thistle herbivores can chew on the leaves (e.g., grasshoppers), suck sap from stems (e.g., leafhoppers), mine the leaves (e.g., leaf-miner flies), and feed on the developing seeds within the flowerhead (e.g., larvae of picture-winged flies, snout moths). Many of the flowerhead and stem boring are specialists of the *Cirsium* thistles (Takahashi 2006). Ecologists have observed significant thistle seed losses due to native insect herbivory in wild ecosystems, approximately 40–90% depending on the thistle species and environment (Louda and Potvin 1995, Louda and Rand 2003, Suwa and Louda 2012). Herbivory pressure can differ regionally; most of the significant herbivory on native and non-native thistles has been observed in the western tallgrass and mixed grass prairies of the Great Plains. It is unclear if such significant herbivory will occur in seed production plots. To date, growers producing field thistle in Indiana and Minnesota have not observed or reported major issues with insect damage in production plots. However, as native thistle production is expanded within nurseries and into new regions, herbivory by insects may become a more significant issue.

FIGURE 6.12: Flowerhead-feeding insect herbivores can impact native thistle seed production in the wild. These snout moth (*Homoeosoma* sp.) larvae were discovered inside wild-collected field thistle (*C. discolor*) seed heads.

Figure 6.13: Songbirds voraciously feed on native thistle seeds. American goldfinches (*Spinus tristis*) are among the most common birds to feed on native thistle seed but other songbirds, such as chickadees (*Poecile atricapillus*), can also feed on the seed.

Seed Predation by Birds

Songbirds, especially goldfinches, feed voraciously on native thistle seeds, both in the wild and in production fields. Goldfinches are often observed picking seeds out of flowerheads before the flowerheads open to disperse seeds, and have been found to congregate in high numbers in production fields. For example, our partner grower in Minnesota observed roughly 100 goldfinches feeding together on a 0.08 ac. field thistle production plot (Keith Fredrick 2016, pers. comm.). Goldfinch feeding can result in flowerheads that appear torn, with their pappus strung out. As feeding progresses, florets are often completely removed, with few seeds remaining inside the still-green flowerheads. Although difficult to quantify, goldfinch feeding is expected to significantly reduce seed yields, and harvest dates may need to be shifted earlier in the season to minimize losses. Interestingly, thistles may benefit native seed farms by acting as a trap crop that protects other higher value seed crops. Our partner grower noted that the goldfinches appeared to prefer field thistle seeds over the highly valuable meadow blazingstar seeds that ripen at the same time (K. Fredrick, pers. comm.).

Thistle Pathogens

Unlike major food crops whose diseases are well-studied, most wild native plants, including thistles, have extremely limited and incomplete information about their diseases, and even less information about recommended treatments. However, with a general understanding of the major diseases of thistles, as well as the conditions that favor disease, most growers can at least make informed decisions about possible prevention and treatment options.

Native thistles have few major diseases, although several minor diseases may become significant problems for large-scale production fields. At least a dozen distinct plant diseases have been identified among native *Cirsium*, and undoubtedly many more diseases exist which have not yet been identified and recorded. Fungal diseases are the most well documented pathogens that attack native thistles.

Known Diseases of Native Thistles

While there are potentially many unrecognized native thistle diseases, a number of distinct pathogens have been identified and recorded. The following list represents the most comprehensive compendium of such pathogens that we know of. These pathogens are categorized by typical symptoms, however symptoms variations beyond those known very likely occur.

Plant pathologists refer to three conditions that must co-occur in order for a plant disease to manifest itself (these three conditions are 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 of these conditions it should be noted that thistles, like all plants, exhibit a wide range of disease susceptibility, even within a single species. Indeed genetic diversity being a focus of using native plants in conservation plantings, there should, and will be, a range of disease susceptibility within a healthy thistle seed production field. This underscores the importance of collecting thistles from large, diverse wild populations to help ensure that there are naturally disease resistant plants in the population. As in any native plants, naturally resistant individuals will be propagated in nurseries whereas susceptible plants may perish. So we expect that some amount of selection for resistant plants will occur in nurseries though we do not recommend breeding thistles for disease-resistance.

The second condition, a conducive environment, is often scale dependent. While plant diseases are unlikely to be significant production challenge in small nursery plots, larger-scale monoculture seed production systems (i.e., with very high numbers of a given species, positioned at close proximity) are likely to experience more frequent and severe disease issues. Other conditions that may favor plant disease include climatic stress (uncharacteristically wet or dry seasons), nutrient deficiencies, insect-feeding or mechanical damage to plants, pollution, and a lack of biological diversity (such as a lack of competition between microorganisms that cause disease, and the other microorganisms that attack them).

Finally, there are the pathogens themselves. As stated previously, fungal diseases are the most well-documented pathogens that attack native thistles.

Table 6.6: Known Pathogens of Native Thistles*

PATHOGEN	*C. altissimum*	*C. discolor*	*C. muticum*	*C. occidentale*	*C. undulatum*
Fungal Leafspot					
Pustula obtusata	✗		✗		✗
Cercospora ditissima					✗
Cercospora kansensis	✗				
Phyllosticta cirsii					✗
Septoria cirsii	✗	✗	✗		
Stagonospora cirsii	✗				
Fungal Canker					
Botryosphaeria obtusa	✗				
Fungal Leaf & Stem Blight					
Diaporthe arctii	✗				
Powdery Mildew					
Erysiphe cichoracearum	✗	✗	✗		✗
Ophiobolus acuminatus	✗				
Fungal Root Rot					
Phymatotrichum omnivorum					✗
Rust					
Puccinia cirsii	✗	✗	✗	✗	✗

* **Source:** USDA 1960.

Figure 6.15: Thistle leaf showing signs of puccinia rust (*Puccinia* sp.).

However, most plants are susceptible to a wide diversity of pathogens that also include bacteria, viruses, various other microscopic organisms (such as nematodes and protozoa), and abiotic conditions (like pollution). Additional research and investigation would undoubtedly identify a variety of these pathogens infecting various native thistle species. Along with this diversity of pathogens it is important to recognize that there are correspondingly diverse infection pathways, including insect-vectored diseases, cell wall degrading enzymes, effector proteins (which send false signals to the host plant triggering openings in the cell wall for pathogens to enter), and more.

In the following sections we briefly describe the most common groups of plant pathogen groups, their symptoms, their infection pathways, and some broad strategies for reducing their impact.

Fungi

Fungal pathogens cause the most—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 lifecycle of various fungal pathogens can be extremely complex and as such is beyond the limits of this guide. It should be noted however that many fungal organisms can produce both sexual (producing genetic recombination) and non-sexual (clonal) spores, and that those spores can be spread long distances by wind, water, and soil particles. Spores can often remain dormant for years, awaiting the ideal combination of environmental conditions to germinate.

Most fungal (and fungal-like) plant pathogens fall into three broad taxonomic categories: the Ascomycetes (sac fungi), the Basidiomycetes (club fungi), and the fungal-like Oomycetes (water molds). Sac fungi comprise the majority of foliar diseases including leafspots, stem and leaf lesions, and powdery mildews. A few specific examples of sac fungal diseases include *Septoria* and *Cercospora* leafspots. 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 thistles by the rusts—a group of diseases that produce orange or black pustules on the undersides of leaves. Depending on the specific organism, rusts can produce up to five different spore types that cycle through complex lifecycles 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 the rust *Stegocintractia junci* is a known pathogen of Canada thistle that completes half of its life cycle on various reed species (*Juncus* spp.).

The water molds are not true fungi, and appear to be most closely related to photosynthetic organisms such as diatoms and brown algae. Unlike fungi which have cell walls made of chitin, these mobile single-celled organisms have cell walls comprised of cellulose (similar to plants and some algae). Contrary to the common name, most water molds are found primarily in soil. Because they are mobile in soil water, they can disperse over short distances toward the chemical signals of food sources (such as host plant roots). Consequently, many well-known and devastating root rot diseases of plants are water molds, such as *Pythium*, a common disease of many native plants. Water molds also produce tough resting spores (*oospores*) that can remain dormant for extended periods of time, and which can be blown in soil dust, 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 native seed crop 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 typically rely upon four fungicide groups for the management of native seed crop diseases, so those groups merit specific discussion. Those fungicide groups include sulfur, copper, strobilurins, and triazoles. Note that individual fungicide products are unlikely to be labeled for native thistles. While we make no recommendations on the legal interpretation of fungicide labels, it is our opinion that thistles in production meet the broad definition of ornamental nursery plants.

Sulfur, the first of the four fungicide classes we have observed in native seed production, represents the oldest known class of plant fungicides. 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, and may be toxic to some plants, especially in warm weather. An important strength of sulfur as a fungicide is the low potential for pathogen resistance to develop. Because of the phytotoxic potential of sulfur, we recommend applying it at the minimum recommended rate to a small group of test plants before it is applied at the field-level scale.

Copper, the second fungicide group, like sulfur is considered a preventative, has low potential for pathogen resistance, and can be phytotoxic. In addition copper fungicides may pose health risks for people, and precautionary guidance on the label should be followed. Like sulfur, we recommend applying it at the minimum recommended rate to a small group of test plants before it is applied 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 disease resistance is relatively high among this chemical group.

The final class of fungicides 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 previously described groups, is considered mostly curative—stopping active infections that are already occurring. The triazole class, which inhibits the development of fungal cell walls, has a relatively high potential for creating fungicide-resistance among diseases, especially rusts.

Note that while these and other fungicides are reasonably effective for many sac and club fungi, they typically have limited effectiveness against water molds. This limited fungicide effectiveness against water molds is unfortunately also true of most fungicide classes even beyond those described here. A few specific fungicides like metalaxyl and foestyl aluminum may be partially effective, however once established in a specific crop, water molds are typically impossible to eradicate and infections are likely to re-occur. Where lab tests confirm such pathogens, and where diseases re-occur, the most profitable management option may be the removal of the susceptible crop, and followed by a resistant species, such as native grasses.

For managing 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 biocides only as a last resort. Native seed producers should keep in mind that fungicides are broad-spectrum in nature, killing both good and bad fungi alike—including the good fungi that may normally be adversarial with the bad fungi. More proactive disease management strategies are described separately, later in this section.

Bacteria

Bacteria are single-celled organisms that while abundant in most soils are, like fungi, largely benign to plants. Like fungi, bacteria play a critical role in nutrient cycling, and a relatively small number of species have been identified as plant pathogens. While a few types of bacteria can degrade the cell walls of a host plant during the infection process, most bacterial infections occur to physically damaged plant tissues (e.g., such as leaf bruising caused by hail). The symptoms of bacterial infection in plants usually appear as wet or water-soaked rots, or irregularly-shaped leafspots (often confined by leaf venation).

In contrast to true bacteria, phytoplasmas are a related group of pathogens that lack true cell walls (and consequently cannot live freely outside of a host cell). Phytoplasmas are vectored by insects, especially aphids and other insects with piercing-sucking mouthparts—when they consume the pathogen while feeding on an infected host—then move to an uninfected plant where they secrete some of the pathogen into the new host along with digestive enzymes injected into the plant to help them feed. A common effect on infected plants is the destabilization of the plant's immune-response, including the production of chemicals which may inhibit feeding by insects (thus making the host plant even more susceptible to insects that may help vector the pathogen). The physical impact on infected plants can often be seen as extreme mutations—especially of flowers which may spontaneously branch where no branching should occur, or which may lack pigment. One phytoplasma, known simply as *Aster Yellows*, is a widespread plant pathogen in the Asteraceae family. While we do not know of specific confirmation of this pathogen in *Cirsium*, we have seen individual Canada thistle plants that appeared to be symptomatic. Given the wide host range of Aster Yellows, we would be surprised if native thistles were not susceptible to this pathogen. Aster Yellows is vectored by leafhoppers.

There are few chemical control options to manage bacterial infections, and while copper hydroxide fungicides may offer some limited efficacy against bacterial infections, for the most part fungicides will not control bacterial plant diseases. In recent years several hydrogen peroxide solutions labeled for crop protection have become available, which may offer some control of bacterial pathogens, however such products are broad-spectrum in nature, killing both good and bad bacterial alike—including the good bacteria that may normally be competing with the bad. 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 native seed crops, 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 native thistles (as opposed to food crops where virus-resistant technology, including genetic modification, has sometimes been developed). Viruses typically consist of single-stranded RNA genomes housed within a protein coat that may be vectored by insects or transported between plasmodesmata cell wall pathways. The replication of viruses 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, such infections may appear as symptoms like yellowing, stunting, leaf or flower deformity, or mosaic color patterns. In some cases plant pathogenic viruses are also seed-borne.

Unfortunately few virus control strategies are available to seed producers. We recommend regular scouting and the immediate removal of symptomatic plants.

Other Organisms

Finally, other biological pathogens of plants may include nematodes, parasitic plants, protozoa, and algae. Of these pathogens, nematodes, which are microscopic roundworms, are typically the most common and widespread of this diverse group of 'other' pathogens. While most nematode 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 (as well as vector viruses). No known treatments exist for these various pathogens in native thistles, however we anticipate few problems among small thistle populations growing among diverse vegetation.

