SPECIES: Carduus nutans

INTRODUCTORY

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FEIS ABBREVIATION:
CARNUT

SYNONYMS:
Carduus nutans ssp. *leiophyllus* (Petrovic) Stoj. & Stef. [42,120]
Carduus nutans ssp. *macrocephalus* (Desf.) Nyman [24,42,58,120]
Carduus nutans ssp. *macrolepis* (Peterm.) Kazmi [120,127]

Carduus thoermeri Weinm. [115]

NRCS PLANT CODE [120]:
CANU4
CANUN

COMMON NAMES:
musk thistle
nodding plumeless thistle
nodding thistle
plumeless thistle

TAXONOMY:
In North American literature, the scientific name *Carduus nutans* L., commonly known as musk thistle, has been applied to an aggregate of large-flowered plumeless thistles in the aster (Asteraceae) family [92]. This report uses *Carduus nutans* L. as the scientific name for the musk thistle complex as it occurs in North America [8,17,37,42,53,60,67,74,87,94,112,128,130].

The *C. nutans*
group has almost continuous variation in several morphological characteristics, and intermediates between taxa can be found [118]. Kartesz and Meachum [59] identify 4 subspecies in North America (see "Synonyms" above), while Flora Europaea identifies only *Carduus nutans* L. ssp. *nutans* as a subspecies that occurs in North America [115]. Detailed treatments of the taxonomy of *Carduus* species are available [21,115,118].

Hybridization and introgression between musk thistle and spiny plumeless thistle (*Carduus acanthoides*) have been reported. The hybrid is referred to as *C.* × *orthocephalus* Wallr. and has been studied extensively in Ontario ([22] and sources therein).

LIFE FORM:
Forb

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
At the time of this writing (2002), musk thistle is classified as a noxious, restricted or prohibited weed or weed seed in 22 states in the United States and 4 Canadian provinces [121]. See the Invaders or Plants databases for more information.

DISTRIBUTION AND OCCURRENCE

SPECIES: Carduus nutans

- GENERAL DISTRIBUTION
- ECOSYSTEMS
- STATES
- BLM PHYSIOGRAPHIC REGIONS
- KUCHLER PLANT ASSOCIATIONS
- SAF COVER TYPES
- SRM (RANGELAND) COVER TYPES

- HABITAT TYPES AND PLANT COMMUNITIES

GENERAL DISTRIBUTION:
Beck [11] provides a discussion of the origin, history, and distribution of musk thistle; the following is a discussion based on that review, except where otherwise cited. Musk thistle is native to western and central Europe, northwards to Scotland and extending to Sicilia, central Yugoslavia, and Ukraine [118], western Siberia, Asia Minor, and North Africa [22]. It has since been introduced to North and South America, Australia, and New Zealand [92]. Worldwide distribution of musk thistle is limited to the temperate zones of the northern and southern hemispheres, although occasional sightings in the tropics at high elevation have been reported. The earliest records of musk thistle in North America are from central Pennsylvania in 1852, followed by several records of its occurrence along the east coast in the late 1800s, apparently associated with ship ballast. Musk thistle began to appear in the Midwest around the turn of the 20th century. By the early 1940s, musk thistle was regarded as a potential problem in North America. In 1976, Dunn [29] reported the presence of musk thistle in at least 1 out of every 10 counties in the U.S. As of 1999, musk thistle was reported to occur in 45 states in the U.S. and all of the southern Canadian provinces [59].

Subspecies of musk thistle described in North America each have a specific area of distribution as described by Kartesz and Meachum [59]. See the Plants
database for distribution maps of musk thistle and described subspecies in the United States.

The following biogeographic classification systems are presented as a guide to demonstrate where musk thistle might be found or is likely to be invasive, based on reported occurrence and biological tolerance to factors that are likely to limit its distribution. Precise distribution information is lacking. Therefore, these lists are speculative and not exhaustive.

ECOSYSTEMS [36]:
FRES15 Oak-hickory
FRES17 Elm-ash-cottonwood
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES25 Larch
FRES28 Western hardwoods
FRES29 Sagebrush
FRES34 Chaparral-mountain shrub
FRES35 Pinyon-juniper
FRES36 Mountain grasslands
FRES37 Mountain meadows
FRES38 Plains grasslands
FRES39 Prairie
FRES40 Desert grasslands
FRES42 Annual grasslands

STATES [59]:

AL	AZ	AR	CA	CO	CT	DE	GA	ID	IL
IN	IA	KS	KY	LA	MD	MA	MI	MN	MS
MO	MT	NE	NV	NH	NJ	NM	NY	NC	ND
OH	OK	OR	PA	RI	SC	SD	TN	TX	UT
VA	WA	WV	WI	WY	DC				

AB BC MB NB NF NS ON PQ SK

BLM PHYSIOGRAPHIC REGIONS [12]:
1 Northern Pacific Border
2 Cascade Mountains
3 Southern Pacific Border
4 Sierra Mountains
5 Columbia Plateau
6 Upper Basin and Range
7 Lower Basin and Range
8 Northern Rocky Mountains
9 Middle Rocky Mountains
10 Wyoming Basin
11 Southern Rocky Mountains
12 Colorado Plateau
13 Rocky Mountain Piedmont
14 Great Plains
15 Black Hills Uplift
16 Upper Missouri Basin and Broken Lands

KUCHLER [65] PLANT ASSOCIATIONS:
K005 Mixed conifer forest
K010 Ponderosa shrub forest
K011 Western ponderosa forest
K012 Douglas-fir forest
K014 Grand fir-Douglas-fir forest
K016 Eastern ponderosa forest
K017 Black Hills pine forest
K018 Pine-Douglas-fir forest
K019 Arizona pine forest
K022 Great Basin pine forest
K023 Juniper-pinyon woodland
K024 Juniper steppe woodland
K025 Alder-ash forest
K026 Oregon oakwoods
K029 California mixed evergreen forest
K030 California oakwoods
K031 Oak-juniper woodland
K032 Transition between K031 and K037
K037 Mountain-mahogany-oak scrub
K038 Great Basin sagebrush
K047 Fescue-oatgrass
K048 California steppe
K050 Fescue-wheatgrass
K051 Wheatgrass-bluegrass
K053 Grama-galleta steppe
K054 Grama-tobosa prairie
K055 Sagebrush steppe
K056 Wheatgrass-needlegrass shrubsteppe
K057 Galleta-threeawn shrubsteppe
K063 Foothills prairie
K064 Grama-needlegrass-wheatgrass

K065 Grama-buffalo grass
K066 Wheatgrass-needlegrass
K067 Wheatgrass-bluestem-needlegrass
K068 Wheatgrass-grama-buffalo grass
K069 Bluestem-grama prairie
K070 Sandsage-bluestem prairie
K072 Sea oats prairie
K074 Bluestem prairie
K075 Nebraska Sandhills prairie
K076 Blackland prairie
K081 Oak savanna
K082 Mosaic of K074 and K100
K085 Mesquite-buffalo grass
K089 Black Belt
K098 Northern floodplain forest
K100 Oak-hickory forest
K101 Elm-ash forest
K104 Appalachian oak forest

SAF COVER TYPES [32]:
14 Northern pin oak
39 Black ash-American elm-red maple
40 Post oak-blackjack oak
42 Bur oak
43 Bear oak
50 Black locust
52 White oak-black oak-northern red oak
53 White oak
55 Northern red oak
63 Cottonwood
95 Black willow
109 Hawthorn
110 Black oak
206 Engelmann spruce-subalpine fir
209 Bristlecone pine
210 Interior Douglas-fir
211 White fir
212 Western larch
213 Grand fir
216 Blue spruce
217 Aspen
219 Limber pine
220 Rocky Mountain juniper
222 Black cottonwood-willow
233 Oregon white oak
234 Douglas-fir-tanoak-Pacific madrone
235 Cottonwood-willow
236 Bur oak
237 Interior ponderosa pine
238 Western juniper
239 Pinyon-juniper
240 Arizona cypress
243 Sierra Nevada mixed conifer

