SPECIES: Centaurea diffusa

INTRODUCTORY

SPECIES: Centaurea diffusa

AUTHORSHIP AND CITATION:
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ABBREVIATION:
CENDIF

SYNONYMS:
No entry

NRCS PLANT CODE [121]:
CEDI3

COMMON NAMES:
diffuse knapweed
white knapweed
tumble knapweed

TAXONOMY:
The currently accepted scientific name for diffuse knapweed is *Centaurea diffusa* Lam. (Asteraceae) [18,30,42,51]. Hybridization with spotted knapweed (*Centaurea stoebe* ssp. *micranthos*) is reported in at least 7 U.S. states [70], including Michigan [126]. The hybrid is named *Centaurea* × *psammogena* Gayer [70]. For more information, see the Centaurea website.

LIFE FORM:
Forb

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:

At the time of this writing, diffuse knapweed is considered a noxious or restricted weed in 13 states in the U.S. and 4 Canadian provinces [122]. See the Invaders or the Plants databases for more information.

DISTRIBUTION AND OCCURRENCE

SPECIES: Centaurea diffusa

GENERAL DISTRIBUTION:
Diffuse knapweed is native to grasslands and shrub steppes of the eastern Mediterranean and western Asia [66] and was introduced into Central Europe and North America [71]. It is thought to have been introduced to North America as a contaminant in alfalfa (*Medicago sativa*) seed from Asia Minor-Turkmenistan or in hybrid alfalfa seed from Germany [58]. The earliest record of diffuse knapweed in North America is from an alfalfa field in Washington state in 1907 [86]. It is currently found from Yukon in the north, throughout most of western Canada, east to Ontario. In the United States, the primary range of diffuse knapweed is the western states, from Washington, Idaho and Montana south to New Mexico and Arizona [42]. Maddox [59] notes that diffuse knapweed is more common on the western side of the Great Basin, and spotted knapweed is more common on the eastern side. Diffuse knapweed has also spread east into several midwestern states and is found in Massachusetts, Connecticut, and New Jersey on the east coast [42]. The Plants database provides a distribution map of diffuse knapweed in the United States.

The following table reflects estimates of spotted knapweed acreage as reported by surveyed states or provinces in 1988 and again in 2000 (from [20]):

State/Province	1988 Acreage	2000 Acreage
Arizona	not reported	1,800
California	not reported	5
Colorado	30,000	83,000
Idaho	1,450,000	1,800,000
Montana	10,349	27,523
Nevada	not reported	500
New Mexico	not reported	200
North Dakota	0	30
Oregon	1,200,000	989,000
South Dakota	1,000	200
Utah	25	1,300
Washington	427,800	500,000
Wyoming	5,000	4,000
Alberta	0	scattered
British Columbia	not reported	75,000
Total		3,482,558

Although inventories are more common and more accurate in the year 2000 than in 1988, 50% of these states reported only 50% accuracy, while 31% reported 51 to 75% accuracy, and 2 states reported 75 to 100% accuracy [20].

The following lists reflect ecosystems and cover types in which diffuse knapweed is known or thought to be invasive. Diffuse knapweed occurs in some midwestern and eastern states and provinces, primarily along roadsides and in "waste places", but it is unclear, from the available literature on these areas, which ecosystems and cover types it occurs in. These lists are not, therefore, exhaustive, as the plant may be invasive in other types as well.

ECOSYSTEMS [29]:
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES22 Western white pine
FRES23 Fir-spruce
FRES26 Lodgepole pine
FRES29 Sagebrush
FRES35 Pinyon-juniper
FRES36 Mountain grasslands
FRES38 Plains grasslands
FRES40 Desert grasslands

STATES:

AZ	CA	CO	CT	ID	IL	IN
IA	KY	MA	MI	MT	NE	NV
NJ	NM	ND	OH	OR	SD	TN
UT	WA	WI	WY			

AB	BC	MB	ON	SK	YK

BLM PHYSIOGRAPHIC REGIONS [10]:
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