Abiotic Diseases

Abiotic plant diseases are those that result from non-living causes such as 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), and all plants in an area tend to be affected in a similar way—even plants of other species.

Mitigating Losses Due to Insects, Birds, and Diseases

Limit Pests by Promoting Biodiversity

Maximizing biodiversity at multiple levels within the crop ecosystem can create conditions less favorable for pest outbreaks and mitigate widespread crop loss. Ideally, this concept of expansive biodiversity should begin with the crop itself by establishing the production field with a large genetic pool of seed (even if it is collected from a single source population). A diverse, locally adapted seed source will be likely to have individuals resistant to diseases and herbivory.

Beyond the seed crop itself, biodiversity can be incorporated into the production system by intercropping native thistles with other plant species. For example, a thistle seed production field could be limited to six rows (or whatever equipment constraints allow), and alternated with six rows with a different crop species (i.e., alternating rows of native thistles with rows of other, unrelated crops). By reducing individual stand size, you will reduce the potential for diseases to spread rapidly across your entire thistle crop population.

Similarly, preliminary investigations on our part have raised questions about the potential promise of interseeding: adding a diversity of crops within native seed production fields themselves. Since many thistles are short-lived perennials, they could potentially be interseeded with other short-lived, non-competitive native and non-native species, such as oats (*Avena sativa*), mustard (*Brassica napus*), or partridge pea (*Chamaecrista fasciculata*) in the eastern United States, or various native annual lupines in western states. Growers should pursue this strategy cautiously as the potential benefits and drawbacks of interseeding are not well understood. Such intercropping may increase the biodiversity of both soil fauna (including fungi antagonistic to thistle diseases), beneficial insects (such as parasitoid wasps) that may feed on disease-vectoring insects such as aphids, and even soil nitrogen availability. At the same time, interseeded plants may compete with native thistles, complicate harvest, or spread to adjoining seed increase plots. Further work is needed to test multiple combinations of interseeded crops for their potential benefits and drawbacks.

Growers should not expect biodiversity to provide immediate or complete suppression of pests.

Rather, pest outbreaks can become less frequent and severe over time as biodiversity is incorporated back into the farming operation. Native thistles can fill a unique niche on native seed farms since they are short lived and can be frequently rotated with other crops. Intermittingly growing thistle and rotating plots to various positions on the farm may disrupt the life cycle of insects, especially the highly destructive flowerhead feeders (e.g., snout moths [*Homeosoma* spp.] and fruit flies [*Paracantha culta*]) that specialize on *Cirsium*. Thistle crop rotation can also assuage persistent and devastating diseases, such a *Pythium* root rot. When rotating thistles we recommend moving them to locations on the farm where structurally different and unrelated crops have been grown, such as native grasses. Establishing new thistle seed increase plots as far away as practical from previous thistle plantings may also reduce the chances of specialist insects re-discovering the new plot.

Managing Invasive Thistles: Preventing Spillover of Herbivory

Herbivores of native thistles often feed on related non-native thistles (Louda and Rand 2003). Invasive insects feeding on non-native thistles can spillover to native thistles nearby causing significant damage. For example, feeding from the thistle head weevil (*Rhynocyllus conicus*) on wavy leaf thistle increases with proximity to the invasive musk thistle (Russell et al. 2007). Controlling invasive thistles on the farm is important for weed management and it may also reduce herbivory from invasive biocontrol insects and native insects in thistle seed production plots.

Figure 6.16: Flowerheads of field thistle (*C. discolor*) can be harvested when florets turn brown, and heads feel springy from drying.

Seed Harvest Considerations

There are several potential strategies for limiting herbivory. Because most losses to herbivory occur at the flowering stage, it is critical to collect seed before it is damaged by seed feeding insects. The authors have employed early harvest for several native thistles (e.g., tall thistle, Hill's thistle, field thistle, and Flodman's thistlei), as well as the related non-native bull thistle (*C. vulgare*) for research purposes (Eckberg et al. 2014) and our nursery partner in Indiana employed this approach to limit herbivory of field thistle. Note however, that harvesting too early can prevent seed maturation, so it is important to carefully weigh herbivory risk against maturation considerations. Ideally, flowerheads should be collected once the florets turn dark brown and the flowerheads become springy as they are about to open. If collected at this stage, the seeds should be able to fully ripen while late season herbivory can be minimized from seed predators including birds and insects. If you are unsure whether seeds will ripen, then dissect a couple flowerheads. Seed likely to ripen will be fully colored (e.g., gray, tan) while unripe seeds will have a pale color and seeds will appear flattened/unfilled. After collection, place closed heads in a paper sack in a cool well-ventilated room for several weeks, allowing seeds to fully ripen. Do not be surprised to see insect herbivores exiting the seed heads, leaving behind a mix of damaged and viable seed.

Non-Chemical Control Products

Seed head bags or mesh netting can help reduce seed herbivory by birds. But because many herbivores oviposit during floral bloom, it would be difficult to use such bags to protect flowerheads from herbivores without also excluding pollinators. Bagging flowerheads is also a very time consuming activity (don't forget that every bag has to also be removed). Therefore, a more practical and effective method for limiting herbivory is to clip heads to stop insect development as described above.

There are numerous sound harassment devices, including bird cannons and distress calls, which can be employed for deterring songbirds when necessary. While these devices can work in the short term, birds may become habituated to the noise. Other devices include scare tape, balloons and even air dancers. While we have not used these for native thistles, cooperating farmers and others have suggested they can be effective tools.

Seed Harvesting and Drying

Flowering is determinate; i.e., the first flowers occurring at the top of the plant. While plants with determinate flowering tend to have narrower flowering windows, native thistles can have fairly wide flowering and maturation windows. This has implications for selecting your harvest strategy. Harvesting native thistles seeds can occur by hand or mechanically.

Hand-Harvest

Depending on the species, thistles can flower for 1–3 months. Species with extended flowering seasons may be effectively harvested by hand over multiple passes. We recommend using pruning shears to cut off stems and reduce the need to touch spines. Wearing gloves can also be helpful, especially for more spiny species.

Hand-harvesting is especially useful for short plants with a few flowerheads (2–10 per plant). Hand harvest becomes impractical with plot sizes greater than ½ ac. or plants with numerous flowerheads (10–40 flowerheads per plant). In our experience, when hand-harvesting wild populations, it seems reasonable to expect one person to harvest approximately ⅕–½ lb of clean seed per hour assuming flowerheads are easily accessible and seed damage is low. We would

FIGURE 6.17: Hand-harvesting field thistle (*C. discolor*) seeds.

recommend that plot sizes not be greater than ½ ac. if planning to harvest by hand, and make sure plots are narrow enough so you can access plants in the center without climbing into the plot.

Figure 6.18: Combining field thistle (*C. discolor*).

Mechanical Harvest

Our partner growers have had some success using a combine to harvest and break apart the flowerheads at the development stage when the majority of plants have mature seeds within unopened flowerheads. Harvesting flowerheads intact may allow for additional ripening in contrast to chopping flowerheads, which may reduce maturation. Further research is needed to determine best harvest practices to allow seed maturation. As noted earlier, harvest can occur when the flowerheads of most plants have brown, dry florets and the flowerheads feel springy as the flowerhead dries. Maintaining uniform growing conditions (e.g., weed control, uniform plot soil conditions, etc) may increase uniformity in flowering and allow for a narrower window of seed maturity and greater harvestable seed yield. Though we have not tried mechanical harvest methods other than a combine, one could also use seed strippers or pluckers (e.g., "native seedsters" or flail vac seed strippers).

Drying Seeds

After combining the flower heads it is important to move them to a cool, dry location with forced air. We recommend harvesting entire flowerheads to allow for potentially longer seed ripening in the flowerhead. Like many native flowers, the drying flowerheads open which allows the pappus (feathery structure attached to seed) to be more easily removed from the seed by threshing and winnowing. Pappus can be released from drying flowerheahds so it is important that the container where flowerheads are drying prevent thistle pappus from floating away. Drying also can cause immature insects to emerge from flowerheads, thus limiting their further herbivory of seeds.

Seed Cleaning

Small Scale (<2 lbs of Seed)

Seed cleaning involves separating the seed from other plant parts such as dried flowers and stems (chaff). In almost all cases, we recommend harvesting entire flowerheads and allowing the seeds to ripen in the flowerheads prior to cleaning. The benefit of additional ripening time may outweigh potential seed losses to herbivory late in the flowerhead development and some insects tend to exit drying flowerheads quickly as noted earlier. The two basic steps in seed cleaning are to: 1) thresh the seed (mechanically break up the material) and 2) separate the seed from chaff using screens, fans, or both. We have some experience cleaning native thistle seed and we draw from lessons learned cleaning milkweed seed because the seed mass, fluffy dispersal structures (pappus versus floss), and floral parts of these plant groups are similar.

Hand-Threshing

Threshing methods can be as simple as carefully pulling the florets with seeds out of the flowerheads. When thistle heads dry they often open up, but not always, especially if they have been packed tightly together while being dried. If they have not opened, you have an advantage as you can pull dry seeds out by their florets and the seeds will appear all on the same plane. Gently squeeze the seeds and they easily fall off the florets. If the flower heads have opened and you have a cloud of seed fluff, you can squeeze the fluff with your hands and shake the seeds out of the fluff. See our methods below to make good use of your time when separating seeds from fluff.

Larger amounts of fluff can be threshed by tumbling in a large rock tumbler or small cement mixer with a tennis ball. Flowerheads need to be completely dry before attempting this. In most cases, it is hard to damage mature seeds by simply pressing on them. Still, you may want to test your threshing method on small batches and inspect the seed to ensure it is intact before proceeding on a large scale.

Hand-Cleaning by Screen-Sorting

Assuming the fluff has expanded during the ripening process, you can use sheets of hardware cloth, screens, or kitchen sieves placed over a large bin to separate the seeds from the fluff and flowerheads. You will want to choose material with a mesh size that is just large enough to allow the seed to fall through. Rub the material over the screen or between your hands to release the seeds from the fluff. The seeds will fall through the screen while most of the fluff, flowerhead, and other non-seed material will be bulkier and will remain on top of the screen to be discarded. A small amount of non-seed material 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 fluff will become airborne and float everywhere, gathering in clusters and floating down hallways. Therefore, it is best to do this in an outside area protected from the wind, to reduce seed loss.

Shop Vacuums

We have used standard shop vacuums ("shop vacs") with cartridge filters to clean milkweed and thistle seed alike. We prefer this method as a low-tech option though the success of this method can vary with seed weight/ quality, vacuum, and operator. 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 fluff will collect around the

Figure 6.19: Shop vac used to separate field thistle (*C. discolor*) fluff from seed and other debris.

filter while seeds and larger material such as stems 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 in to the vacuum for several minutes, you will need to stop and remove the accumulated fluff from the filter. The majority of the fluff can be peeled off in a single strip and discarded. Some fluff 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.

Winnowing

As a final step, seed can be separated from small bits of chaff by winnowing. This seed cleaning method takes advantage of the fact that seed is relatively heavy for its size, while chaff tends to be lightweight. To winnow seed, pour it from a bucket held several feet above ground into a bin positioned in front of a low speed fan (it is best to do this outside!). The heavier seed will fall into the bin despite the airflow, while lightweight dust and chaff will be blown beyond the bowl. This process can be repeated multiple times if necessary to remove large amounts of dust. Note that seed dust can exacerbate allergies for some people, and can contain spores of fungi such as *Aspergillus*, which may be harmful to breath. Because of this we recommend wearing a dust mask when winnowing seed with a fan.

Large Scale Seed Cleaning (>2 lbs of Seed)

Mechanized Seed Cleaning

Before using mechanized equipment to process thistle flowerheads, it is helpful to dry the flowerheads for several days, ideally in a forced-air drying bin. Because drying flowerheads can open, especially when they are spread out, it is important to contain the flowerheads during dyring to prevent clouds of pappus from floating away. Threshing will be more effective when moisture content in the seeds is low. Also, dryer seeds are more resistant to being damaged by cleaning equipment.

Figure 6.20: Hammermills can be used to process native thistle flowerheads similar to their use in processing other species such as milkweed (pictured here). Clockwise from upper left: Hammermill, partially processed milkweed (*Asclepias speciosa*) pods, milkweed seed lot condition after one pass through a hammermill.

Equipment for Removing Fluff (Pappus)

Hammermills

A hammermill can very effectively break up flowerheads and separate seeds from fluff and flowerheads. One potential main drawback of using a hammermill is that they may damage seed. 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 fluff.

Debearders and Fanning Mills

A debearder can be used in combination with a fanning mill (i.e., air screen cleaner) to further separate the seed from the chaff. One of our farmer partners has found this method to be effective. Debearders (or de-awners) typically contain metal bars 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 the mixture of seed and chaff are fed into a debearder, seeds and debris will flow out of the end. Following this step, a fanning mill can be used to separate the heavy seeds from the light fluff and other parts of the flowerheads.