245 Pacific ponderosa pine
246 California black oak
249 Canyon live oak
250 Blue oak-foothills pine

SRM (RANGELAND) COVER TYPES [105]:
101 Bluebunch wheatgrass
102 Idaho fescue
103 Green fescue
104 Antelope bitterbrush-bluebunch wheatgrass
105 Antelope bitterbrush-Idaho fescue
106 Bluegrass scabland
107 Western juniper/big sagebrush/bluebunch wheatgrass
109 Ponderosa pine shrubland
110 Ponderosa pine-grassland
201 Blue oak woodland
203 Riparian woodland
208 Ceanothus mixed chaparral
209 Montane shrubland
210 Bitterbrush
215 Valley grassland
216 Montane meadows
235 Cottonwood-willow
301 Bluebunch wheatgrass-blue grama
302 Bluebunch wheatgrass-Sandberg bluegrass
303 Bluebunch wheatgrass-western wheatgrass
304 Idaho fescue-bluebunch wheatgrass
305 Idaho fescue-Richardson needlegrass
306 Idaho fescue-slender wheatgrass
307 Idaho fescue-threadleaf sedge
308 Idaho fescue-tufted hairgrass
309 Idaho fescue-western wheatgrass
310 Needle-and-thread-blue grama
311 Rough fescue-bluebunch wheatgrass
312 Rough fescue-Idaho fescue
314 Big sagebrush-bluebunch wheatgrass
315 Big sagebrush-Idaho fescue
316 Big sagebrush-rough fescue
317 Bitterbrush-bluebunch wheatgrass
318 Bitterbrush-Idaho fescue
319 Bitterbrush-rough fescue
320 Black sagebrush-bluebunch wheatgrass
321 Black sagebrush-Idaho fescue
322 Curlleaf mountain-mahogany-bluebunch wheatgrass
323 Shrubby cinquefoil-rough fescue
324 Threetip sagebrush-Idaho fescue
401 Basin big sagebrush
402 Mountain big sagebrush
403 Wyoming big sagebrush
404 Threetip sagebrush
405 Black sagebrush
406 Low sagebrush
407 Stiff sagebrush

408 Other sagebrush types
409 Tall forb
412 Juniper-pinyon woodland
413 Gambel oak
415 Curlleaf mountain-mahogany
416 True mountain-mahogany
417 Littleleaf mountain-mahogany
420 Snowbrush
421 Chokecherry-serviceberry-rose
422 Riparian
503 Arizona chaparral
504 Juniper-pinyon pine woodland
509 Transition between oak-juniper woodland and mahogany-oak association
601 Bluestem prairie
602 Bluestem-prairie sandreed
603 Prairie sandreed-needlegrass
604 Bluestem-grama prairie
605 Sandsage prairie
606 Wheatgrass-bluestem-needlegrass
607 Wheatgrass-needlegrass
608 Wheatgrass-grama-needlegrass
609 Wheatgrass-grama
610 Wheatgrass
611 Blue grama-buffalo grass
612 Sagebrush-grass
613 Fescue grassland
614 Crested wheatgrass
703 Black grama-sideoats grama
704 Blue grama-western wheatgrass
705 Blue grama-galleta
706 Blue grama-sideoats grama
707 Blue grama-sideoats grama-black grama
708 Bluestem-dropseed
709 Bluestem-grama
710 Bluestem prairie
713 Grama-muhly-threeawn
714 Grama-bluestem
715 Grama-buffalo grass
717 Little bluestem-Indiangrass-Texas wintergrass
720 Sand bluestem-little bluestem (dunes)
721 Sand bluestem-little bluestem (plains)
722 Sand sagebrush-mixed prairie
724 Sideoats grama-New Mexico feathergrass-winterfat
725 Vine mesquite-alkali sacaton
727 Mesquite-buffalo grass
733 Juniper-oak
801 Savanna
802 Missouri prairie
803 Missouri glades
804 Tall fescue
805 Riparian

HABITAT TYPES AND PLANT COMMUNITIES:

Rees and others [97] suggest that musk thistle can be found on all types of land except deserts, dense forests, high mountains, coastal areas, and newly cultivated fields. Musk thistle is most often described as occurring on disturbed sites and waste areas, and along roads. Associated plant communities are not often mentioned in the literature.

In the western United States, musk thistle may be found spreading into sagebrush (*Artemisia* spp.) and pinyon-juniper (*Pinus-Juniperus*) communities [23,34,128], and has been observed in the fir-spruce (*Abies-Picea*) zone in Wyoming [55]. Desrochers and others [22] list grasses and forbs that are commonly found with musk thistle in Canada.

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Carduus nutans

GENERAL BOTANICAL CHARACTERISTICS:
Musk thistle in an invasive biennial, and sometimes summer or winter annual forb. Musk thistle populations in North America exhibit almost continuous variation in characteristics such as hairiness, leaf size, spine length, flower stalk diameter, width and shape of bracts, and corolla length [118]. Correct identification of musk thistle is important if control strategies are planned since it can be easily confused with native thistles: some of which may be threatened or endangered, and the vast majority of which fill specific ecological niches and have traits useful to humans [11,108]. The following description provides characteristics of musk thistle that may be relevant to fire ecology, and is not meant to be used for identification. Keys for identifying musk thistle are available (e.g. [21,42,118]). An online publication provided by Oklahoma Cooperative Extension Service (OSU-Extension) provides photos and detailed descriptions of both invasive and native thistles in Oklahoma. Check with the Native Plant Society in your state for more information.

As a biennial, musk thistle initially forms a prostrate rosette. Rosette leaves can grow up to 10 inches (25 cm) long and 4 inches (10 cm) wide, and rosettes can be 2 feet (0.6 m) or more in diameter. Musk thistle rosettes have numerous small roots in the fall, and develop a large, fleshy taproot in the spring [97] that is hollow near the soil surface. The root crown and upper root tissues contain buds, normally suppressed by apical dominance, which may sprout following damage to plants [92]. Harris and Clapperton [48] report infection of musk thistle roots by vesicular arbuscular mycorrhizae.

Musk thistle may have 1 to 7 branched stems that grow 2 to 6 feet (0.6-1.8 m) tall. Stem leaves are 3 to 6 inches (7.6-15.2 cm) long and spiny. Stems have spiny wings their full lengths except for a few inches below flowerheads. Flowerheads are large (1.5 to 3 inches (3.8-7.6 cm) in diameter), solitary, and terminal on shoots. Flowers are subtended by numerous large, lance-shaped, spine-tipped bracts that resemble a pinecone. The fruit is an achene bearing 0.13- to 0.19-inch (0.3-0.5 cm) seeds with a hair-like pappus [11,22,92].

Musk thistle is capable of forming dense stands, especially on highly disturbed sites where competition is low, or in overgrazed or disturbed pastureland. Population size may fluctuate in response to climatic conditions [22]. Musk thistle patches are usually denser than patches of other biennial thistles, but less dense than those of perennial thistles [72].

Researchers have found some evidence of allelopathy in musk thistle (e.g. [125]). Aqueous extracts, leachates, and ground plant material from musk thistle all showed some inhibition of germination and radicle growth rate of several pasture species. Additionally, growth of musk thistle seedlings appears to be stimulated by adding musk thistle tissue to the soil. Musk thistle may thus stimulate recruitment of its own kind as it invades [125].

RAUNKIAER [95] LIFE FORM:
Hemicryptophyte
Therophyte

REGENERATION PROCESSES:
Musk thistle is typically a biennial, but it may complete its life cycle as an annual [11,92]. Populations may have plants of mixed ages and of differing life cycles [92].

Breeding system:
Musk thistle florets mature progressively from the periphery of the capitula inward. Each floret bears male and female organs and fertilization is primarily by outcrossing [57,78,92]. Reports of outcrossing rates vary [109,126]. Musk thistle can also produce a large number of seeds through self-pollination. Therefore, an isolated plant has the potential to expand into a large infestation [11].