KUCHLER [48] PLANT ASSOCIATIONS:
K005 Mixed conifer forest
K010 Ponderosa shrub forest
K011 Western ponderosa forest
K012 Douglas-fir forest
K013 Cedar-hemlock-pine forest
K014 Grand fir-Douglas fir forest
K015 Western spruce-fir forest
K018 Pine-Douglas-fir forest
K019 Arizona pine forest
K023 Juniper-pinyon woodland
K024 Juniper steppe woodland
K050 Fescue-wheatgrass
K051 Wheatgrass-bluegrass
K053 Grama-galleta steppe
K055 Sagebrush steppe
K056 Wheatgrass-needlegrass shrubsteppe

K063 Foothills prairie
K064 Grama-needlegrass-wheatgrass
K066 Wheatgrass-needlegrass

SAF COVER TYPES [23]:
205 Mountain hemlock
206 Engelmann spruce-subalpine fir
210 Interior Douglas-fir
215 Western white pine
218 Lodgepole pine
220 Rocky Mountain juniper
224 Western hemlock
235 Cottonwood-willow
237 Interior ponderosa pine
238 Western juniper
239 Pinyon-juniper
243 Sierra Nevada mixed conifer
244 Pacific ponderosa pine-Douglas-fir
245 Pacific ponderosa pine
247 Jeffrey pine

SRM (RANGELAND) COVER TYPES [103]:
101 Bluebunch wheatgrass
102 Idaho fescue
104 Antelope bitterbrush-bluebunch wheatgrass
105 Antelope bitterbrush-Idaho fescue
107 Western juniper/big sagebrush/bluebunch wheatgrass
109 Ponderosa pine shrubland
110 Ponderosa pine-grassland
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
309 Idaho fescue-western wheatgrass
314 Big sagebrush-bluebunch wheatgrass
315 Big sagebrush-Idaho fescue
317 Bitterbrush-bluebunch wheatgrass
318 Bitterbrush-Idaho fescue
320 Black sagebrush-bluebunch wheatgrass
321 Black 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
420 Snowbrush
421 Chokecherry-serviceberry-rose
612 Sagebrush-grass
613 Fescue grassland
614 Crested wheatgrass

HABITAT TYPES AND PLANT COMMUNITIES:
Pacific Northwest: Diffuse knapweed is found primarily in the eastern part of Washington state, on the northwest slopes of the

Columbia River Basin. Here it may be found in shrub steppe, natural grassland, and dry forest steppe types [87]. Diffuse knapweed demonstrates superior invasiveness in antelope bitterbrush (*Purshia tridentata*)/bluebunch wheatgrass (*Pseudoroegneria spicata*) communities, with or without needle-and-thread grass (*Hesperostipa comata*) in eastern Washington [85,115]. It may also be dominant in bitterbrush habitat types with or without an overstory of ponderosa pine (*Pinus ponderosa*). Diffuse knapweed is also common in ponderosa pine/shrub, Douglas-fir/common snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*), and Douglas-fir/ninebark (*Physocarpus malvaceus*) habitat types that have been cleared and either converted to pasture or support tree regeneration. Most dryland pastures now dominated by diffuse knapweed were previously dominated by Kentucky bluegrass (*Poa pratensis*). On the east slope of the Cascades, diffuse knapweed can be found at middle to low elevations from ponderosa pine and bunchgrass habitats into big sagebrush (*Artemisia tridentata*)/bunchgrass types [85], where it may be found with bluebunch wheatgrass, Sandberg bluegrass (*Poa secunda*), Russian-thistle (*Salsola kali*), and cheatgrass (*Bromus tectorum*) [96].

In Utah, the antelope bitterbrush/bunchgrass shrub steppe is highly susceptible to invasion by diffuse knapweed [85].

In Colorado, diffuse knapweed invades the shortgrass steppe along the Front Range, including the foothills. Adjacent montane zones and the lower elevation pinyon-juniper-oak (*Pinus*-*Juniperus*-*Quercus* spp.) brush zones are also susceptible [85]. Diffuse knapweed is also found on upland sites in pinyon and juniper woodlands in the interior west [114].

In Montana, diffuse knapweed infestations are found primarily on grasslands and fringe forest areas near Helena, Big Timber, and Ennis [49]. It is well adapted to open-forested areas, especially after logging or other disturbances [27].