Stationary Combines

Combines very effectively break up plant material and remove fluff. Through our experience cleaning milkweed, we have found that flowerheads can be fed into a stationary combine to complete the initial phase of seed processing. First lay tarps both behind and in front of the combine to catch any unthreshed seed. Then, flowerheads can be deposited in the header while the combine is running. This requires extreme caution and steps must be taken to ensure that people can maintain a safe distance from the header. The majority of the fluff will exit the machine as the material is threshed and winnowed. Note that stationary plot threshers essentially process flowerheads in the same manner as combines.

Equipment for Separating Seeds from Fine Debris and Other Inert Materials

Air-Screen Cleaners and Gravity Separators

This type of equipment is ideal for fine cleaning seed after removal of fluff. 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 fluff is removed

Figure 6.21: Plant material is carefully fed into a stationary combine, with staff wearing dust masks and standing at a safe distance from the equipment (above), with the fluff exiting a combine while harvested material is being processed (below).

Figure 6.22: Plant material moving across the top screen of an air-screen cleaner. Seed will fall through the holes in the screen and the fluff and other debris that travels across the screen will be discarded.

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

FIGURE 6.23: Using a rake to manually thresh seeds.

Manual Threshing

If you lack equipment for breaking up flowerheads and removing fluff but have equipment to separate seeds from leaves, flowerheads, and other inert materials (e.g., air-screen cleaners, gravity separators), raw harvested material can be manually threshed to remove the majority of the fluff 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. 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. Thistle fluff is very sensitive to wind; even a light breeze can carry thistle fluff away. Caution should be excercised if threshing seed outdoors.

Seed Viability, Testing, and Storage

At the time of this writing there are no comprehensive studies on native thistle seed viability. From our experience working with wild populations, commercial seed production plots, and research studies, we have observed high variability in seed viability across species and within the season. The variation can be driven by herbivory, which can be high in some wild populations, as well as timing in seed harvest. Harvesting too early can limit seed fill.

The shelf-life of native thistle seed (how long thistle seed can be stored before losing viability) is not well known. We found germination of 70% in tall thistle seed that had been refrigerated for two-and-a-half years and left at room temperature for an additional six months. Thistle seeds are likely to have similar storage requirements as most temperate species. The two most important factors influencing wildflower seed longevity in storage are temperature and seed moisture content (Young and 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 can occur. Suggested rules of thumb or the "Harrington Rule" states that: 1) Each 1% reduction in seed moisture doubles the life of the seeds, within a range of 5–14%; and 2) Each 10°F reduction in seed temperature doubles the life of the seeds for temperatures over 32°F (Harrington 1972).

7

Native Thistle Marketing & Habitat Restoration Opportunities

There is great potential for the native seed industry to devote space in print catalogs, nursery websites, and sales brochures highlighting seed mixes that include native thistles and other high-value nectar plants (e.g., camas [*Camas* spp.], checkerblooms[*Sidalcea* spp.], goldenrods [*Solidago* spp.], cardinal flowers [*Lobelia* spp.], Joe Pye weeds [*Eutrochium* spp.], ironweeds [*Vernonia* spp.], blazing stars [*Liatris* spp.], various asters[*Symphyotrichum* spp.], or others). These seed mixes can provide an avenue for attracting new customers while also helping to raise awareness of the broader value of native thistles. Numerous studies and observations show that native thistles are not invasive; in fact, many species are quite rare. Nurseries can market native thistles as a non-weedy plant.

To support greater inclusion of thistles in restoration seed mixes, both the seed industry and the pollinator conservation community should advocate for the inclusion of native thistles in revegetation plantings supported by state and federal agencies. There are opportunities for state transportation agencies to include native thistles in roadside revegetation projects, and for the USDA's Natural Resources Conservation Service (NRCS) to recommend native thistle as part of pollinator seed mix specifications for agricultural lands. Similarly, the use of native thistle seed is consistent with the U.S. Forest Service and Bureau of Land Management's National Seed Strategy for the design and sourcing of restoration seed mixes. Given the importance of native thistles as nectar plants to monarchs, including them in conservation plantings for monarchs should be a priority for federal agencies. Another focal group that can benefit from the use of thistles in habitat plantings is songbirds. Indeed, native thistles can be a workhorse plant in songbird food plot seed mixes.

Within farm settings, planting native thistles and other native wildflowers in noncropped areas will help support bees, monarchs and other pollinators. Examples of on-farm pollinator habitat enhancement plantings include field borders, hedgerows, and wildflower meadows. We have also observed numerous beneficial predatory insects of crop pests (e.g., lady beetles [Coccinellidae], lacewings [Chrysopoidea, Hemerobiidae]) on native thistles; planting native thistles may attract and support these beneficial insects and boost biological control of agricultural pests.

To support this type of habitat restoration on working agricultural lands, NRCS offers various financial and technical support incentive programs such as the Environmental Quality Incentives Program (EQIP). Through these voluntary programs, NRCS provides qualifying landowners with cost-share

Figure 7.1: Blooming prairie native wildflowers, including tall thistle (*C. altissimum*) and goldenrod (*Solidago* spp.).

assistance that can help offset the expenses of project implementation. Similarly, the USDA Farm Service Agency (FSA) administers several largescale conservation easements that provide long-term rental payments to landowners willing to maintain environmentally sensitive lands in a noncropped condition. One of the best known FSA programs is the Conservation Reserve Program (CRP). 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. Beyond simply engaging with the NRCS as a participating landowner, the agency is also supported by State Technical Committees 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 groups, and they are a logical avenue for expanding dialogue around thistle conservation. 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, studies demonstrate that roadsides with native plants support more butterflies and bees than roadsides dominated by non-native grasses and flowers. Including native thistle in roadside revegetation projects within known monarch (*Danaus plexippus*) migratory and breeding areas can support both flight and migration. Many native thistles flower as monarchs are migrating back to Mexico. Additionally, training on native thistle identification can allow land managers to recognize native thistles already growing on roadsides and alter mowing timing, or avoid mowing or spraying patches of flowering native thistle especially during the late summer migration of monarchs.

FIGURE 7.2: Native thistles are an essential nectar source for migrating monarch butterflies in late summer and early fall.

8

Establishing & Maintaining Native Thistles in Conservation Plantings

Based on our experience and our knowledge of ecological field studies, we know that many species of native thistles readily establish from seed but may not persist over the long term. We describe several ways to improve the initial establishment and long-term persistence of native thistles.

Initial Planting and Establishment

Site Preparation

To ensure success when establishing any native plant from seed, it is critical to first eliminate existing weed cover and deplete the weed seed in the soil. A study from the grasslands of eastern Nebraska showed that seedling establishment of native tall thistle nearly doubled when vegetation was sprayed with glyphosate prior to planting the native thistles (Suwa and Louda 2012). In addition to herbicides, weeds can be controlled using smother crops, solarization (using UV-stabilized greenhouse plastic to heat the soil below and kill 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 perform shallow cultivation. To successfully control weeds, multiple herbicide applications, repeat cultivation, or other intervention is necessary for ensuring minimal weed pressure during the initial stages of native thistle seedling development. 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. For more information about the process of site preparation and pollinator habitat installation, visit http://www.xerces.org/pollinator-conservation/agriculture/pollinator-habitat-installation-guides/.

Timing

In most parts of the United States, native thistle seeds should be planted in the fall as is recommended for most plantings that include wildflowers. Exposure to cold temperatures and moist conditions during winter typically stimulate germination in the spring, and winter precipitation can help work seeds into the soil. Spring planting may also be possible but if seed dormancy is high, consider planting as early in the spring as possible to expose seeds to cold, moist conditions.

Planting Method

Studies suggest natural germination and emergence rates of native thistles varies from 1–13% in established grasslands (Louda and Potvin 1995, Russell et al. 2010, Suwa and Louda 2012). One study reduced cover of grasses with an herbicide prior to seeding but this only resulted in a small increase in seedling numbers, from 7–13% (Suwa and Louda 2012). The low establishment of surface broadcasted seeds into established grasslands(Louda and Potvin 1995, Russell et al. 2010) suggests that native thistle seed may establish more effectively when drilled into the soil. There are few examples of seeding native thistles for conservation plantings. Additional research is required to compare the success rate of drill seeding versus surface broadcasting, but we suspect (based on the literature and the relatively large size of thistle seeds) that drill seeding may be the most effective establishment method. Where drill seeding is used, thistle seed should be planted to a depth approximately ⅛–¼." Planting seeds at a depth of ⅛–¼" can help reduce losses to seed predators.

Maintaining Native Thistles in Conservation Plantings

Many native thistles are early successional species that establish quickly but may not persist in environments without disturbance, especially areas with dense grasses. Ensuring native thistles persist in the plant community over the long term is anticipated as a major challenge for native thistle conservation. Including thistles as a large component of seed mixes (e.g., >4%), regular disturbances, and abundant pollinators as well as increased education and awareness are all important to maintaining native thistle populations.

In grasslands, fire and grazing may both be important to maintaining thistle populations. Fire can enhance seedling emergence (F. L. Russell, unpublished data). Fire also prevents encroachment by trees and shrubs, which is a significant threat to some native thistles including the Carolina thistle (*C.*

Figure 8.1: Mountaintop thistle (*C. eatonii var. eriocephalum*) blooming with other native alpine flowers in a native wildflower meadow.

carolinianum) (Keil 2006). Grazing can also benefit native thistles as it tends to reduce competition from grasses and create open disturbances where seedlings can more easily emerge, grow, and flower. Examples of grasslands from the tallgrass and shortgrass prairie suggest greater native thistle abundance with long-term grazing. For example, over the past 30 years, more wavyleaf thistle (*C. undulatum*) have been observed on grazed tallgrass prairie at the Konza Prairie Biological station in the Flint Hills of Kansas. And, there is a large population of tall thistle on a grazed grassland in northwest Minnesota (I. Lane 2016, pers. comm.). Many of these observations are anecdotal at this point; more research is needed into the burning and grazing regimes that can maintain native thistle populations. In regions where farmers do not have access to livestock or fire, mowing or haying during the fall (after seed set) may be a suitable alternative to fire and grazing.

Insect pollination is critical for many thistle species. Native thistles depend on insect pollination to set seed. Plant native thistle as a part of a plant community or farm can support a diversity of pollinators that maintain high rates of pollination and seed set. One study, which experimentally excluded pollinators, showed that the absence of insect pollination led to a 50–95% reduction in seed set in thistles native to California (Powell et al. 2011). When planted as a single species hedgerow on a seed farm in Minnesota, author James Eckberg observed abundant, diverse wild bees, butterflies, predators, moths and other insects.

Finally, native thistles may be viewed as a threat by some, given the negative history of many invasive thistles. Training in plant identification can help land managers and herbicide applicators avoid killing native thistles. For this reason, including interpretive signage about native thistles in your restoration planting can help spread the message that native thistles are valuable and are not invasive weeds. Talking with neighbors and sharing this guide and other reference materials can further promote this message and address concern that such thistles will spread onto a neighbor's farm or natural area. This message applies more broadly to policy makers, restoration practitioners, and the growing citizenry that cares about the conservation of biodiversity.

Figure 8.2: Grazing by cattle (above) and bison (below) may have a beneficial impact on native thistle species that are found on rangeland and prairies (circled in blue) by reducing competition from other species, especially grasses.

Male bumble bee (*Bombus* sp.) feeding on edible thistle (*C. edule*).

9

Conclusion

In his 1917 book, *Our Backyard Neighbors*, Iowa naturalist Frank Chapman Pellet described his modest farmstead in the third person saying,

> "There were many wild flowers, such as asters and goldenrod, crownbeard and rudbeckia, which the neighbors regarded as weeds, but which the Naturalist guarded with jealous care."

In the years that followed, Pellet went on to author a small library of additional books, many of which focused on the propagation of native plants and the value of native plants for beekeeping. Those books, and work of other naturalists and plant enthusiasts went on to usher in a new era of ornamental American horticulture. In the century that followed, those "weeds" have become common standards in the home garden. Whole industries are now devoted to their propogation and use in habitat restoration projects. And they are incorporated into a dazzling array of engineered conservation features from rain gardens and bioswales to roadside plantings, greenroofs, and more. Native plant societies advocate on their behalf, and government agencies fund conservation easement programs that encourage their planting across millions of acres. This change has been refreshing and long overdue, but for native thistles this change continues to be slow in coming.

There is a sad irony that just as some native thistles now teeter toward extinction, they are only now finally being recognized for their role in supporting pollinators and other wildlife, and for their unique beauty. While we hope this guide makes a useful contribution in accelerating thistle conservation, it's only a first step. Much real work remains to be done. Your interest in these unique plants and the skill of the entire conservation community is the next critical link in their recovery. For your role, we extend our humble comraderie and thanks.