Pollination:
The sticky nature of musk thistle pollen prevents wind dispersal. Nectar secreted in the corolla tube is harvested by a wide range of short- and long-tongued insects that effect pollination, but these relationships have not been studied in great detail [92]. Due to asynchronous development of florets, autogamous, geitonogamous, and xenogamous pollination (see the FEIS Glossary) is effected mostly by insects [92] including bees, bumblebees, and various Lepidoptera [22,31,78,109].

Seed production:
Seed production is quite variable. It is determined by habitat conditions, size of plant at flowering, and duration of flowering. Hull and Evans [92] observed musk thistle plants growing in a stand of native vegetation in southeastern Idaho. They varied from 8 to 40 inches (20-100 cm) tall with 1 to 40 or more seedheads. A single musk thistle growing nearby with little plant competition was 6 feet (1.8 m) tall with 643 seedheads [55]. The life cycle exhibited by a particular musk thistle plant also influences seed production, with biennials producing more than winter annuals, and winter annuals producing more than summer annuals [92,106]. It is best to assume that even individual and sparsely separated plants can potentially add thousands of seeds to the soil seed bank [106].

The first flowerheads to emerge (terminal and topmost branch) are usually solitary, and are the largest and produce the most seeds [78]. The number of seeds per inflorescence decreases over time along with inflorescence size [57]. Musk thistle can continue to produce flowers and seeds throughout the growing season if soil moisture levels are adequate. The amount of seed produced is therefore markedly affected by spring and summer rainfall patterns [106]. Lower branches often develop secondary and sometimes tertiary flowerheads. Terminal flowers average about 1,000 seeds per head, while the last ones to bloom produce about 125 seeds or fewer per head [78]. A review by Desrochers and others [22] reports an average of 165 to 256 seeds per flowerhead and 10,000 to 11,000 achenes per individual musk thistle plant. Hull and Evans [55] report that 10 large, terminal seedheads from musk thistle plants in southern Idaho, northern Utah, and western Wyoming had an average of 535 seeds, and 10 smaller flowerheads, midway up the stem, averaged 298 seeds. Seeds collected from these plants in September averaged 81% germination when placed in moist sand in the greenhouse [55]. Stuckey and Forsythe [113] report that many seedheads do not have fully developed achenes at the time of dispersal.

Seed dispersal:
Wind, water, wildlife, livestock, and human activities disperse musk thistle seed. Musk thistle seeds are attached to a pappus, but less than 5% of seed remains attached to the pappus when it breaks off the flowerhead and floats away on wind currents [9]. Under controlled, windy conditions (up to 18.5 feet per second (5.6 m/s)), fewer than 1% of musk thistle seeds moved more than 330 feet (100 m), and most seeds were deposited within 160 feet (50

m) of the point of release [107]. Many musk thistle seeds fail to separate from the receptacle, so fruiting heads with seeds often fall to the ground. Thus, the majority of seeds are deposited in a dense pattern near the parent plant [107,113]. This may help to explain musk thistle's slow rate of spread into favorable habitats close to existing populations [92]. Similarly, in seedheads that are attacked by the thistlehead weevil, *Rhinocyllus conicus*,
many seeds become tightly fixed in the seedhead. These may still germinate, although competition among germinating seeds will cause high rates of intraspecific mortality [107].

Musk thistle seed dispersal over long distances is most common along travel and water corridors, and as a contaminant in crop seed and hay. Musk thistle seeds may also be distributed by birds and mammals [11,97]. Upon contact with moisture, the seedcoat of mature musk thistle seeds thickens and releases sticky mucilage, thus allowing adhesion to moving objects [57]. Reviews by Desrochers and others [22] and by Popay and Medd [92] suggest that cattle and domestic sheep and goats may facilitate seed dispersal by eating seedheads, though more information is needed regarding the proportion of viable seed voided in livestock excreta. Musk thistle seeds also have elaiosomes (fleshy appendages) that promote seed dispersal by ants [91].

Seed banking:
Scientific information on seed banking in musk thistle under field conditions is lacking, although it is suggested that musk thistle seeds may remain viable in the soil for 10 to 15 years or more [11,15,22,92]. Popay and Medd [92] indicate that depth of burial influences musk thistle seed longevity, with seeds buried in the top 2 cm of soil surviving 3 years, and seed buried at greater depths maintaining viability for longer periods. Examples of musk thistle invasion following disturbances such as fire [34,38,39], insect kill [75], or other vegetation removal [19] suggest that musk thistle seeds may be present and viable in soil if there is a history of musk thistle plants on site, or if a musk thistle population is nearby.

Popay and Medd [92] report densities of up to 477 musk thistle seeds per square foot (5,300/m^2) in the top 2 inches (4-5 cm) of soil. Observations suggest that substantial losses may occur prior to recruitment. However, factors influencing the fate of seeds and the conditions of these high losses are incompletely understood [92]. Greenfield and others [43] suggested that losses of seeds (including musk thistle seeds) due to soil microbial action may be comparable to those caused by predation and environmental extremes.

Germination: McCarty [78] measured the weight and germinability of musk thistle seeds at 4 stages of seedhead maturity. At full maturity (just prior to seed dispersal), seeds were divided by weight into "quality" classes. About 32% of musk thistle seeds rated "good" quality (95% viability), 11% were rated "fair" quality (37% viability), and the remaining 57% were considered "poor" quality seeds (2% viability). Terminal heads produced the most viable seeds, with successive flowering producing progressively fewer good quality seeds. McCarty [78] estimated that a musk thistle plant producing about 11,000 seeds could potentially produce about 3,870 seedlings. Jessep [57] made a similar observation in a New Zealand musk thistle population.

Germination of musk thistle seeds in the field occurs over several months in the fall and spring [69]. A review by Desrochers and others [22] indicates that some researchers report no dormancy period for musk thistle seeds, and that germination of musk thistle seeds in the field usually occurs within 14 to 21 days of shedding. Several other studies indicate that musk thistle seeds may have a period of innate dormancy [66,81,92]. A dormancy period could prevent seeds from germinating all at once in response to transient summer rainfall, and allow time for some seed to become buried [92]. In a greenhouse study optimum levels of germination, survival, and growth occurred in treatments that provided microhabitats with reduced evaporation (a light covering of litter and/or cracked and irregular surface topography) [46]. Inadequate soil moisture can hinder musk thistle germination and stand establishment [46,81], although some musk thistle seeds may germinate and establish under dry soil conditions [11].

In the laboratory, germination of musk thistle seed is initiated under moist conditions, between temperatures of 59 to 86 degrees Fahrenheit (15-30 °C), and is strongly enhanced by white or red light [46,81,92]. This suggests that more seeds germinate and establish on bare soils in open pastures and other poorly vegetated sites [9], where there is abundant red light. Exposure to darkness or far-red light inhibited germination of musk thistle seeds, suggesting an induced dormancy. This dormancy may be broken when the light regime changes or possibly by other factors such as increased soil nitrate levels or seedcoat damage [11,81,92].

Seedling establishment/growth:
Most musk thistle seedlings emerge in the fall, although seedlings can also emerge in large numbers in the spring [69,92]. Development from seedling to rosette occurs rapidly [22]. Most plants die before flowering, and the percentage of seedlings that survive to flowering can range from 0 to 46% [22,69]. Because most seed is disseminated within the immediate vicinity of the parent plant, seedling density tends to be high, resulting in intraspecific competition and mortality [9]. The greatest mortality occurs in late spring and summer [69], and whole cohorts of biennial thistles could conceivably die during very hot, dry summers [106]. Survivorship, flowering, and seed production in musk thistle are associated with site conditions, competition, time of emergence, and rosette size.

Successful establishment of musk thistle may be rare in dense pastures due to thick litter and low light levels at the surface [46]. Established stands of musk thistle are thought to be self-perpetuating for several reasons. At high stand densities, the seedbed is devoid of competing vegetation. Additionally, dead flowering stalks of musk thistle can trap winter snow and thus provide additional moisture for spring seed germination [22]. One study also suggests that musk thistle litter may encourage germination of musk thistle seeds [125]. Early autumn germination favors high survivorship and early flowering of musk thistle, with larger, more productive individuals than those germinating late in the fall or spring [69,92]. McCarty and Scifres [77] observed that musk thistle plants growing with competition suffered more mortality than those with no competition and that seedlings emerging in spring had higher survival rates than those emerging in late summer and fall. Musk thistle plants with larger rosettes are also more likely to survive and flower and produce more seed [69].