Canada: The interior natural grasslands and fringe forest areas of southern British Columbia and the shortgrass prairies of Alberta and Saskatchewan are considered vulnerable to diffuse knapweed invasion [36,68]. Native bunchgrasses may be replaced with annual grasses, sagebrush (*Artemisia* spp.), and diffuse and spotted knapweed [80]. Diffuse knapweed may be found with bluebunch wheatgrass, Idaho fescue (*Festuca idahoensis*), bluegrasses (*Poa* spp.), needle-and-thread grass, Columbia needlegrass (*Achnatherum nelsonii* ssp. *dorei*), sand dropseed (*Sporobolus cryptandrus*), and slender wheatgrass (*Elymus trachycaulus*) [11,41,68]. In British Columbia, diffuse knapweed is also found in areas supporting ponderosa pine, Douglas-fir, antelope bitterbrush, and ninebark communities. Diffuse knapweed has also established on dry subzones of the ponderosa pine, interior Douglas-fir, montane spruce, and interior cedar-hemlock biogeoclimatic zones in southern interior of British Columbia. Here it may be found with Douglas-fir, lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and understory components such as pinegrass (*Calamagrostis rubescens*), fireweed (*Epilobium angustifolium*), and *Vaccinium* spp. [79].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Centaurea diffusa

GENERAL BOTANICAL CHARACTERISTICS:
Diffuse knapweed is an exotic, annual, biennial, or short-lived perennial forb [22]. During the juvenile stage, diffuse knapweed is a rosette with deeply divided basal leaves borne on short stalks on a central crown with a taproot. At maturity diffuse knapweed produces 1 upright stem, rarely 2. Stems are 1 to 3 feet (0.3-1 m) tall, with numerous, spreading branches that give the plant a ball-shaped appearance and tumble-weed mobility when broken off. Stem leaves on diffuse knapweed are stalkless, getting smaller and less divided higher up the stem. Flowerheads are solitary or borne in clusters of 2 or 3 at the ends of branches. Diffuse knapweed flowerheads are 3-6 mm in diameter and 8-11 mm long, excluding spines and flowers. Bracts are edged with a fringe of spines, with a longer 1.5-4 mm, erect spine at the tip. Seeds are achenes, 2-3 mm long with a plume of bristle-like hairs that vary from scalelike to 1/8 the length of the seed [18,85].

Once it is established, the highly competitive diffuse knapweed can form monotypic stands. The competitive ability of diffuse knapweed has been attributed to its being adept at depleting soil moisture [108], to allelopathy [14,15,26], and to other competitive or interference mechanisms [14,15].

RAUNKIAER [82] LIFE FORM:

Hemicryptophyte

REGENERATION PROCESSES:
Diffuse knapweed reproduces by seed and is generally biennial. The plants begin as low rosettes and may remain in this form for 1 to several years, until they reach a critical size (e.g. root crown diameter [80]), or stage of development (e.g. leaf number). At this point they respond to vernalization (i.e. low temperatures) by bolting, flowering, setting seed, and dying. Thus, they may behave as annuals, biennials, or short-lived perennials, a habit sometimes designated as "semelparous perennial" [116].

Pollination: Diffuse knapweed is primarily insect pollinated [39,129]. Honeybees, bumble bees, and digger bees are frequent diffuse knapweed flower visitors [39]. Fertilization in diffuse knapweed requires cross-pollination between flowers on different plants. This can limit the reproductive success of isolated individuals, but it also promotes genetic diversity and may thereby improve competitive ability. Watson and Renney [128] reported that diffuse knapweed is self-compatible, but the results of Harrod and Taylor [39] refute this assertion.

Seed production: Average seed production by diffuse knapweed is reported by area as follows:

Location	Flowerheads per plant	Seeds per flowerhead	Seeds per plant	Seeds per m^2	Reference
British Columbia - rangeland	74	12	925	not reported	
British Columbia - irrigated	1404	13	18,248	not reported	[128]
Washington state - averaged across diverse sites and years	89	13	1157	26,400	[93]

Considerable variation in seed production was observed between sites and years in northeastern Washington; nonetheless, seed production was estimated to be 1,000 times what would be necessary to maintain observed levels of infestation [93].