Thistle Species Native to the United States, Canada, and Mexico[1]

SCIENTIFIC NAME	COMMON NAME	🔁	Range[1,2]	Conservation Status[3]	Habitat	Hybridization	Comments
C. altissimum (L.) Sprengel	Tall thistle, roadside thistle	B/MP*	**USA**—AL, AR, D.C., DE, FL, GA, IA, IL, IN, KS, KY, LA, MA, MD, MI, MN, MO, MS, NC, ND, NE, NY, OH, OK, PA, SC, SD, TN, TX, WI, WV	NS: Secure[G5]	Prairies, woodlands, disturbed sites, often in damp soil	Widespread hybridization with *C. discolor*.	
C. andersonii (A. Gray) Petrak	Anderson's thistle, rose thistle	P⁑	**USA**—CA, ID, NV	NS: Secure[G5]	Moist to dry soils, openings in montane woodlands, montane coniferous forests, aspen groves		⁑Often biennial
C. andrewsii (A. Gray) Jepson	Franciscan thistle	B/MP*	**USA**—CA	NS: Imperiled[G2]	Headlands, ravines, seeps near coast, sometimes on serpentine	Hybridizes with *C. quercetorum* (Keil 2006, Howell 1960)	
C. arizonicum (A. Gray) Petrak **var. *arizonicum***	Arizona thistle	P	**USA**—AZ, CA, NM, NV, UT	NS: Secure[G5]	Pine-oak-juniper woodlands, montane coniferous forests, subalpine		
C. a. (A. Gray) Petrak **var. *bipinnatum*** (Eastwood) D.J. Keil	Four corners thistle	P	**USA**—AZ, CO, NM, UT	NS: Apparently Secure[G4]	Canyons, rocky slopes, desert scrub, pine-oak-juniper woodlands, openings in coniferous forests		
C. a. (A. Gray) Petrak **var. *chellyense***	Navajo thistle	P	**USA**—AZ, NM	NS: Secure[G5]	Desert scrub, grasslands, pine-oak-juniper woodlands, ponderosa pine forests		
C. a. (A.Gray) Petrak **var. *rothrockii*** (A. Gray) D. J. Keil	Rothrock's thistle	P	**USA**—AZ, NM	NS: Vulnerable[G3]	Rocky slopes, pine-oak-juniper-cypress woodlands, montane coniferous forests		
C. a. (A. Gray) Petrak **var. *tenuisectum*** D. J. Keil	Desert mountains thistle	P	**USA**—CA, NV	NS: Imperiled[G2]	Rocky slopes, drainages, roadsides, pine-oak-juniper woodlands, montane coniferous forests		
C. barnebyi S.L. Welsh & Neese	Barneby's thistle	P	**USA**—CO, UT, WY	NS: Vulnerable[G3]	Dry juniper woodlands, sagebrush scrub, on shale, limestone, or sandstone		
C. brevifolium Nuttall	Palouse thistle	P†⁑	**USA**—ID, OR, WA	NS: Vulnerable[G3]	Palouse prairie		⁑Horizontal root sprouts
C. brevistylum Cronquist	Indian thistle, clustered thistle, short-style thistle	A/B	**USA**—CA, ID, MT, OR, WA; **CAN**—BC	NS: Secure[G5]	Coastal meadows, marshes, swamps, riparian woodlands, moist areas in coastal scrub, chaparral, coastal woodlands, mixed conifer-hardwood forests, coniferous forests	Hybridizes with *C. edule*	
C. canescens Nuttall	Platte thistle, prairie thistle	B/MP	**USA**—CA, CO, MO, MT, NE, NV, SD, WY; **CAN**—SK	NS: Apparently Secure[G4]	Sandy or gravelly soils in short-grass prairie, often in disturbed areas, mountain meadows, grassy slopes in montane coniferous forests	Hybridizes with *C. scariosum* and *C. parryi*	⁂Impacted by seedhead weevil
C. carolinianum (Walter) Fernald & B.G. Schubert	Carolina thistle, purple thistle, soft thistle, smallhead thistle	B	**USA**—AL, AR, GA, IL, ***IN***⚑, KY, LA, MO, MS, NC, ***OH***⚑, OK, SC, TN, TX	NS: Secure[G5]	Open woods, fields, roadsides		⚑Rare in IN[5]; threatened in OH[5]
C. ciliolatum (L.F. Henderson) J.T. Howell	Ashland thistle	P‡	**USA**—***CA***⚑, OR	NS: Vulnerable[G3]⁂	Grassy areas, open woodlands		⚑Endangered in CA[5]
C. clavatum (M.E. Jones) Petrak **var. *clavatum***	Fish lake thistle	B/PP	**USA**—CO, UT	NS: Vulnerable[G3]	Sagebrush scrub, aspen groves, meadows, openings in montane coniferous forests	Potentially hybridizes with *C. eatonii* var. *eatonii*	
C. c. (M.E. Jones) Petrak **var. *americanum*** (A. Gray) D.J. Keil	Rocky mountain fringed thistle	B/PP	**USA**—CO, UT, WY	NS: Apparently Secure[G4]	Oak scrub, sagebrush scrub, grasslands, juniper-pine woodlands, aspen groves, openings in montane coniferous forests	Potentially hybridizes with *C. pulcherrimum* var. *pulcherrimum*	
C. c. (M.E. Jones) Petrak **var. *osterhoutii*** (Rydberg) D.J. Keil	Osterhout's thistle	B/PP	**USA**—CO	NS: Imperiled[T2]	Openings in montane coniferous forests, subalpine, alpine		
C. crassicaule (Greene) Jepson	Slough thistle	A/B	**USA**—***CA***⚑	NS: Imperiled[G2]	Freshwater marshes, canal banks		⚑Species of greatest conservation need in CA[6]
C. cymosum (Greene) J.T. Howell **var. *cymosum***	Peregrine thistle	B/P	**USA**—CA, NV, OR	NS: Apparently Secure[G4]	Grassy areas, sagebrush steppe, California woodlands, open coniferous or conifer-hardwood forests, roadsides		
C. c. (Greene) J.T. Howell **var. *canovirens***	Graygreen thistle	B/P	**USA**—CA, ID, MT, NV, OR, WY	NS: Apparently Secure[G4]	Grasslands, sagebrush steppe, pinyon-juniper woodlands, dry coniferous forests, roadsides		
C. discolor (Muhlenberg ex Willdenow) Sprengel	Field thistle, chardon discolore	B⁑	**USA**—AL, AR, CT, D.C., DE, GA, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, NC, NE, NH, NY, OH, PA, RI, SC, SD, TN, VA, VT, WI; WV, **CAN**—MB, NB, ON, QC, SK	NS: Secure[G5]	Tallgrass prairie, deciduous woodlands, forest openings, disturbed sites, often in damp soil	Hybridizes with *C. muticum* and widespread hybridization with *C. altissimum*	⁑Sometimes perennial
C. douglasii de Candolle **var. *douglasii***	California swamp thistle, Douglas's thistle	B/MP*	**USA**—CA	NS: Apparently Secure[G4]	Springs, seeps, streamsides, coastal bluffs, coniferous and hardwood forests, often serpentine		
C. d. de Candolle **var. *breweri*** (A. Gray) D.J. Keil & C.E. Turner	Brewer's thistle	B/MP*	**USA**—CA, NV, OR	NS: Apparently Secure[G4]	Streams, fens, marshes, springs in montane coniferous forests, often serpentine		
C. drummondii Torrey & A. Gray	Drummond's thistle, dwarf thistle, short-stemmed thistle	B/MP	**USA**—CO, SD, WY; **CAN**—AB, BC, MB, NT, ON, SK	NS: Secure[G5]	Dry to moist soil, prairies, pastures, meadows, forest edges, woodland openings, roadsides		

Monarch butterfly (*Danaus plexippus*) nectaring on field thistle (*C. discolor*).

Thistle Species Native to the United States, Canada, and Mexico[1] *continued*

SCIENTIFIC NAME	COMMON NAME	⟳	Range[1,2]	Conservation Status[3]	Habitat	Hybridization	Comments
C. eatonii (A. Gray) B.L. Robinson **var. *eatonii***	Eaton's thistle	P	**USA**—NV, UT	NS: Apparently Secure[G4]	Rocky slopes, canyons, pinyon-juniper woodlands, montane coniferous forests, subalpine forests, alpine slopes		
C. e. (A. Gray) B. L. Robinson **var. *clokeyi*** (S.F. Blake) D.J. Keil	Clokey thistle, spring mountains thistle, or white-spine thistle	P	**USA**—NV	NS: Imperiled[G2]	Gravelly slopes, ravines, montane coniferous forests, subalpine forests, alpine scree		
C. e. (A. Gray) B.L. Robinson **var. *eriocephalum*** (A. Gray) D. J. Keil	Mountaintop thistle, alpine thistle	P	**USA**—CO, NM, UT	NS: Apparently Secure[G4]	Forest openings, alpine and subalpine meadows, windswept alpine ridges		
C. e. (A. Gray) B.L. Robinson **var. *hesperium*** (Eastwood) D.J. Keil	Tall mountain thistle	P	**USA**—CO	NS: Vulnerable[T3]	Rocky slopes, subalpine meadows, forest openings	Hybridizes with *C. pulcherrimum* var. *pulcherrimum* and *C. scariosum* var. *scariosum*	
C. e. (A. Gray) B.L. Robinson **var. *murdockii*** S.L. Welsh	Northern mountain thistle	P	**USA**—CO, ID, MT, NV, UT, WY	NS: Imperiled[G2]	Talus slopes, rocky subalpine and alpine ridges, openings in subalpine forests, subalpine meadows	Hybridizes with *C. inamoenum*	
C. e. (A. Gray) B.L Robinson **var. *peckii*** (L.F. Henderson) D.J. Keil	Steens mountain thistle, ghost thistle	P	**USA**—NV, OR	NS: Apparently Secure[G4]	Grasslands, juniper woodlands, grass-sagebrush steppes, subalpine slopes, roadsides		
C. e. (A. Gray) B.L. Robinson **var. *viperinum*** D. J. Keil	Snake range thistle	P	**USA**—NV	NS: Critically Imperiled[T1]	Rocky subalpine slopes, open bristlecone pine forests	Potentially hybridizes with *C. inamoenum*	
C. edule Nuttall **var. *edule***	Hall's thistle	B/MP	**USA**—AK, OR, WA; **CAN**—BC	NS: Secure[G5]	Sea bluffs, roadsides, damp soil in edges and openings in conifer or conifer-hardwood forests		
C. e. Nuttall **var. *macounii*** (Greene) D.J. Keil	Macoun's thistle	B/MP	**USA**—AK, OR, WA; **CAN**—BC	NS: Secure[G5]	Damp soil, mostly montane meadows, forests, alpine		
C. e. Nuttall **var. *wenatchense*** D.J. Keil	Wenatchee thistle	B/MP	**USA**—WA	NS: Secure[G5]	Stream banks, rocky slopes		
C. engelmannii Rydberg	Blackland thistle, Engelmann's thistle	B/MP	**USA**—LA, OK, TX	NS: Apparently Secure[G4]	Tallgrass prairies, old fields, roadsides, oak savannas, forest edges, in calcareous clay or rarely sand soils		
C. flodmanii (Rydberg) Arthur	Praire thistle, Flodman's thistle, chardon de Flodman	P‡	**USA**—CO, IA, IL, KS, MI, MN, MT, ND, NE, SD, WI, WY; **CAN**—AB, BC, MB, ON, QC, SK	NS: Secure[G5]	Tallgrass, mixedgrass, shortgrass prairies, meadows, pastures, often in damp soil	Hybridizes with *C. muticum* and *C. undulatum*. Hybrids with *C. undulatum* are often sterile (Dabydeen 1987)	
C. foliosum (Hooker) de Candolle	Leafy thistle, foliose thistle, elk thistle	B/MP	**USA**—WY; **CAN**—AB, BC, NT, YT	NS: Apparently Secure[G4]	Moist soils, grasslands, meadows, edges and openings in boreal forest, subalpine forests and alpine slopes		
C. fontinale (Greene) Jepson **var. *fontinale***	Fountain thistle	MP	**USA**—*CA*⚑	NS: Critically Imperiled[T1] ESA: Endangered	Serpentine seeps		⚑Federally endangered[4] and in CA[5,6]
C. f. (Greene) Jepson **var. *campylon*** (H. Sharsmith) Pilz ex D.J. Keil & C. E. Turner	Mount Hamilton thistle	MP	**USA**—CA	NS: Imperiled[T2]	Serpentine seeps in areas of chaparral, valley grasslands, foothill woodlands		
C. f. (Greene) Jepson **var. *obispoense*** J.T. Howell	Chorro creek bog thistle	MP	**USA**—*CA*⚑	NS: Imperiled[T2] ESA: Endangered	Serpentine seeps, coastal live oak woodlands, grasslands, riparian areas		⚑Federally endangered[4] and in CA[5,6]
C. grahamii A. Gray	Graham's thistle	B	**USA**—AZ, NM; **MEX**—CH, DU, SO	NS: Apparently Secure[G4]	Damp soil in oak woodlands, coniferous forests, meadows	Hybridizes with *C. parryi* and *C. scariosum* var. *coloradense*	
C. helenioides (L.) Hill	Melancholy thistle	P‡	Greenland, Iceland, Europe, Asia	NS: Not Ranked	Fjordlands		
C. hookerianum Nuttall	Hooker's thistle, white thistle	B/MP‡	**USA**—ID, MT, WA, WY; **CAN**—AB, BC	NS: Secure[G5]	Moist soil in grasslands, aspen parkland, forest edges and openings, subalpine, alpine meadows	Hybridizes with *C. undulatum*	‡Potentially polycarpic perennial
C. horridulum* var. *horridulum Michaux	Horrid thistle	B/P†	**USA**—AL, *CT*⚑, DE, FL, GA, LA, *MA*⚑, MD, ME, MS, NC, *NH*⚑, NJ, NY, *PA*⚑, *RI*⚑, SC, TN, TX, VA	NS: Secure[G5]	Meadows, pinelands, roadsides, often in damp soil	Hybridizes with *C. pumilum* var. *pumilum*	⚑Species of greatest conservation need in MA[6]; threatened in RI; endangered in CT, NH, PA[5]
C. h.* var. *megacanthum	Bigspine thistle	B/P†	**USA**—AL, AR, FL, LA, MS, OK, TX	NS: Secure[G5]	Meadows, pastures, roadsides, forest openings, low ground, often in damp soil		
C. h.* var. *vittatum	Florida thistle	B/P†	**USA**—AL, FL, GA, LA, MS, NC, SC	NS: Vulnerable[T3]	Meadows, pastures, old fields, pinelands, coastal plain, usually in damp soil		
C. hydrophilum (Greene) Jepson **var. *hydrophilum***	Suisun thistle	B/MP	**USA**—CA	NS: Critically Imperiled[T1] ESA: Endangered	Tidal marshes		⚑Federally endangered[4,5,6]
C. h. (Greene) Jepson **var. *vaseyi*** (A. Gray) J.T. Howell	Mount Tamalpais thistle, Vasey's thistle	B/MP	**USA**—CA	NS: Imperiled[T2] ESA: Endangered	Spring-fed serpentine marshy meadows in chaparral and mixed evergreen forest		
C. inamoenum (Greene) D.J. Keil **var. *inamoenum***	Greene's thistle	B/MP	**USA**—CA, ID, NV, OR, UT, WA, WY	NS: Apparently Secure[G4]	Arid slopes, roadsides, grasslands, sagebrush scrub, pinyon-juniper woodlands, montane coniferous forests	Hybridizes with *C. eatonii* var. *peckii* and potentially *C. eatonii* var. *viperinum*	
C. i. (Greene) D.J. Keil **var. *davisii*** (Cronquist) D.J. Keil	Davis's thistle	B/MP	**USA**—ID, NV, UT, WY	NS: Apparently Secure[G4]	Arid slopes, roadsides, grasslands, sagebrush scrub, dry woodlands, montane forests		
C. joannae S.L. Welsh	Joanna's thistle	P	**USA**—UT	NS: Critically Imperiled[T1]	Endemic to Zion National Park		
C. kamtschaticum Ledebour ex de Candolle	Kamchatka thistle	P	**USA**—AK; Asia (Japan, Siberia)	NS: Vulnerable[G3]	Meadows, tundra		