Asexual regeneration: Vegetative reproduction has not been reported for musk thistle [22].

SITE CHARACTERISTICS:
Musk thistle may germinate and grow under a wide range of environmental conditions, infesting arid areas in Nevada and relatively high moisture areas of Virginia and the east coast. In the Intermountain region of western North America, musk thistle occupies habitats ranging from saline soils in low altitude valleys to acidic soils at 8,000 feet (2,400 m) [11]. In Canada, musk thistle infestations can be found in soils with pH ranging from 6 to 9, which represents most of the soils in the southern part of that country (Holm and others 1997, as cited by [11]). Distribution of musk thistle is restricted mainly by extremes in soil water content, nutrient deficient or acid soils, and competition from other plant species (Doing and others 1969, as cited by [22]).

Musk thistle is frequently found on grasslands in many parts of North America [22] and is more common in the northern portion of the temperate grassland region than the southern portion [41]. Musk thistle may produce viable seeds with as little as 10 inches (250 mm) of annual rainfall, but seems to prefer moist, alluvial soils [55] and abundant spring moisture. In Canadian prairies, musk thistle is common in areas covered by snowdrifts in winter such as gullies, fence lines, brush patches, and the lee side of stone piles (Holm and others 1997, as cited by [11]). In Ohio, musk thistle is commonly found on high, dry ridges and hillsides where the limestone or dolomite bedrock is less than 6 feet (1.8 m) below the surface [113]. Similarly, serious infestations of musk thistle in the northeastern U.S. are associated with fertile soils formed over limestone (Batra 1978, as cited by [22]). Abundant soil nitrogen may favor musk thistle [81,96]. A review of the habitat requirements of musk thistle in Australia and New Zealand is provided by Popay and Medd [92].

The following table provides some elevational ranges for musk thistle as reported by area:

Location	Elevation range	Reference
California	330 to 3,960 ft (100-1,200 m)	[52]
Colorado	9,000 to 10,000 ft (2,700 to 3,000 m)	(Holm and others 1997, as cited by [11])

Montana	up to 6,000 ft (1,800 m)	[67]
New Mexico	4,500-8,500 ft (1,400-2,600 m)	[74]
Utah	4,400 to 8,100 ft (1,340-2,440 m)	[128]

SUCCESSIONAL STATUS:
Musk thistle is an early successional species that establishes well on open, disturbed sites. Musk thistle was part of the earliest postfire successional stage in pinyon-juniper communities in Colorado [38,39]. On a pinyon-juniper site in central Utah that was chained to remove trees and seeded with a grass/forb/shrub mix, musk thistle density increased dramatically over the 3 years following treatment [19]. Similarly, musk thistle production increased on a site in north-central Colorado following death of the ponderosa pine overstory due to mountain pine beetle attack [75]. Another example can be seen at Mesa Verde National Park, where fungal and insect pathogens have killed thousands of Colorado pinyons (*Pinus edulis*), leaving patches in the woodland that have been invaded by nonnative plants. The largest invasion of musk thistle coincides with patches where black stain root disease has killed the Colorado pinyon overstory [35].

Established stands of musk thistle may be self-perpetuating [22]. However, increases in interspecific competition can cause musk thistle populations to decline. In Nebraska pastures, competition with Kentucky bluegrass (*Poa pratensis*) reduced musk thistle plant size and flower number and increased mortality [77]. In Australia, musk thistle is more productive in communities where levels of inter- and intraspecific competition are low [6]. Musk thistle seedlings may be sensitive to competition with neighboring plants for light. When musk thistle seedlings received 2, 8, or 14% of full sunlight, growth was reduced by 97, 68, and 35%, respectively [81].

SEASONAL DEVELOPMENT:
The phenology of musk thistle is complicated by the variability of its life history; usually behaving as a biennial, and sometimes as a summer or winter annual.

Germination of musk thistle seed occurs in the spring and fall beginning approximately 14 to 21 days after dispersal [69]. Musk thistle overwinters as either seeds or rosettes. Musk thistle plants spend approximately 90% of their life cycle as rosettes, then bolt, flower, produce seed, and die [11]. The major environmental factors controlling development of musk thistle are temperature and day length, which may be modified by the duration of vernalizing (low) temperatures and/or musk thistle rosette size [106]. The variability in flowering behavior may also be due to genetic variability [44,92].

While Jessep [57] observed no vernalization requirement in musk thistle in New Zealand, it is generally believed that musk thistle requires vernalization for floral initiation. Desrochers and others [22] cite Haderlie and McCarty (1980) in reporting a minimum vernalization requirement for musk thistle of at least 40 days below 50 degrees Fahrenheit (10 °C). The length of the required vernalization period varies with the size of musk thistle plant, with smaller plants requiring a longer vernalization period [69,82]. Rosette size at the onset of vernalization influences whether the plants flower during their 1st or 2nd summer [30]. Musk thistle plants that grow rapidly in winter and spring are more likely to behave as annuals and flower during the 1st summer. By contrast, under competition, drought, or low fertility during the seedling stage, growth is reduced and the time necessary to initiate flowering increases, leading to more biennials [77,106]. The usual growth cycle of a biennial is to remain as a rosette through 2 winters, after which stem elongation and flowering begin in the spring of the 2nd year [106].

Flowering in musk thistle begins with the terminal bud and proceeds downward toward the base of the plant [11,78,92]. Time of flowering is variable, beginning in spring and continuing for several weeks, with the number of inflorescences per plant increasing each week [57,72,78].

Typical flowering dates are reported by area as follows:

Location	Flowering dates	Reference

Texas	June thru September	[24]
Kansas	late May to early August	[8]
Intermountain region	June thru September	[17]
New Mexico	July and August	[74]
Tennessee and Virginia	June-Oct	[130]
Carolinas	late May-frost	[94]
West Virginia	July-October	[112]
Illinois	June thru October	[87]
Northeastern US	June thru Oct	[37]
Canada	June to July	[22]

Musk thistle flowers and seeds are produced over a long period, with seed maturation and dispersal occurring from 7 days to 2 months after 1st bloom [11,22,78], and continuing as later flowers mature until after fall frost [9,55]. It is common to observe musk thistle with heads in several stages of floral development and senescence [9]. The number of viable seeds in a flowerhead increases as flowers mature as reported by McCarty [78]:

Phenology	Number of "good" seeds	Number of "fair" seeds
	(µ germination=95%)	(µ germination=37%)
full bloom	26	226
2 days past	72	619
4 days past	774	1,137
full maturity (just before dissemination)	3,580	1,270

Plants that bloom late in the season (just prior to frost), tend to have higher rates of survival, as most seed-feeding insects complete their life cycle before the last flowers set seed [72]. Musk thistle plants die soon after setting seed [9].

FIRE ECOLOGY

SPECIES: Carduus nutans

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:

Fire adaptations:

Musk thistle can produce abundant seed and establish well in high light environments. Fire creates conditions that are favorable to the establishment of musk thistle (i.e. open canopy, reduced competition, areas of bare soil), so if musk thistle seeds are present and competition minimal, musk thistle may be favored in the postfire community.

Fire regimes:

Musk thistle commonly occurs in tallgrass prairie ecosystems where fire can stimulate flowering of warm-season grasses and increase stem density. In Kansas, frequent burning of tallgrass prairie is said to be effective in keeping out exotic plants such as musk thistle, especially on sites where prairie grasses are vigorous [54]. Effects of musk thistle on native fire regimes in temperate grasslands are unknown and research is needed in this area [41]. Musk thistle also occurs in pinyon-juniper communities where fire return intervals may range from 10 to 70 years or more [34,90]. These ecosystems tend to be heavily influenced by introduced species. Following fire, cheatgrass (*Bromus tectorum*) and other invasives such as musk thistle tend to establish and dominate in place of native grasses and forbs [34,38,39]. Musk thistle has established since fire exclusion began, and it is unclear how the presence of musk thistle might affect fire regimes in these communities.