Thistle Species Native to the United States, Canada, and Mexico[1] *continued*

SCIENTIFIC NAME	COMMON NAME		Range[1,2]	Conservation Status[3]	Habitat	Hybridization	Comments
C. lecontei Torrey & A. Gray	Black thistle, Le Conte's thistle	P†⁑	**USA—*AL*⚑**, FL, LA, MS, NC, SC	NS: Vulnerable[G3]	Sandy pinelands of coastal plain, often in damp soil		⁑Sometimes biennial ⚑AL species of conservation concern[6]
C. longistylum R.J. Moore & Frankton	Long-style thistle	MP	**USA—**MT	NS: Imperiled[G2]	Moist soil in roadsides, meadows, forest edges and openings	Potentially hybridizes with *C. scariosum* var. *scariosum*	
C. mohavense (Greene) Petrak	Mojave thistle	B/P	**USA—**AZ, CA, NV, UT	NS: Imperiled[G2]	Wet soil, streams, springs, meadows in desert and desert woodlands		
C. muticum Michaux	Swamp thistle, dunce-nettle, horsetops, chardon mutique	B	**USA—*AL*⚑, *AR*⚑**, CT, DE, FL, GA, IA, IL, IN, KY, LA, MA, MD, ME, MI, MN, MO, NC, ND, NH, NJ, NY, OH, OK, PA, RI, SC, TN, TX, VA, VT, WI, WV; **CAN—**MB, NB, NF, NS, ON, PE, QC, SK	NS: Secure[G5]	Wet soil in meadows, prairies, marshes, swamps, bogs, open woods	Hybridizes with *C. discolor* and *C. flodmanii*	⚑AL species of conservation concern[1]; threatened in AR[5]
C. neomexicanum A. Gray	New Mexico thistle, Desert thistle	B	**USA—**AZ, CA, CO, NM, NV, TX, UT, WA; **MEX—**SO	NS: Secure[G5]	Canyons, slopes, roadsides in deserts, dry grasslands, arid woodlands dominated by pinyon pines, juniper, oaks, Joshua trees		
C. nuttallii de Candolle	Nuttall's thistle	B	**USA—*AL*⚑**, FL, GA, LA, MS, NC, SC, TX, VA	NS: Secure[G5]	Damp soil in roadsides, ditches, woodlands		⚑AL species of conservation concern[6]
C. occidentale (Nuttall) Jepson **var. *occidentale***	Cobwebby thistle	B	**USA—**CA	NS: Vulnerable[T3]	Coastal scrub, chaparral, oak woodlands, stabilized dunes, roadsides		
C. o. (Nuttall) Jepson **var. *californicum*** (A. Gray) D.J. Keil & C.E. Turner	California thistle	B	**USA—**CA	NS: Vulnerable[T3]	Pine-oak woodlands, riparian woodlands, chaparral, openings in mixed evergreen forests, roadsides		
C. o. (Nuttall) Jepson **var. *candidissimum*** (Greene) J.F. Macbride	Snowy thistle	B	**USA—**NV, OR	NS: Vulnerable[T3]	Coastal scrub, grassy openings in montane coniferous forests, arid woodlands, sagebrush scrub, roadsides		
C. o. (Nuttall) Jepson **var. *compactum*** Hoover	Compact cobwebby thistle	B	**USA—**CA	NS: Imperiled[T2]	Coastal see bluffs, dunes in grassland and coastal scrub		
C. o. (Nuttall) Jepson **var. *coulteri*** (Harvey & A. Gray) Jepson	Coulter's thistle	B	**USA—**CA	NS: Vulnerable[G3]	Coastal slopes and ridges, dunes, coastal scrub, grassland, oak woodlands		
C. o. (Nuttall) Jepson **var. *lucianum*** D.J. Keil	Cuesta Ridge thistle	B	**USA—**CA	NS: Imperiled[T2]	Chaparral, openings in closed cypress conifer forests, mixed evergreen forests, oak woodlands		
C. o. (Nuttall) Jepson **var. *venustum*** (Greene) Jepson	Venus thistle	B	**USA—**CA, NV	NS: Vulnerable[T3]	Foothill oak-pine woodlands, grasslands, chaparral, pinyon-juniper woodlands, Joshua tree woodlands, roadsides		
C. ochrocentrum A. Gray **var. *ochrocentrum***	Yellowspine thistle	P‡	**USA—**AZ, CA, CO, KS, NE, NM, OK, SD, TX, UT, WY	NS: Secure[G5]	Short-grass prairies, desert grasslands, sagebrush steppes, pinyon-juniper, mesquite woodlands, often in disturbed areas		
C. o. A. Gray **var. *martini*** (Barlow-Irick) D.J. Keil	Martin's thistle	P‡	**USA—**AZ, NM; MEX	NS: Secure[G5]	Desert grassland, arid shrubland, pine-, oak-, juniper-, or mesquite-dominated woodlands, often in disturbed areas, grassy slopes in montane pine forests		
C. ownbeyi S.L. Welsh	Ownbey's thistle	P	**USA—**CO, UT, WY	NS: Vulnerable[G3]	Dry soils, sometimes on seeps, stony soils in open areas of pinyon-juniper woodlands, sagebrush scrub, arid grasslands, riparian scrub		
C. parryi (A. Gray) Petrak	Parry thistle	B	**USA—*AZ*⚑**⁑, CO, NM	NS: Apparently Secure[G4]	Stream banks, montane meadows, damp soil in montane coniferous forests	Hybridizes with *C. grahamii* and *C. canescens*	⚑Salvage restricted in AZ[5]
C. perplexans (Rydberg) Petrak	Adobe hills thistle	B	**USA—*CO***[5]	NS: Imperiled[G2]	Barren shale hillsides, open areas in pinyon-juniper woodlands, sagebrush scrub, saltbush scrub, gambel oak brush, roadsides		⚑Species of greatest conservation need in CO[6]
C. pitcheri (Torrey ex Eaton) Torrey & A. Gray	Pitcher's thistle, Dune thistle, Sand-dune thistle	B/MP*	**USA—*IL*⚑, *IN*⚑, *MI*⚑, *WI*⚑; CAN—**ON	NS: Imperiled[G2] ESA: Threatened	Sand dunes and beaches		⚑Federally threatened species[4,5]; threatened in IL, IN, MI, WI[5]
C. praeteriens J.F. Macbride	Lost thistle, Palo Alto thistle	B/P	**USA—**CA	NS: Extinct[GX]	Unknown		
C. pulcherrimum (Rydberg) K. Schumann **var. *pulcherrimum***	Wyoming thistle	PP	**USA—**CO, ID, MT, NE, UT, WY	NS: Secure[G5]	Often stony soils, grasslands, sagebrush scrub, coniferous forest openings, roadsides	Hybridizes with *C. eatonii* var. *murdockii* and potentially *C. clavatum* var. *americanum*	
C. p. (Rydberg) K. Schumann **var. *aridum*** (Dorn) D.J. Keil	Cedar rim thistle	PP	**USA—**WY	NS: Imperiled[G2]	Barren slops in shallow, stony soil in open, arid grasslands		
C. pumilum (Nuttall) Sprengel **var. *pumilum***	Pasture thistle	B/MP†⁑	**USA—**CT, DE, MA, MD, ME, NC, NH, NJ, NY, OH, PA, RI, SC, VA, VT, WV	NS: Apparently Secure[G4]	Fields, pastures, open woods, roadsides		⁑Sometimes with root sprouts
C. p. (Nuttall) Sprengel **var. *hillii*** (Canby) B. Bolvin	Hill's thistle	B/MP†⁑	**USA—**IA, ***IL*⚑**, I***N*⚑**, MI, ***MN*⚑**, ***WI*⚑**; CAN—ON	NS: Vulnerable[G3]	Sandy or gravelly soils, prairies, limestone barrens, pastures, pine barrens, open woods, oak savannas	Hybridizes with *C. horridulum* var. *horridulum*	⁑Sometimes with root sprouts ⚑Special concern in MN[6], threatened in IL, WI[5], endangered in IN[5]
C. quercetorum (A. Gray) Jepson	Brownie thistle, Alameda County thistle	P	**USA—**CA	NS: Vulnerable[G3]	Dry coastal bluffs, grasslands, oak woodlands, coastal scrub	Hybridizes with *C. andrewsii*, *C. douglasii*, *C. occidentale*, *C. remotifolium* var. *odontolepis*, and *C. fontinale* var. *fontinale* (Keil 2006, Howell 1960)	

Thistle Species Native to the United States, Canada, and Mexico[1] *continued*

SCIENTIFIC NAME	COMMON NAME		Range[1,2]	Conservation Status[3]	Habitat	Hybridization	Comments
C. remotifolium (Hooker) de Candolle **var. *remotifolium***	Remote-leaved thistle	P	**USA**—CA, OR, WA	NS: Secure[G5]	Meadows, forest openings, open woods, brushy slopes		
C. r. (Hooker) de Candolle **var. *odontolepis*** Petrak	Pacific fringed thistle, fringe-scaled thistle	P	**USA**—CA, OR	NS: Secure[G5]	Grasslands, meadows, stream banks, brushy slopes, open coniferous or mixed conifer-hardwood forests		
C. r. (Hooker) de Candolle **var. *rivulare*** Jepson	Klamath thistle	P	**USA**—CA, OR	NS: Apparently Secure[G4]	Sea bluffs, river valleys, meadows, grasslands, open coniferous or mixed coniferous-hardwood forests		
C. repandum Michaux	Sand-hill thistle, coastal-plain thistle	P⁑	**USA**—GA, NC, SC, VA	NS: Secure[G5]	Sandhills, pine barrens, roadsides		⁑P with creeping roots, sometimes B
C. rhothophilum S.F. Blake	Surf thistle	B/MP*	**USA**—*CA*⚑	NS: Critically Imperiled[G1]	Coastal dunes and bluffs	Hybridizes with *C. occidentale* var. *occidentale* and *C. scariosum* var. *citrinum*	⚑Threatened in CA[5]
C. rydbergii Petrak	Rydberg's thistle, alcove thistle	P	**USA**—AZ, UT	NS: Vulnerable[G3]	Hanging gardens, seeps, stream banks		
C. scariosum Nuttall **var. *scariosum***	Meadow thistle, elk thistle, chardon écailleux	B/MP	**USA**—CA, CO, ID, MT, OR, UT, WA, WY; **CAN**—AB, BC, QC	NS: Secure[G5]	Moist, sometimes saline soils, meadows, ditches, stream banks, forest openings, sagebrush zone to subalpine forests	Hybridizes with *C. eatonii* var. *murdockii*	
C. s. Nuttall **var. *americanum*** (A. Gray) Keil	Dinnerplate, thistle, sessile thistle, stemless thistle	B/MP	**USA**—CA, CO, ID, NV, OR, UT, WY; **MEX**—BN	NS: Apparently Secure[G4]	Seasonally damp, sometimes saline soil in grasslands, meadows, open forests, sagebrush scrub		
C. s. Nuttall **var. *citrinum*** (Petrak) Keil	La Graciosa thistle	B/MP	**USA**—*CA*⚑; **MEX**	NS: Critically Imperiled[G1] ESA: Endangered	Wet ground, meadows, pastures, springs, marshes, coastal and interior	Potentially hybridizes with *C. canescens* and *C. undulatum*	⚑Federally endangered and in CA[5,6]
C. s. Nuttall **var. *coloradense*** (Rydberg) D.J. Keil	Colorado thistle	B/MP	**USA**—AZ, CO, NM, UT, WY	NS: Apparently Secure[T4]	Wet soil, forests, meadows, roadsides	Potentially hybridizes with *C. occidentale* var. *occidentale* and *C. rhothophilum*	
C. s. Nuttall **var. *congdonii*** (R. J. Moore & Frankton) Keil	Rosette thistle	B/MP	**USA**—CA, NV	NS: Secure[G5]	Meadows, springs, stream banks		
C. s. Nuttall **var. *robustum*** Keil	Shasta Valley thistle	B/MP	**USA**—CA, OR	NS: Secure[G5]	Wet ground, meadows, pastures, marshes		
C. s. Nuttall **var. *thorneae*** Welsh	Thorne's thistle	B/MP	**USA**—CO, ID, NV, UT	NS: Imperiled[T2]	Meadows, streamsides, valley bottoms		
C. s. Nuttall **var. *toiyabense*** Keil	Toiyabe thistle	B/MP	**USA**—ID, NV, OR	NS: Secure[G5]	Meadows, pastures, springs	Potentially hybridizes with *C. grahamii* and *C. undulatum*	
C. texanum Buckley	Texas thistle, Texas purple thistle, southern thistle	A/B	**USA**—AR, LA, MO, NM, OK, TX; **MEX**—CA, DU, NL, SL, TM	NS: Secure[G5]	Roadsides, pastures, fields, shrub-tree savannas	Potentially hybridizes with *C. undulatum*	
C. tracyi (Rydberg) Petrak	Tracy's thistle	P	**USA**—CO, NM, UT	NS: Secure[G5]	Dry slopes, sagebrush deserts, pinyon-juniper woodlands, openings in montane coniferous forests, disturbed ground		
C. turneri Warnock	Cliff thistle	P	**USA**—*TX*⚑; **MEX**	NS: Vulnerable[G3]	Crevices in limestone or basaltic cliffs		⚑Vulnerable species in TX[6]
C. undulatum (Nuttall) Sprengel	Wavyleaf thistle, gray thistle, pasture thistle	P†	**USA**—AZ, CA, CO, GA, IA, ID, IL, IN, KS, MI, MN, MO, MT, ND, NE, NM, OK, OR, PA, SD, TX, UT, WA, WI, WY; **CAN**—AB, BC, MB, SK; **MEX**—CA, CH, DU, SO	NS: Secure[G5]	Mixedgrass prairie, shortgrass prairie, Palouse prairie, sagebrush desert, pinyon-juniper woodlands, openings in montane coniferous forest, often in disturbed areas	Hybridize with *C. flodmanii*, *C. hookerianum*, *C. scariosum* var. *coloradense* and possibly *C. brevifolium*	
C. vinaceum (Wooton & Standley) Wooton & Standley	Sacramento mountains thistle	P	**USA**—*NM*⚑	NS: Critically Imperiled[G1] ESA: Threatened	Wet soil around calcareous springs and seeps, stream banks, montane meadows, coniferous forest margins	Hybridizes with *C. wrightii*	⚑Federally and state threatened[4,5,7]
C. virginianum (L.) Michaux	Virginia thistle	B/P	**USA**—DE, FL, *GA*⚑, NC, *NJ*⚑, SC, VA	NS: Vulnerable[G3]	Moist savannas, pine barrens, coastal plain bogs		⚑Endangered in NJ[4], potentially imperiled in GA[6]
C. wheeleri (A. Gray) Petrak	Wheeler's thistle	P†⁑	**USA**—AZ, CO, NM, TX, UT; **MEX**—CH, SO	NS: Vulnerable[G3]	Coniferous forests, pine-oak, juniper-dominated woodlands, meadows		⁑Deep-seated root sprouts
C. wrightii (A. Gray)	Wright's marsh thistle	B/MP	**USA**—AZ, *NM*⚑, TX; **MEX**—CH, SO	NS: Imperiled[G2] ESA: Under consideration	Springs, seeps, marshes, stream banks	Hybridizes with *C. vinaceum*	⚑Endangered in NM[7]; Under consideration for federal listing[4]

Notes

Life Cycle notes:
- * Short-lived
- † With root sprouts
- ‡ With runner roots
- ⁑ See Comments for more information

1. Information regarding distribution records of species with varieties is presented from Dr. David J. Keil's summary of the genus *Cirsium* appearing in Flora of North America (Keil 2006). Distribution records of species *without* varieties are based on Keil 2006 and Kartesz 2015.
2. Range—Canadian (CAN) provinces and territories are abbreviated as: Alberta (AB), British Columbia (BC), Manitoba (MB), New Brunswick (NB), Newfoundland and Labrador (NF), Nova Scotia (NS), Northwest Territories (NT), Ontario (ON), Prince Edward Island (PE), Quebec (QC), Saskatchewan (SK), Yukon (YT); Mexican (MEX) states are abbreviated as: Baja California (BN), Coahuila (CA), Chihuahua (CH), Durango (DU), Nuevo León (NL), San Luis Potosí (SL), Sonora (SO), Tamaulipas (TM)
3. Conservation Status—NatureServe (NS) conservation status (www.natureserve.org), Endangered Species Act (ESA) legal status (fws.gov/endangered).

⚑ Species of Conservation Concern (see Comments)—

4. Source: U.S. Fish & Wildlife Service federal listings (ecos.fws.gov/ecp/)
5. Source: USDA plants database (plants.usda.gov)
6. Source: Statewide Wildlife Action Plan
7. Source: New Mexico Energy, Minerals and Natural Resources Department (www.emnrd.state.nm.us/SFD/ForestMgt/Endangered.html)

Floral Visitors of Native North American Thistles*

	Family	Subgroup	Floral Visitor(s)†	Native Thistle(s)	Source(s)‡
Hymenoptera	ANDRENIDAE	Mining bees	*Andrena helianthi, A. miranda, A. runcinatae, Pseudopanurgus parvus*	*C. undulatum*	Krombein et al. 1979 (*Andrena helianthi, A. miranda*), Discover Life 2016 (*A. runcinatae, P. parvus*)
			A. crataegi	*C. hookerianum*	Stubbs et al 1994
	APIDAE	Bumble bees	*Bombus* spp.	*C. douglasii* var. *brewerii, C. muticum*	Gut et al. 1977 (*C. douglassii* var. *brewerii*), K. Chakya[1] (*C. muticum*)
			B. affinis, B. fernaldae	*C. altissimum*	Graenicher 1909 (*B. affinis*), Macior 1967 (*B. fernaldae*)
			B. appositus, B. ternarius	*C. undulatum*	Drons 2012 (*B. appositus, B. ternarius*), Discover Life 2016 (*B. ternarius*)
			B. auricomus	*C. altissimum, C. discolor, C. muticum, C. pumilum* var. *hilliii*	Graenicher 1909, Robertson 1929 (*C. altissimum*), Robertson 1929, Reed 1995 (*C. discolor*), S. Hendrix/University of Iowa[2] (*C. p.* var. *hillii*), D. Crawford[1] (*C. muticum*)
			B. balteatus, B. californicus	*C. scariosum*	Discover Life 2016
			B. bimaculatus	*C. altissimum, C. discolor, C. horridulum, C. p.* var. *hillii*	Hall and Ascher 2010, J. Eckberg/Xerces Society (*C. discolor*), S. Hendrix/University of Iowa[2] (*C. p.* var. *hillii*), Discover Life 2016 (*C. horridulum*)
			B. borealis	*C. discolor, C. undulatum*	D. Crawford[1] (*C. discolor*), Discover Life 2016 (*C. undulatum*)
			B. centralis, B. nevadensis	*C. canescens*	Discover Life 2016
			B. citrinus	*C. discolor*	M. Lucas[1]
			B. fervidus	*C. altissimum, C. discolor, C. flodmanii, C. undulatum*	K. Jokela/Xerces Society[1] (*C. altissimum*), Reed 1995 (*C. discolor*), K. Audette-Luebke[1] (*C. flodmanii*), Discover Life 2016 (*C. undulatum*)
			B. flavifrons, B. insularis	*C. hookerianum*	Discover Life 2016
			B. fraternus	*C. altissimum, C. discolor*	Robertson 1929
			B. griseocollis	*C. altissimum, C. discolor, C. undulatum*	Graenicher 1909 (*C. altissimum*), Robertson 1929, Reed 1995 (*C. discolor*), Discover Life 2016 (*C. undulatum*)
			B. huntii	*C. foliosum, C. ownbeyi*	T. Koerner/USFWS[2] (*C. foliosum*), Discover Life 2016 (*C. ownbeyi*)
			B. impatiens	*C. altissimum, C. discolor, C. horridulum*	Robertson 1929 (*C. altissimum*), Robertson 1929, Reed 1995 (*C. discolor*), Larsen 2016 (*C. horridulum*)
			B. morrisoni	*C. ownbeyi, C. rydbergii*	Discover Life 2016
			B. pensylvanicus	*C. altissimum, C. discolor, C. horridulum, C. p.* var. *hillii, C. undulatum*	Graenicher 1909, Robertson 1929 (*C. altissimum, C. discolor, C. p.* var. *hillii*), Reed 1995 (*C. discolor*), N. Adamson/Xerces Society[2] (*C. horridulum*), Discover Life 2016 (*C. undulatum*)
			B. perplexus	*C. pitcheri*	Keddy & Keddy 1984
			B. rufocinctus	*C. canescens, C. undulatum*	Discover Life 2016 (*C. canescens*), Discover Life 2016 (*C. undulatum*)
			B. vagans	*C. altissimum, C. discolor, C. pitcheri, C. p.* var. *hillii, C. undulatum*	Graenicher 1909, Robertson 1929 (*C. altissimum*), Reed 1995 (*C. discolor*), S. Hendrix/University of Iowa[2] (*C. p.* var. *hillii*), Keddy & Keddy 1984 (*C. pitcheri*)
			B. variabilis	*C. altissimum, C. discolor, C. p.* var. *hillii*	Graenicher 1909, Robertson 1929 (*C. altissimum*), Robertson 1929 (*C. discolor*), Robertson 1929 (*C. p.* var. *hillii*)
			B. vosnesenskii	*C. andrewsii, C. brevistylum, C. douglasii, C. fontinale, C. occidentale* var. *californicum, C. o.* var. *venustum, C. quercetorum*	Powell et al. 2011 (*C. andrewsii, C. brevistylum, C. fontinale, C. o.* var. *californicum, C. o.* var. *venustum, C. quercetorum*), Lopez 2017 (*C. douglasii*)
		Carpenter bees	*Xylocopa* spp.	*C. o.* var. *californicum*	Gut et al. 1977
			X. californica	*C. clokeyi, C. rydbergii*	Discover Life 2016 (*C. rydbergii*), Griswold et al 2006 (*C. clokeyi*)
			X. micans	*C. wheeleri*	P. Barabe[4]
			X. virginica	*C. horridulum*	L. Allain/USGS
		Chimney bees	*Diadasia enavata*	*C. canescens, C. undulatum*	Discover Life 2016
			D. ochracea	*C. undulatum*	Discover Life 2016
			Melitoma taurea	*C. discolor*	Robertson 1929
		Cuckoo bees	*Nomada rohweri, Triepeolus paenepectoralis*	*C. undulatum*	Discover Life 2016 (*N. rohweri*), Betancourt 2014b (*T. paenepectoralis*)
			Triepeolus concavus	*C. discolor*	Robertson 1929
			T. donatus	*C. altissimum, C. crassicaule, C. undulatum*	Graenicher 1909 (*C. altissimum*), Buchman et al. 2010 (*C. crassicaule*), Betancourt 2014a (*C. undulatum*)
			T. lunatus, T. remigatus	*C. crassicaule*	Buchman et al. 2010
			T. texanus	*C. scariosum, C. texanum, C. undulatum*	Betancourt 2014c
		Digger bees	*Anthophora* spp.	*C. d.* var. *brewerii, C. o.* var. *californicum*	Gut et al. 1977
			A. montana, A. walshii	*C. undulatum*	Discover Life 2016
			A. occidentalis	*C. horridulum*	Discover Life 2016
			A. terminalis	*C. discolor, C. o.* var. *californicum*	Reed 1995 (*C. discolor*), Discover Life 2016 (*C. o. var californicum*)
			A. urbana	*C. clokeyi, C. douglasii, C. drummondii, C. rydbergii, C. undulatum*	Griswold et al 2006 (*C. clokeyi*), Lopez 2017 (*C. douglasii*), Discover Life 2016 (*C. drummondii, C. rydbergii, C. undulatum*)
		Honey bee	*Apis mellifera*	*C. altissimum, C. texanum*	Graenicher 1909, Robertson 1929 (*C. altissimum*), Coakley 2008 (*C. texanum*)
		Long-horned bees	*Melissodes agilis*	*C. altissimum, C. discolor*	Robertson 1929 (*C. altissimum, C. discolor*), Reed 1995 (*C. discolor*)
			M. coloradensis, M. communis	*C. discolor*	Robertson 1929
			M. confusa, M. rivalis‡	*C. undulatum*	Discover Life 2016 (*M. confusa*), Lopez 2017 (*M. rivalis*)
			M. desponsa‡, *Svastra obliqua obliqua*	*C. altissimum, C. discolor, C. undulatum*	Graenicher 1909 and Robertson 1929 (*C. altissimum*), Discover Life 2016 (*M. desponsa/C. discolor, C. undulatum*), Reed 1995 (*S. o. obliqua/C. discolor*)
			M. trinodis	*C. altissimum*	Graenicher 1909
		Small carpenter bees	*Ceratina* spp.	*C. discolor*	Reed 1995
			C. calcarata	*C. p.* var. *hillii*	S. Hendrix/University of Iowa[2]