The following table provides fire regime intervals for some of the communities in which musk thistle may be found.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
bluestem prairie	*Andropogon gerardii* var. *gerardii-Schizachyrium scoparium*	< 10 [64,90]
Nebraska sandhills prairie	*A. g.* var. *paucipilus-Schizachyrium scoparium*	< 10
bluestem-Sacahuista prairie	*A. littoralis-Spartina spartinae*	< 10
sagebrush steppe	*Artemisia tridentata/Pseudoroegneria spicata*	20-70 [90]
basin big sagebrush	*A. t.* var. *tridentata*	12-43 [101]
mountain big sagebrush	*A. t.* var. *vaseyana*	15-40 [3,14,85]
Wyoming big sagebrush	*A. t.* var. *wyomingensis*	10-70 (40**) [122,132]
saltbush-greasewood	*Atriplex confertifolia-Sarcobatus vermiculatus*	< 35 to < 100
desert grasslands	*Bouteloua eriopoda* and/or *Pleuraphis mutica*	5-100
plains grasslands	*B.* spp.	< 35
blue grama-needle-and-thread grass-western wheatgrass	*B. gracilis-Hesperostipa comata-Pascopyrum smithii*	< 35
blue grama-buffalo grass	*B. g.-Buchloe dactyloides*	< 35
cheatgrass	*Bromus tectorum*	< 10

California montane chaparral	*Ceanothus* and/or *Arctostaphylos* spp.	50-100 [90]
curlleaf mountain-mahogany*	*Cercocarpus ledifolius*	13-1000 [4,102]
mountain-mahogany-Gambel oak scrub	*C. l.-Quercus gambelii*	< 35 to < 100
blackbrush	*Coleogyne ramosissima*	< 35 to < 100
Arizona cypress	*Cupressus arizonica*	< 35 to 200 [90]
beech-sugar maple	*Fagus* spp.-*Acer saccharum*	> 1000 [123]
California steppe	*Festuca-Danthonia* spp.	< 35 [90]
black ash	*Fraxinus nigra*	< 35 to 200 [123]
juniper-oak savanna	*Juniperus ashei-Quercus virginiana*	< 35
Ashe juniper	*J. a.*	< 35
western juniper	*J. occidentalis*	20-70
Rocky Mountain juniper	*J. scopulorum*	< 35
cedar glades	*J. virginiana*	3-7
tamarack	*Larix laricina*	35-200 [90]
western larch	*L. occidentalis*	25-100 [2]
creosotebush	*Larrea tridentata*	< 35 to < 100
Ceniza shrub	*L. t.-Leucophyllum frutescens-Prosopis glandulosa*	< 35 [90]
yellow-poplar	*Liriodendron tulipifera*	< 35 [123]
wheatgrass plains grasslands	*Pascopyrum smithii*	< 35 [90]
Engelmann spruce-subalpine fir	*Picea engelmannii-Abies lasiocarpa*	35 to > 200
pine-cypress forest	*Pinus-Cupressus* spp.	< 35 to 200 [2]
pinyon-juniper	*P.-Juniperus* spp.	< 35 [90]
jack pine	*P. banksiana*	<35 to 200 [28]
Mexican pinyon	*P. cembroides*	20-70 [88,114]
shortleaf pine	*P. echinata*	2-15
shortleaf pine-oak	*P. e.-Quercus* spp.	< 10 [123]
Colorado pinyon	*P. edulis*	10-49 [90]
slash pine	*P. elliottii*	3-8
slash pine-hardwood	*P. e.*-variable	< 35
sand pine	*P. e.* var. *elliottii*	25-45 [123]
Jeffrey pine	*P. jeffreyi*	5-30
western white pine*	*P. monticola*	50-200 [2]
longleaf-slash pine	*P. palustris-P. elliottii*	1-4 [89,123]

longleaf pine-scrub oak	*P. p.-Quercus* spp.	6-10 [123]
Pacific ponderosa pine*	*P. ponderosa* var. *ponderosa*	1-47 [2]
interior ponderosa pine*	*P. p.* var. *scopulorum*	2-30 [2,7,68]
Arizona pine	*P. p.* var. *arizonica*	2-10 [2]
Table Mountain pine	*P. pungens*	< 35 to 200 [123]
pitch pine	*P. rigida*	6-25 [13,51]
pocosin	*P. serotina*	3-8
pond pine	*P. serotina*	3-8
loblolly pine	*P. taeda*	3-8
loblolly-shortleaf pine	*P. t.-P. echinata*	10 to < 35
Virginia pine	*P. virginiana*	10 to < 35
Virginia pine-oak	*P. v.-Quercus* spp.	10 to < 35
sycamore-sweetgum-American elm	*Platanus occidentalis-Liquidambar styraciflua-Ulmus americana*	< 35 to 200 [123]
galleta-threeawn shrubsteppe	*Pleuraphis jamesii-Aristida purpurea*	< 35 to < 100
eastern cottonwood	*Populus deltoides*	< 35 to 200 [90]
aspen-birch	*P. tremuloides-Betula papyrifera*	35-200 [28,123]
quaking aspen (west of the Great Plains)	*P. t.*	7-120 [2,45,83]
mesquite	*Prosopis glandulosa*	< 35 to < 100 [80,90]
mesquite-buffalo grass	*P. g.-Buchloe dactyloides*	< 35
Texas savanna	*P. g.* var. *glandulosa*	< 10 [90]
black cherry-sugar maple	*Prunus serotina-Acer saccharum*	> 1000 [123]
mountain grasslands	*Pseudoroegneria spicata*	3-40 (10**) [1,2]
California oakwoods	*Quercus* spp.	< 35 [2]
oak-hickory*	*Q.-Carya* spp.	< 35[123]
oak-juniper woodland (Southwest)	*Q.-Juniperus* spp.	< 35 to < 200 [90]
northeastern oak-pine	*Q.-Pinus* spp.	10 to < 35
southeastern oak-pine	*Q.-Pinus* spp.	< 10 [123]

coast live oak	*Q. agrifolia*	<35 to 200
canyon live oak	*Q. chrysolepis*	<35 to 200
blue oak-foothills pine	*Q. douglasii-Pinus sabiniana*	<35 [2]
northern pin oak*	*Q. ellipsoidalis*	< 35 [123]
Oregon white oak	*Q. garryana*	< 35 [2]
bear oak*	*Q. ilicifolia*	< 35 >[123]
California black oak	*Q. kelloggii*	5-30 [90]
bur oak*	*Q. macrocarpa*	< 10 [123]
oak savanna*	*Q. m./Andropogon gerardii-Schizachyrium scoparium*	2-14 [90,123]
interior live oak	*Q. wislizenii*	< 35 [2]
blackland prairie	*Schizachyrium scoparium-Nassella leucotricha*	< 10
Fayette prairie	*S. s.-Buchloe dactyloides*	< 10
little bluestem-grama prairie	*S. s.-Bouteloua* spp.	< 35 [90]
elm-ash-cottonwood	*Ulmus-Fraxinus-Populus* spp.	< 35 to 200 [28,123]

*fire return interval varies widely; trends in variation are noted in the species summary
**mean

POSTFIRE REGENERATION STRATEGY [111]:
Ground residual colonizer (on-site, initial community)
Initial off-site colonizer (off-site, initial community)
Secondary colonizer (on-site or off-site seed sources)

FIRE EFFECTS

SPECIES: Carduus nutans

- IMMEDIATE FIRE EFFECT ON PLANT
- DISCUSSION AND QUALIFICATION OF FIRE EFFECT
- PLANT RESPONSE TO FIRE
- DISCUSSION AND QUALIFICATION OF PLANT RESPONSE
- FIRE MANAGEMENT CONSIDERATIONS

IMMEDIATE FIRE EFFECT ON PLANT:
Musk thistle may or may not be killed by fire. A review by Heidel [50] (musk thistle ESA) suggests that high-severity fire may kill musk thistle plants by destroying the root crown, although there is no direct evidence

of this. He does, however, cite evidence of musk thistle plants bolting and blooming after the rosettes were scarred by a late spring fire in Nebraska, which concurs with a review by Smith [108]. Popay and Medd [92] suggest that combustion would only readily take place on mature musk thistle plants from which most seed would have already dispersed.