Floral Visitors of Native North American Thistles* *continued*

	Family	Subgroup	Floral Visitor(s)†	Native Thistle(s)	Source(s)‡
Hymenoptera *continued*	APIDAE (continued)	Small carpenter bees	*C. dupla dupla*	*C. altissimum, C. p.* var. *hillii*	Graenicher 1909 and Robertson 1929 (*C. altissimum*), S. Hendrix/University of Iowa[2] (*C. p.* var. *hillii*)
			C. mikmaqi	*C. altissimum, C. undulatum*	Discover Life 2016
			C. pacifica	*C. o.* var. *californicum*	Hung 2014 (*C. o.* var. *californicum*)
	COLLETIDAE	Cellophane bees	*Colletes eulophi*	*C. discolor*	Robertson 1929
		Yellow faced bees	*Hylaeus* spp.	*C. discolor*	Reed 1995
			H. annulatus	*C. undulatum*	Drons 2012
			H. rudbeckiae, H. nevadensis	*C. douglasii*	Lopez 2017
	HALICTIDAE	Green sweat bees	*Agapostemon* spp.	*C. o.* var. *californicum*	Gut et al. 1977
			A. angelicus	*C. drummondii, C. undulatum*	Discover Life 2016
			A. splendens	*C. altissimum*	Hall and Ascher 2010
			A. texanus	*C. o.* var. *occidentale*	A. E. Sims[5]
			A. virescens	*C. altissimum, C. discolor, C. horridulum, C. p.* var. *hillii, C. undulatum*	Graenicher 1909 (*C. altissimum*), Moure & Hurd 1987 (*C. discolor*), S. Hendrix/University of Iowa[2] (*C. p.* var. *hillii*), Discover Life 2016 (*C. horridulum, C. undulatum*)
			Augochlorella aurata	*C. altissimum*	Hall and Ascher 2010
			A. gratiosa	*C. horridulum*	Deyrup et al. 2002
			A. pomoniella	*C. o.* var. *venustum, C. rydbergii*	Gary McDonald[5] (*C. o.* var. *venustum*), Discover Life 2016 2016 (*C. rydbergii*)
		Sweat bees	*Halictus confusus*	*C. discolor*	Moure & Hurd 1987
			H. ligatus	*C. discolor, C. horridulum, C. neomexicanum, C. p.* var. *hillii, C. undulatum*	Robertson 1929 (*C. discolor*), S. Hendrix/University of Iowa[2] (*C. p.* var. *hillii*), Discover Life 2016 (*C. horridulum, C. neomexicanum, C. undulatum*)
			H. poeyi	*C. altissimum*	Hall and Ascher 2010
			H. rubicundus	*C. undulatum*	Discover Life 2016
			Lasioglossum spp.	*C. d.* var. *breweri*	Gut et al. 1977
			L. albipenne, L. comulum, L. manitouellum, L. perpunctatum	*C. undulatum*	Discover Life 2016
			L. cinctipes, L. leucozonium, L. pictum	*C. p.* var. *hilli*	S. Hendrix/University of Iowa[2]
			L. connexus, L. pilosus pilosus, Nomia nortoni nortoni	*C. altissimum*	Graenicher 1909 (*L. connexus, L. p. pilosus*), Moure & Hurd 1987 (*N. n. nortoni*)
			L. coriaceum	*C. horridulum*	Discover Life 2016
			L. egregium	*C. clokeyi*	Griswold et al 2006
			L. imitatum, L. zephyrus	*C. altissimum, C. discolor*	Graenicher 1909 and Robertson 1929 (*L. imitatum*), Robertson 1929 (*L. imitatum/C. discolor*), Reed 1995 (*L. zephyrus/C. discolor*)
			L. lineatulus, L. pruinosum, L. rohweri, L. versatum	*C. discolor*	Reed 1995 (*L. lineatulus, L. rohweri*), Robertson 1929 (*L. pruinosus, L. versatus*)
			L. pectorale	*C. horridulum, C. p.* var. *hillii, C. undulatum*	Deyrup et al. 2002 (*C. horridulum*), Robertson 1929 (*C. p.* var. *hillii*), Discover Life 2016 (*C. undulatum*)
			L. tegulariforme	*C. rydbergii*	Discover Life 2016
	MEGACHILIDAE	Leafcutter bees	*Ashmeadiella cactorum, A. opuntiae, Megachile gravita, M. lippiae, M. subnigra*	*C. o.* var. *californicum*	Discover Life 2016
			Megachile spp.	*C. d.* var. *breweri, C. muticum*	Gut et al. 1977 (*C. douglasii* var. *breweri*), S. Foltz Jordan/Xerces Society[3] (*C. muticum*)
			M. centuncularis, M. fidelis, M. perihirta	*C. undulatum*	Discover Life 2016
			M. frugalis	*C. neomexicanum*	Discover Life 2016
			M. inermis	*C. discolor, C. drummondii, C. o.* var. *californicum, C. scariosum, C. undulatum*	Spivak and Holzenthal 2013 (*C. discolor*), Discover Life 2016 (*C. drummondii, C. o.* var. *californicum, C. scariosum, C. undulatum*)
			M. latimanus‡	*C. altissimum, C. discolor, C. o.* var. *californicum, C. pitcheri, C. undulatum*	Discover Life 2016 (*C. altissimum, C. o.* var. *californicum, C. undulatum*), Robertson 1929, Reed 1995 (*C. discolor*), Keddy & Keddy 1984 (*C. pitcheri*), (Gardner and Spivak 2014)
			M. melanophaea	*C. o.* var. *californicum, C. pitcheri*	Discover Life 2016 (*C. o.* var. *califormicum*), Keddy & Keddy 1984 (*C. pitcheri*)
			M. montivaga	*C. altissimum, C. neomexicanum, C. o.* var. *californicum, C. p.* var. *hillii, C. undulatum*	Graenicher 1909 (*C. altissimum*), Robertson 1929 (*C. p.* var. *hillii*), Discover Life 2016 (*C. neomexicanum, C. o.* var. *californicum, C. undulatum*)
			M. onobrychidis	*C. drummondii*	Discover Life 2016
			M. pugnata	*C. douglasii, C. p.* var. *hillii, C. undulatum*	Lopez 2017 (*C. douglasii*), Robertson 1929 (*C. p.* var. *hillii*), Discover Life 2016 (*C. undulatum*)
			M. relativa	*C. discolor*	Reed 1995
			M. rivalis‡	*C. canescens, C. douglasii, C. occidentale, C. s.* var. *coloradense, C. undulatum*	Discover Life 2016 (*C. s. var. coloradense, C. canescens, C. undulatum*), Lopez 2017 (*C. douglasii, C. occidentale*), ‡*Cirsium* specialist
			M. xylocopoides	*C. altissimum*	Hall and Ascher 2010
		Leafcutter/mason cuckoo bees	*Coelioxys rufitarsis*	*C. altissimum, C. horridulum, C. neomexicanum, C. undulatum*	Graenicher 1909 (*C. altissimum*), Discover Life 2016 (*C. horridulum, C. neomexicanum, C. undulatum*)
			Stelis ater	*C. horridulum*	Hall and Ascher 2010
		Lithurgine bees	*Lithurgus apicalis*	*C. o.* var. *californicum, C. wheeleri*	Discover Life 2016 (*C. o.* var. *californicum, C. wheeleri*)
			L. gibbosus	*C. horridulum*	Deyrup et al. 2002

Floral Visitors of Native North American Thistles* *continued*

	Family	Subgroup	Floral Visitor(s)[†]	Native Thistle(s)	Source(s)[‡]
Hymenoptera *continued*	MEGACHILIDAE (continued)	Mason bees	*Hoplitis albifrons, H. hypocrita, H. producta*	*C. undulatum*	Discover Life 2016
			H. sambuci	*C. o.* var. *californicum*	Discover Life 2016
			Osmia spp.	*C. o.* var. *venustum*	Gut et al. 1977
			O. californica[‡], *O. nemoris*	*C. o.* var. *californicum, C. o.* var. *venustum*	Discover Life 2016
			O. chalybea[‡]	*C. horridulum*	Hall and Ascher 2010
			O. juxta, O. malina, O. montana, O. nifoata	*C. o.* var. *californicum*	Discover Life 2016
			O. simillima	*C. pitcheri*	Keddy & Keddy 1984
			O. texana[‡]	*C. arizonicum*, *C. canescens, C. discolor, C. douglasii, C. o.* var. *californicum, C. o.* var. *venustum, C. s.* var. *americanum C. undulatum*	Discover Life 2016 (*C. arizonicum, C. canescens, C. o.* var. *californicum, C. o.* var. *venustum, C. undulatum*), Lopez 2017 (*C. douglasii*)
		Resin bees	*Heriades carinatus*	*C. drummondii*	Discover Life 2016
			H. leavitti	*C. altissimum*	Robertson 1929
			H. occidentalis	*C. o.* var. *californicum*	Discover Life 2016
			H. variolosus	*C. drummondii, C. undulatum*	Discover Life 2016 (*C. drummondii*), Discover Life 2016 (*C. undulatum*)
		Wool-carder bees	*Anthidiellum notatum, Dianthidium singulare*[‡]	*C. douglasii*	Lopez 2017
			Anthidium edwini, A. emarginatum	*C. undulatum*	Hicks 1926 (Also documented to collect fibers from stems and undersides of leaves)
			A. maculosum	*C. a.* var. *bipinnatum*	Gonzalez and Griswold 2013
			A. placitum	*C. a.* var. *bipinnatum, C. neomexicanum*	Gonzalez and Griswold 2013
			Dianthidium heterulkei	*C. clokeyi*	Griswold et al 2006
	FORMICIDAE	Ants	*Unidentified species*	*C. o.* var. *californicum*	Gut et al. 1977
	ICHNEUMONIDAE	Ichneumonid wasps	*Temelucha ferrugineus*	*C. discolor*	Reed 1995
	PTEROMALIDAE	Chalcid wasps	*Pteromalus* spp.	*C. altissimum*	Takahashi 2006
	SPHECIDAE	Sphecid wasps	*Unidentified species*	*C. d.* var. *breweri, C. o.* var. *californicum*	Gut et al. 1977
	VESPIDAE	Vespid wasps	*Unidentified species*	*C. o.* var. *californicum*	Gut et al. 1977
Lepidoptera	HESPERIIDAE	Skippers	*Asbolis capucinus, Atalopedes campestris, Atrytonopsis loammi, Euphyes arpa, Nastra lherminier, Polites vibex*	*C. nuttallii*	M. Keim[4]
			Anatrytone logan	*C. altissimum, C. nuttallii*	T. Burk/Creighton University[2] (*C. altissimum*), M. Keim[4] (*C. nuttallii*)
			Epargyreus clarus	*C. altissimum, C. muticum*	J. Hopwood/Xerces Society[3] (*C. altissimum*), M. Barrett[1] (*C. muticum*)
			Hesperia leonardus	*C. discolor, C. muticum*	Reed 1995, M. Slater[1] (*C. muticum*)
			Oligoria maculata	*C. horridulum**, *C. nuttallii*	M. Keim[4]
			Polites peckius	*C. altissimum, C. discolor, C. flodmanii, C. p.* var. *hillii*	T. Burk/Creighton University[2] (*C. altissimum*), K. Chayka[1] (*C. discolor*), Robertson 1929 (*C. p.* var. *hillii*), K. Audette-Luebke[1] (*C. flodmanii*)
			P. themistocles	*C. altissimum*	Graenicher 1909
			Thorybes bathyllus	*C. p.* var. *hillii*	Robertson 1929
	NYMPHALIDAE	Brush-footed butterflies	*Agraulis vanillae*	*C. altissimum, C. horridulum, C. texanum*	E. Honeycutt[1] (*C. altissimum*), Jan Nagalski[4] (*C. horridulum*), J. McCulloch[4] (*C. texanum*)
			Danaus plexippus	*C. altissimum, C. discolor, C. o.* var. *californicum, C. pitcheri, C. p.* var. *hillii, C. texanum*	Graenicher 1909 (*C. altissimum*), Robertson 1929 (*C. discolor*), Jeff Skrentny[4] (*C. pitcheri*), Robertson 1929 (*C. p.* var. *hillii*), Las Pilitas Nursery 2016[2] (*C. o.* var. *californicum*)
			D. gilippus	*C. altissimum, C. texanum*	J. McCulloch[4] (*C. texanum*)
			Limenitis spp., *Speyeria* spp.	*C. o.* var. *californicum*	Gut et al. 1977
			L. archippus, S. aphrodite alcestis, Vanessa atalanta	*C. altissimum*	Graenicher 1909 (*L. archippus, S. aphrodite alcestis, V. virginiensis*), Robertson 1929 (*V. atalanta*)
			L. arthemis arthemis, S. atlantis	*C. pitcheri*	Keddy & Keddy 1984
			Speyeria cybele	*C. altissimum, C. discolor, C. muticum, C. p.* var. *hillii*	Graenicher 1909, Robertson 1929 (*C. altissimum*), Robertson 1929 (*C. discolor*), Robertson 1929 (*C. p.* var. *hillii*), M. Barrett[1] (*C. muticum*)
			S. idalia	*C. altissimum, C. discolor, C. flodmanii, C. p.* var. *hillii*	Graenicher 1909 (*C. altissimum*), Robertson 1929 (*C. discolor*), D. Jungst[1] (*C. flodmanii*), Robertson 1929 (*C. p.* var. *hillii*)
			Vanessa cardui	*C. discolor, C. texanum*	Robertson 1929 (*C. discolor*), J. McCulloch[4] (*C. texanum*)
			V. virginiensis	*C. altissimum, C. nuttallii, C. texanum*	Graenicher 1909 and Robertson 1929 (*C. altissimum*), M. Keim[4] (*C. nuttallii*), J. McCulloch[4] (*C. texanum*)
	PAPILIONIDAE	Swallowtails	*Battus philenor*	*C. horridulum, C. p.* var. *hillii, C. texanum*	Robertson 1929 (*C. p.* var. *hillii*), J. Englert/NRCS 2016[4] (*C. horridulum*), Coakley 2008 and R. Nussbaumer[7] (*C. texanum*)
			Papilio spp.	*C. o.* var. *californicum*	Gut et al. 1977
			P. cresphontes	*C. altissimum, C. discolor, C. muticum, C. p.* var. *hillii, C. texanum*	Robertson 1929 (*C. altissimum, C. discolor, C. p.* var. *hillii*), Zach Castern[1] (*C. muticum*), R. Nussbaumer[7] (*C. texanum*)
			P. eurymedon	*C. o.* var. *venustum*	Las Pilitas Nursery 2016[2]
			P. glaucus	*C. altissumum, C. discolor, C. muticum*	Graenicher 1909, Robertson 1929 (*C. altissimum*), M. Barrett[1] (*C. discolor*), K. Chayka[1] (*C. muticum*)
			P. palamedes	*C. repandum*	Theis and Raguso 2005
			P. polyxenes asterias	*C. altissimum, C. discolor, C. muticum*	Graenicher 1909 (*C. altissimum*), Robertson 1929 (*C. discolor*), M. Barrett[1] (*C. muticum*)
			P. troilus	*C. altissimum, C. p.* var. *hillii*	Robertson 1929 (*C. altissimum, C. p.* var. *hillii*)

Floral Visitors of Native North American Thistles* *continued*

Order	Family	Subgroup	Floral Visitor(s)†	Native Thistle(s)	Source(s)‡
Lepidoptera	PIERIDAE	Sulphurs	*Colias eurytheme*	*C. discolor, C. texanum*	Hilty 2016 (*C. discolor*), C. Fabre[6] and R. Nussbaumer[7] (*C. texanum*)
			C. philodice	*C. p.* var. *hillii*	Robertson 1929
			Phoebis sennae	*C. discolor*	Robertson 1929
			Zerene eurydice	*C. o.* var. *venustum*	Las Pilitas Nursery 2016[2]
		Whites	*Pieris rapae*	*C. altissimum*	Graenicher 1909
	SPHINGIDAE	Hawk moths	*Hemaris diffinis*	*C. discolor*	Tartaglia 2013
			H. thysbe, Hyles lineata	*C. altissimum, C. discolor*	Robertson 1929 (*Hyles lineata, H. thysbe/C. altissimum*), Tartaglia 2013 (*H. thysbe/C. discolor*)
			Unidentified species	*C. d.* var. *breweri*	Gut et al. 1977
Diptera	SYRPHIDAE	Hover flies	Syrphini (tribe), *Eristalis tenax, Eupeodes volucris*	*C. altissimum*	K. Chayka[1] (Syrphini), Graenicher 1909 (*Eristalis tenax, Eupeodes volucris*)
			Platycheirus inversus	*C. discolor, C. pitcheri*	Reed 1995 (*C. discolor*), Keddy & Keddy 1984 (*C. pitcheri*)
			Toxomerus marginatus	*C. discolor*	Reed 1995
	BOMBYLIIDAE	Bee flies	*Exoprosopa fasciata, Systoechus vulgaris*	*C. discolor*	Robertson 1929
	STRATIOMYIDAE	Soldier flies	*Stratiomys badia*	*C. pitcheri*	Keddy & Keddy 1984
	TACHINIDAE	Tachinid flies	*Onychogonia flaviceps*	*C. pitcheri*	Keddy & Keddy 1984
Coleoptera	CHRYSOMELIDAE	Leaf beetles	*Diabrotica longicornis*	*C. discolor*	Robertson 1929
			D. undecimpunctata	*C. altissimum*	Graenicher 1909
	CANTHARIDAE	Soldier beetles	*Chauliognathus pennsylvanicus*	*C. altissimum, C. discolor, C. muticum*	Williams 2006
			Unidentified species	*C. texanum*	R. Nussbaumer[7] (*C. texanum*)
	MELLOIDAE	Blister beetles	*Nemognatha* spp.	*C. flodmanii, C. mohavense, C. repandum*	K. Chayka[1] (*C. flodmanii*), C. Naventi[4] (*C. mohavense*), L. Fogo/USFWS[4] (*C. repandum*)
	SCARABAEIDAE	Scarab beetles	*Trichiotinus piger*	*C. altissimum, C. p.* var. *hillii*	Graenicher 1909 (*C. altissimum*), Robertson 1929 (*C. p.* var. *hillii*)
	MORDELLIDAE	Tumbling flower beetles	Unidentified species	*C. repandum*	N. Adamson/Xerces Society[2]
	CERAMBYCIDAE	Long-horned beetles	*Typocerus sinuatus*	*C. p.* var. *hillii, C. texanum*	Robertson 1929 (*C. p.* var. *hillii*), J. Mcculloch[4] (*C. texanum*)
Other Orders	CHRYSOPIDAE	Green lacewings	Unidentified species	*C. discolor*	J. Eckberg/Xerces Society[3]
	COREIDAE	Leaf-footed bugs	*Leptoglossus phyllopus*	*C. horridulum*	C. Fannon[6]
	PHYMATIDAE	Ambush bugs	*Phymata* spp.	*C. altissimum, C. discolor, C. flodmanii*	D. Jungst[1] (*C. altissimum*), A. Coppens[1] (*C. discolor*), K. Chayka[1] (*C. flodmanii*)
	SALTICIDAE	Jumping spiders	Unidentified species	*C. altissimum, C. discolor*	D. Jungst[1] (*C. altissimum*), S. Foltz Jordan/Xerces Society[3] (*C. discolor*)
	TETTIGONIIDAE	Katydids	Unidentified species	*C. discolor*	M. Lucas[1]
	TROCHILIDAE	Hummingbirds	*Amazilia yucatanenensis, Calothorax lucifer, Archilochus alexandri*	*C. texanum*	R. Nussbaumer[7]
			Archilochus colubris	*C. discolor, Cirsium texanum*	Hilty 2017
			Calypte anna	*C. coulteri, C. o.* var. *venustum, C. o.* var. *californicum*	B. Schram[4] (*C. coulteri*), Las Pilitas Nursery 2016[2] (*C. o.* var. *venustum*), M. Cheng[4] (*C. o.* var. *californicum*)
			Selasphorus platycercus, S. rufus	*C. undulatum*	T. Barnwell[4]
			S. calliope	*C. andersonii*	J. Bloomdale[4]
			Unidentified species	*C. d.* var. *breweri, C. o.* var. *californicum*	Gut et al. 1977

Notes

* This list is not comprehensive, but demonstrates the wide diversity of animals that are attracted to and supported by native thistle flowers.
⁑ Variety not specified.
⁂ *Cirsium* specialist—this species has been documented to prefer or feed exclusively on *Cirsium* spp., even when other nectar resources are available.
† Floral Visitor(s) are sorted by order, family, and genus.
‡ Source(s) notes:
1. Via the Pollinators on Native Plants Facebook Group: https://www.facebook.com/groups/PollinatorsNativePlants/
2. Personal communication
3. Personal observation
4. Via Flickr: https://www.flickr.com/
5. Via BugGuide: http://bugguide.net/
6. Via the Ladybird Johnson Wildflower Center: https://www.wildflower.org/
7. Via Rolf Nussbaumer Photography: http://rolfnussbaumer.photoshelter.com/

Figure B: From left to right: *Bombus impatiens*, *B. pensylvanicus*, *Xylocopa virginica*, and *Osmia chalybea* on *C. horridulum*.

APPENDIX C

Thistle Identification Resources

Web Resources for Identifying Native Thistles and Other Native Plants:

Flora of North America
http://efloras.org
(Family Asteraceaea, tribe Cardueae, genus *Cirsium*)

USDA Plants
http://plants.usda.gov

Go Botany
https://gobotany.newenglandwild.org

Ladybird Johnson Wildflower Center
www.wildflower.org

Minnesota Wildflowers
www.minnesotawildflowers.info

Illinois Wildflowers
http://illinoiswildflowers.info

Calflora
www.calflora.org

The Jepson Herbarium Jepson eFlora
http://ucjeps.berkeley.edu/eflora

SEINet Arizona–New Mexico Chapter
http://swbiodiversity.org/seinet/index.php

Regional Thistle Guides

Alabama Plant Atlas
http://floraofalabama.org

Atlas of Florida Plants
http://florida.plantatlas.usf.edu

Minnesota's Thistles (Minnesota Board of Water & Soil Resources Featured Plant)
http://bwsr.state.mn.us/native_vegetation/featured_plant/March2013_FP_Minnesota%20Thistles.pdf

Thistles of Nebraska
neweed.org/Documents/Thistles%20of%20Nebraska.pdf

New Mexico Thistle Identification Guide
http://www.npsnm.org/wp-content/uploads/2016/02/NM_Thistles_screen_or_8.5x11_2162016.pdf

Weakley's Flora of the Southern and Mid-Atlantic States
http://herbarium.unc.edu/flora.htm
(*Cirsium* identification key on pages 1103-1104)

University of North Carolina—Flora of the Southeastern United States
http://herbarium.unc.edu/seflora/firstviewer.htm

The Thistles of North Dakota
http://ag.ndsu.edu/publications/crops/the-thistles-of-north-dakota

Thistles in Oklahoma and Their Identification
http://okrangelandswest.okstate.edu/files/grazing%20management%20pdfs/PSS-2776web.pdf

University of South Carolina Herbarium
http://herbarium.biol.sc.edu/scplantatlas.html

A Guide to the Common Native and Exotic Thistles of South Dakota
http://openprairie.sdstate.edu/cgi/viewcontent.cgi?article=1020&context=extension_ss

Southeast Regional Network of Expertise and Collections (SERNEC)
http://sernecportal.org/portal/#

Southeastern Flora
http://southeasternflora.com/SearchForm.php

University of Texas Plant Resources Center
http://w3.biosci.utexas.edu/prc

Digital Atlas of the Virginia Flora
http://vaplantatlas.org

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Betancourt, V. H. G. 2014b, September 3. "*Triepeolus paenepectoralis* (Viereck, 1905)." Anthophila—an Online Repository of Bee Diversity. http://apoidea.myspecies.info/node/923. [Accessed 21 June 2017.]

Betancourt, V. H. G. 2014c, September 3. "*Triepeolus texanus* (Cresson, 1878)." Anthophila—an Online Repository of Bee Diversity. http://apoidea.myspecies.info/node/949. [Accessed 21 June 2017.]

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The Xerces Society/Kelly Gill: Figure 6.7 (drill seeding)

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Brown-belted bumble bee (*Bombus griseocollis*) foraging on field thistle (*Cirsium discolor*).

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