It is unclear what effects fire has on musk thistle seeds in the soil, although incidents of rapid colonization after fire suggest that musk thistle seeds may have been present in the soil at the time of the fire and survived to germinate after the overstory was removed [34,39,50].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
No entry

PLANT RESPONSE TO FIRE:
Musk thistle colonization may be either enhanced [34,39] or depressed [54] by fire. The response of musk thistle likely depends on fire severity, ecosystem type, prefire abundance and location of musk thistle plants and seeds, and plant competition [34,41,50,54].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Response of musk thistle to fire appears to be primarily related to the abundance of competitors and their response to fire. Hulbert's summary [54] of fire effects on tallgrass prairie indicates that musk thistle can be eliminated with or without fire on ungrazed prairie, although spring burning was recommended to promote the vigor of native warm-season grasses [41]. Similarly, observations in tallgrass prairie sites in South Dakota indicate that late spring prescribed burning (when native species are still dormant) on a 4- to 5-year rotation (as per the historic fire regime) encourages the growth of native plants and discourages the growth of Canada, bull, and musk thistles [18]. Additionally, Hulbert [54] suggests that late spring burning in these ecosystems results in fewer forbs but greater grass production than fall or early spring burning.

Following the Long Mesa fire in Mesa Verde National Park, response of musk thistle differed between the 2 plant communities that burned. In pinyon-juniper woodlands where the overstory was killed and mineral soils were exposed, invasive species including musk thistle dominated the postfire community. Where shrubs dominated the prefire community (in the northern section of the fire), sprouts from native perennials repopulated the area within the 1st postfire year [34,35]. A pinyon-juniper site in Utah was burned in 1976, after which cheatgrass and other weeds (including musk thistle) established [38]. The area was then prescribe burned and aerially seeded with crested wheatgrass (*Agropyron cristatum*) and other introduced perennial species in 1990. Parts of the burn were missed in the seeding treatment, allowing for comparison of seeded and non-seeded areas. Frequency of musk thistle occurrence was lower in areas that were seeded following fire (756 plants per acre (1,871/ha)) than in areas that were not seeded (7,849 plants/acre (19,424/ha)) [39].

More research is needed on long-term secondary effects of fire on musk thistle. See "Postfire colonization potential" below for more details.

The Research Project Summary
Vegetation response to restoration treatments in ponderosa pine-Douglas-fir forests of western Montana provides information on prescribed fire and postfire response of plant community species including musk thistle.

FIRE MANAGEMENT CONSIDERATIONS:
Fire as a control agent: Although several reviews suggest that fire cannot control musk thistle [92,108], using prescribed fire to control musk thistle may have some indirect positive effects. Examples from tallgrass prairie sites in Kansas and South Dakota suggest that fire can encourage the growth of native plants and discourage the growth of musk and other thistles [18,50,54]. Livestock use must be carefully timed following burning, since grazing early in the growing season can potentially negate beneficial effects of prescribed fire [18].

Fick and Peterson [121] suggest that prescribed burning can also make chemical control methods more effective.

More information is needed regarding the role of fire in musk thistle management.

Postfire colonization potential:
There is evidence that musk thistle can colonize recently burned prairie sites where grasses are not vigorous [54], and pinyon-juniper sites where there is essentially no native seed bank and a musk thistle seed source is on-site or nearby [34,38]. Plant competition and dry conditions may limit musk thistle establishment after fire on some sites. On the Konza Prairie in Kansas, burning favored establishment of musk thistle in areas where grazing had reduced the vigor of prairie grasses. However, on sites where grasses were vigorous, musk thistle was crowded out whether the site was burned or unburned [54]. Similarly, plant competition limited or prevented musk thistle invasion on sites in Colorado and Utah where native perennials resprouted [34], and where the burn was seeded with a mixture of grasses and forbs. The seed mix included several aggressive, introduced grasses such as crested wheatgrass (*Agropyron cristatum*), intermediate wheatgrass (*Thinopyrum intermedium*), orchardgrass (*Dactylis glomerata*), and smooth brome (*Bromus inermis*) [39].

General precautions should be followed to prevent musk thistle establishment after fire. The USDA Forest Service's "Guide to noxious weed prevention practices" [119] provides several fire management considerations for weed prevention that can be applied to musk thistle. Wildfire managers might consider the following: include weed prevention education and providing weed identification aids during fire training; avoiding known weed infestations when locating firelines, monitoring camps, staging areas, and helibases, to be sure they are kept weed free; take care that equipment is weed free; incorporating cost of weed prevention and management into fire rehabilitation plans; and acquire restoration funding [119]. Careful postfire vigilance to identify and record the establishment of invasive plant populations is critical. About 1 month after fire, survey for signs of new or resprouting weeds. Repeated surveys will be needed, with the frequency and intensity guided by local conditions [5].

Potential weed problems must be addressed during prefire planning of prescribed burns, and following both wildland and prescribed fires. When planning a prescribed burn, preinventory the project area and evaluate cover and phenology of any musk thistle present on or adjacent to the site and evaluate the potential for increased musk thistle populations in the area [5]. Avoid ignition and burning in areas at high risk for musk thistle establishment or spread, and/or plan for follow-up treatments in succeeding years. Avoid creating soil conditions that promote weed germination and establishment. Discuss weed status and risks in burn rehabilitation plans [119].

To prevent infestations, re-establish vegetation on bare ground as soon after fire as possible, using either natural recovery or artificial techniques as appropriate to site conditions and objectives. When reseeding after wildfires and prescribed burns, use only certified weed-free seed [5,40,119]. In some cases, it may not be practical to reseed with native species [39]. Monitor the burn site and associated disturbed areas after the fire and the following spring for emergence of musk thistle, and treat to eradicate any emergent musk thistle plants. Regulate human, pack animal, and other livestock entry into burned areas at risk for weed invasion until desirable vegetation has recovered sufficiently to resist weed invasion. Additional guidelines and specific recommendations and requirements are available [5,40,119].

MANAGEMENT CONSIDERATIONS

SPECIES: Carduus nutans

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Livestock rarely eat musk thistle foliage; however, cattle and domestic sheep and goats have been observed consuming flowers and seedheads. It is unclear whether this results in musk thistle seed dispersal. A number of

species of birds also graze on mature musk thistle seed in Australia [92]. Dense infestations of the plant discourage animals from occupying that portion of the field in which it grows [97].

Palatability/nutritional value: No information

Cover value: No information

OTHER USES:
The thistles have long been associated with humans, and have been used as both food and medicine [86]. "However, they are also notoriously associated with unkempt agricultural land. While this may be true of invasive thistles that are not native to North America, the vast majority of native thistles fill specific ecological niches and have traits useful to humans" [11]. Bare [8] states that dried musk thistle flowers have been used as rennet to curdle milk, and that the pith of the stem is edible when boiled.

IMPACTS AND CONTROL:
Impacts:
Musk thistle is a problem on range and pastures because it competes with desirable forage, and its sharp spines can limit recreation, hinder movement, and deter livestock, and presumably wildlife, from grazing [11,22,55,97]. Even at low densities of musk thistle, losses in production of native and/or forage species can occur because rosettes of musk thistle can grow greater than 3 feet (1 m) in diameter [106]. A review by Rees and others [97] suggests that 1 musk thistle plant per 16 square feet (1.5 m^2) can reduce forage production by 23%. Musk thistle may also threaten rare or sensitive species, such as the Mescalero thistle (*Cirsium vinaceum*) in New Mexico, by crowding into populations [110]. Musk thistle spreads most rapidly along roadsides, fence lines, and sparsely vegetated areas. Though plants are hardier where there is little competition, musk thistle can also grow in native and seeded ranges, irrigated pastures, and wet meadows with dense stands of graminoids [55].

Control:
Musk thistle should be accurately identified before attempting any control measures, since several native species of thistles have a similar appearance. See the "General Botanical Characteristics" section of this review for information on proper identification.

The key to successful management of musk thistle is to prevent seed production. Control data suggest that the threshold for viable seed production by biennial thistles is zero to achieve long-term population decreases, although zero seed production may not be a realistic goal. The transition from seedling to rosette may be the most precarious stage in the life cycle of musk thistle. Seedling and rosette growth stages are the most logical to target for control efforts in biennial thistles [11].

Combining control methods into an integrated management system will result in the best long-term population decreases. Desirable plant competition is important in any biennial thistle management strategy to deter establishment of thistle seedlings and the transition to the rosette growth stage. Recovery of infested areas should not be considered complete until a diverse population of desirable plants has replaced invasive biennial thistles and the thistles are a minor to nonexistent component to the plant community [11]. The requirement of light for musk thistle seed germination highlights the importance of maintaining dense pasture canopies in order to suppress thistle germination [106]. Beck [11] suggests that land managers control musk thistle diligently for 15 years or more to eradicate it, because of the long-lived seed bank. He also encourages monitoring and evaluating weed management programs to determine whether and when to repeat and/or modify control treatments.

Prevention: Prevention is the most effective method for managing invasive species, including musk thistle [11,55,72,104]. The best way to prevent or reduce musk thistle invasion is to deny it a suitable habitat. Maintaining a healthy stand of desirable vegetation will prevent or slow musk thistle invasion, since seedlings are intolerant of intense competition, especially for light [55,81,92]. Pastures that are growing rapidly, especially at the time of peak musk thistle recruitment in the fall, can suppress musk thistle germination [93], enhance competition upon seedings, prolong the rosette stage of thistle development [30], and ultimately reduce musk thistle population density and seed production [92]. Careful grazing management will help keep pastures and rangeland healthy by enhancing grass competition and deterring thistle survival from seedlings to rosettes [11]. Overgrazing by livestock and wildlife should be avoided, because survival of musk thistle rosettes is said to increase as grazing intensity increases [54,70,100], and bare spots caused by over-grazing are prime sites for musk thistle germination and establishment [11].

Preventing or dramatically reducing seed production and dispersal decreases the spread of musk thistle. It is important to clean mowers, vehicles, and other equipment after operating in an infested area. When seeding is necessary, use clean, certified weed-free seed and mulch to ensure that thistles and/or other weeds are not being sown [11]. Remove single plants and control small infestations so they do not expand, as they will furnish adjacent areas with abundant seed for infestation [55]. Control measures must be followed-up to prevent reinfestation, and monitoring programs developed to locate any new infestations [11,55].

Integrated management:

The goal of any management plan should be to not only control invasive plants, but to also improve the affected community, maximizing forage quality and quantity and/or preserving ecosystem integrity, and preventing reinvasion or invasion by other invasive species, in a way that is complementary to the ecology and economics of the site [25,56]. Effective long-term control requires that invasive plants be removed and replaced by more desirable and weed-resistant plant communities [56]. Once the desired plant community has been determined, an integrated weed management strategy can be developed to direct succession toward that plant community by identifying key mechanisms and processes directing plant community dynamics (site availability, species availability, and species performance) and predicting plant community response to control measures [103]. This requires a long-term integrated management plan [11].

Most often, a single control method is not enough to sufficiently control an invasive plant, but there are many possible combinations of methods that can achieve the desired objectives. Methods selected for removal or control of musk thistle on a specific site will be determined by land use objectives, desired plant community, extent and nature of the infestation(s), environmental factors (nontarget vegetation, soil types, climatic conditions, important water resources), economics, and effectiveness and limitations of available control techniques [98].

Herbicide applications in spring followed by dormant seeding of competitive perennial grasses in the fall is an example of an effective management system for biennial thistles in the western United States. Similarly, integrating herbicides and biological control agents is likely to be more effective than using biological control insects alone [11] (see "Biological control" below, for more information). For information on integrated weed management without herbicides, see the BIRC website.

Some examples of combined approaches and considerations are presented within the following sections. Managers are encouraged to use combinations of control techniques in a manner that is appropriate to the site objectives, desired plant community, available resources, and timing of application.

Physical/mechanical:

Any mechanical or physical method that severs the root below the soil surface will kill musk thistle. However, it is essential to revegetate the site with desirable plants, particularly competitive grasses, to compete with biennial thistles that may reinvade from seeds left in the soil. Mechanical methods are not always practical on rangeland and natural areas, but can be effective in improved pastures and roadsides. Tillage, hoeing, and hand pulling may provide effective control of musk thistle, providing these operations are done before the reproductive growth stage to prevent seed production [11].

Hand pulling is a common and effective practice for musk thistle infestations of low density or as a follow-up operation after broad-scale treatment of dense or large infestations. Plants must be severed 2 to 4 inches (5-10 cm) below the surface to prevent resprouting [33,92,108]. This may be done with a sharpened shovel or other implement. Plants may be less likely to regrow if allowed to bolt before severing the root crown [108]. Any musk thistle flowerheads must be removed and burned or otherwise destroyed to eliminate seeding [33,55], since florets are sometimes capable of maturing and producing viable seed on severed plants [92]. Hand chopping at ground level just before flowering eliminated musk thistle from a 350-acre pasture on the Konza Prairie [108]. Hand pulling of musk thistle reduced the density of infestations following fires in Mesa Verde National Park [34].

Mowing or slashing can improve the appearance of thistle-infested pastures [92] and affectively reduce the population size, but proper timing is critical. Plants cut before the appearance of the terminal flower bud are likely to regrow and produce viable seed. Viable seeds can be also be produced from heads severed later than 4 days after anthesis [76]. The greatest reduction in seed production is when musk thistle plants are mowed just before flowering [55,108]. Mowing within 2 days of the 1st terminal flowerheads in a plant population showing anthesis eliminated the production of germinable seed from all mowed stalks [76]. If cut after plants have flowerheads, they should be burned or otherwise destroyed so the seeds will not mature [55]. A single mowing will not control a musk thistle infestation, because infestations often consist of plants of variable age, and stands therefore have nonuniform development and flowering [11,76]. For this reason it is necessary to mow several times each year to effectively minimize seed production [11,72,92]. Combining mowing with chemical control may improve results [72].

Musk thistle rarely occurs in croplands suggesting that it is intolerant of repeated cultivation procedures. Evidence suggests that musk thistle seed longevity is prolonged by burial; however, shallow tillage may help control musk thistle by promoting more rapid depletion of seed stocks and killing seedlings [92]. Tillage is not appropriate in wildlands and rangelands since it can damage important desirable species, increase erosion, alter soil structure, and expose the soil for rapid reinfestation by musk thistle and other invasive species [70].

Fire:
See "Fire Management Considerations: Fire as a control agent" in the FIRE EFFECTS section of this summary.

Biological:
Biological control of invasive species has a long history, and there are many important considerations to be made before the implementation of a biological control program. The reader is referred to other sources (e.g. [98,129]) and the Weed Control Methods Handbook [117] for background information on biological control. Additionally, Cornell University, Texas A & M University, and NAPIS websites offer information on biological control.

Biological control of musk thistle has had substantial success in at least part of its range. Several agents have been considered and tested for musk thistle control, and those in the following table have been introduced in North America:

Biological control agent	Mode of action	Areas established	References
thistlehead weevil (*Rhinocyllus conicus*)	larvae eat seed-producing tissue	well established in most northwestern and northern plains states; GA, TN, TX, VA	[20,49,61,97,99]
thistle crown weevil (*Trichosirocalus horridus*)	larvae feed on the growing points of thistle rosettes and developing shoots	CO, KS, MO, MT, NC, OR, VA, WA, WY	[20,61,79,97,99]
thistle crown fly (*Cheilosa corydon*)	larvae burrow into shoots where feeding causes a disruption of the plant's water and nutrient transport, decreasing flowering and seed production	MD	[97,99]

musk thistle rust (*Puccinia carduorum*)	attacks leaves, stems and bract leaves throughout the season; reducing seed set and seed quality	DE, GA, IN, KT, MD, OH, SC, TN, VA	[97]

Rhinocyllus conicus
was introduced from Europe to Montana and Virginia in 1969. It does not destroy 100% of musk thistle seeds, and decreases in seed production are highly variable, ranging from 10 to 78%. It can be extremely effective by itself in those areas where the plant and insect life cycles are synchronized. A review by DeLoach [20] indicates 90 to 99% reduction of in musk thistle stands in Montana and Virginia and 80 to 90% reduction in Missouri. *Rhinocyllus conicus* will use *Carduus*, *Cirsium*, *Silybum*, and *Onopordum* genera as hosts but prefer the *Carduus nutans* group [11,97]. Several strains of *R. conicus* have been identified and they vary in their utilization of various thistle species. At least 1 of these strains does attack some native *Cirsium* species [20,71,97], and reviews by Beck [11] and Wilson and McCaffrey [129] indicate that it is known to attack native and rare thistles. Therefore, before releasing insects in a new area containing native *Cirsium* species, investigate whether any of the local species may be attacked [97]. A detailed discussion of the biology of *R. conicus* is given by Harris and Shorthouse [49].

Trichosirocalus horridus
was introduced to the U.S. in 1974. This weevil uses thistles of the subtribe Carduinae, including musk thistle, plumeless thistle (*Carduus acanthoides*), Italian thistle (*C. pycnocephalus*), Canada thistle (*Cirsium arvense*), bull thistle (*C. vulgare*), and Scotch thistle (*O. acanthium*). Reports of suppression vary from slight to great. *Trichosirocalus horridus* is more effective when used in conjunction with *R. conicus* [97]. In areas of Missouri where *R. conicus* and *T. horridus*
have been present for over 15 years, an 80 to 90% reduction in thistle population has occurred [108].

Integrated management systems may be developed utilizing knowledge of thistle and weevil life cycles, to encourage survival of the weevils over the long-term, while reducing the size or limiting the spread of bull thistle infestations in the short term. There is evidence that both *Rhinocyllus conicus* [116] and *Trichosirocalus horridus* [62] are somewhat tolerant of certain phenoxy herbicides, although more research is suggested. It may be useful, in the meantime, to create spatial or temporal separation of herbicide use and biological control. For example, insects can be released in the center of a biennial thistle infestation, and the borders sprayed to prevent further weed spread. Or, herbicides can be applied at a time when direct exposure of insects to herbicides will be minimized, such as when insects are pupating [11].

Cattle and domestic sheep and goats sometimes consume musk thistle flower and seedheads, and it has been suggested that domestic goats can help to minimize the presence of both bull [131] and musk [92] thistles. There is concern regarding whether cattle and domestic goats may facilitate musk thistle seed dispersal by eating seedheads. However domestic goats may prefer early flowering stages [92].

Chemical:
Herbicides are effective in gaining initial control of a new invasion or a severe infestation, but are rarely a complete or long-term solution to weed management [16]. Herbicides are more effective on large infestations when incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations. Control with herbicides is temporary, as it does not change conditions that allow infestations to occur [133]. See the Weed Control Methods Handbook for considerations on the use of herbicides in natural areas and detailed information on specific chemicals. Chemical control of musk thistle is reviewed by Beck [11].

Clopyralid, dicamba, MCPA, picloram, 2,4-D, metsulfuron, and chlorsulfuron and some combinations thereof will all kill bull and musk thistles. Herbicide choice and rates are influenced by growth stage, stand density, and environmental conditions (e.g. drought or cold temperatures) [11]. Auxin herbicides are effective only when applied during periods of active growth of seedlings or rosettes, usually during spring or fall [11,22,84,96]. Fall is a good time to control biennial thistles with herbicides because all live plants will be seedlings or rosettes, though cold weather may decrease the effectiveness of some chemicals [11]. Popay and Medd [92] and Medd and Lovett [82] suggest that spring application of herbicides may be more effective since musk thistle seedlings may still emerge in the spring after fall treatments. Herbicide tolerance of musk thistle increases after bolting [33,76]. Spraying thistles after they have bolted may reduce, but not eliminate, viable seed production. Because of the large numbers of seeds produced by musk thistle, reduction of flowering and seed production is unlikely to lead to an overall reduction in levels of infestation. Since seeds accumulate in soil, even effective herbicide treatment may have only a short term effect on musk thistle populations [92]. Clorsulfuron and metsulfuron are effective when applied in the bolting and early bud stages and may, therefore, be compatible with biocontrol agents [11].

Combinations of herbicides and nitrogen fertilizer were tried in Nebraska, with results suggesting that the added nitrogen favored the thistle over the perennial grasses [96]. Similarly, Austin and others [6] determined in a greenhouse experiment that yield of musk thistle increased in response to increasing nutrient concentration.

Musk thistle was found to be resistant to 2,4-D in New Zealand and may also be cross-resistant to other synthetic auxin herbicides [47]. When herbicides are used for musk thistle control, managers should consider an herbicide rotation to prevent development of resistance [73]. See weedscience.org for more information on herbicide resistance.

Cultural:

No matter what method is used to kill weeds, reestablishment of competitive, desirable plant cover is imperative for long-term control. Reseeding with competitive, adapted species is often necessary in areas without a residual understory of desirable plants [98]. Vegetative suppression is applicable both before weed establishment and after weed control.

Bull and musk thistle germination and establishment are favored in open areas and by disturbance [11]. Vigorously growing grass competes with musk thistle, and fewer thistles occur in pastures where grazing is deferred. However, musk thistle can also become a problem in pasture or rangeland that is in good condition [9]. In New Zealand, pasture species and legume swards inhibited seedling shoot and root growth of both bull and musk thistles. Rate of musk thistle seedling emergence was also negatively correlated with pasture cover density ($r=-0.666$; $p<0.05$), presumably as a consequence of alteration of light quality by the pasture [124]. On Konza Prairie, musk thistle was present in heavily grazed spots, and burning favored establishment of musk thistle seedlings in areas where grazing had reduced vigor of prairie grasses. However, where the native prairie plants were vigorous, musk thistle was crowded out, whether burned or not [54]. A field plot study in Virginia indicated that musk thistle growth was seriously reduced by competition with tall fescue (*Festuca arundinacea*), more than infection by *T. horridus*, and *R. conicus*. Musk thistles planted simultaneously with tall fescue produced flowering plants but with reduced size and number of seeds per plant. When musk thistle was planted in 1-year-old tall fescue, germination was low and seeds that did germinate did not reach reproductive age. Because of its extensive root system and its ability to effectively compete for nutrients, seeding tall fescue where it is well adapted may be a practical method of musk thistle control in pastures, waste areas, and roadsides [63]. Tall fescue is not appropriate in drier areas [70]. Tall fescue is also an exotic, invasive species and is not, therefore, appropriate for natural areas.

Re-establishment of desirable vegetation after controlling existing populations of musk thistle will usually be necessary for successful control. Choice of species to sow will depend upon climate, location, and management objectives. The Natural Resource Conservation Service and land grant universities are sources of information about appropriate species for a particular purpose and location [11]. Reece and Wilson [96] express the importance of controlling weeds for more than 1 year to provide grasses with a competitive advantage that will help grasses recover fully. Following musk thistle population explosion after fire at Mesa Verde National Park, planting native perennial grasses slowed but did not stop the spread of musk thistle. Aerial seeding was the most effective treatment for preventing the spread of musk thistle when compared with hand pulling and biocontrol [34]. Pasture competition decreases germination and increases mortality of musk thistle seedlings, and slows growth of survivors. Encouraging early, rapid growth of pasture in fall can help reduce numbers of established musk thistle seedlings [30]. Management that allows grasses to grow taller in spring can also shade musk thistle seedlings, thus decreasing musk thistle establishment and growth [11].

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