Seed dispersal:
Dispersal of diffuse knapweed seed is mainly by wind. Seeds usually remain in the flowerheads after they mature and break away from the receptacle. Dispersal in the vicinity of the parent plant is facilitated by horizontally placed seedheads that open at the top and release seeds as dehydration occurs and plants sway in the wind. Dispersal over longer distances occurs when plants are broken off at ground level and tumble in the wind, dispensing seeds individually from the small opening at the top of the seedheads [128]. This technique adapts well to "hitchhiking" on the frames of vehicles and colonizing the bare shoulders of roads. Seeds may also be transported in mud adhering to vehicles or shoes [129]. Plants bearing seeds may also be carried in rivers and irrigation systems, thus colonizing the banks of waterways [85]. In British Columbia, logging trucks, off-road vehicles, and trail bikes have greatly contributed to the spread of both spotted and diffuse knapweed [112].

Seed banking: Evidence suggests that diffuse knapweed seed germination is distributed over time [69]. This may be considered as evidence of seed banking, although the length of time that diffuse knapweed seeds remain viable in the soil seed bank is undetermined.

Viability:
Seed viability information for diffuse knapweed is scarce. In British Columbia , diffuse knapweed seed removed from seedheads at maturity exhibited 40% germination; 25-day-old seed stored under dry conditions exhibited 68% germination; and seeds that overwintered in the seedhead under field conditions exhibited 88% germination [128]. Watson [129] reports successful (93-95%) laboratory germination of 20-month-old seed stored at room temperature [138]. Another laboratory germination test showed greater than 95% viability of diffuse knapweed seeds, although germination values observed in the field were <70% [93].

Germination:
Diffuse knapweed seeds germinate in spring (May/June) or late summer/early fall (August/September), and develop into low-lying, tap-rooted rosettes given sufficient moisture [11,68,128]. Diffuse knapweed seeds germinated under a wide range of environmental conditions simulated in the laboratory. Germination of over 80% occurred between 55 and 82 degrees Fahrenheit (13-28 °C) at optimum moisture levels [128]. Diffuse knapweed seeds require more than 55% soil moisture to initiate germination, with optimum emergence between 65 and 70% [107]. Diffuse knapweed seeds germinate best on the soil surface, with emergence rate decreasing as seeding depth increases, and little to no emergence below 1 inch (2.5 cm) [107,128]. Spears and others [107] found diffuse knapweed seeds germinated equally well over the range of 0 to 100% canopy cover. Nolan and Upadyaya [69] observed 3 types of germination behavior in diffuse knapweed with respect to light conditions: nondormant

seeds that can germinate in the dark; light-sensitive seeds that germinate after exposure to red light; and light-insensitive dormant seeds that do not respond to exposure to red light. They concluded that bunchgrass rangeland and other open canopy conditions provide favorable light conditions for diffuse knapweed seed germination.

Seedling establishment: Stannard [108] reports high seedling vigor in diffuse knapweed, while Myers and Berube [68] indicate that the greatest mortality in diffuse knapweed occurs between the seedling and rosette stages. Seedling mortality is highest during the summer and is largely related to moisture availability [68,80,93,128]. Once diffuse knapweed seedlings establish as rosettes, they become very drought resistant [11]. Crowding of plants is also a factor in seedling and juvenile mortality, with mortality rates highest among the smallest rosettes, and declining with size under crowded conditions. The proportion of diffuse knapweed plants that flower and produce seed each year (and subsequently die) increases with available growing space [80]. Additionally, Powell [80] observed that the majority of diffuse knapweed rosettes that died during the summer at 1 site in British Columbia were infested with the larvae of the introduced biocontrol beetle *Sphenoptera jugoslavica*, and suggested that the damage caused by the larvae increased the susceptibility of rosettes to interference-related mortality. Amount and pattern of rainfall are important for diffuse knapweed survival. Wetting increases germination, but when followed by drying (e.g. the wet-dry cycle occurring with the summer convective storms in British Columbia ranges) seedling survival is diminished [11]. High spring precipitation appears to favor diffuse knapweed seedling establishment [101].

Asexual regeneration: Diffuse knapweed can sprout from the root crown after top-kill [85,128]. Other methods of asexual regeneration are not known to occur in diffuse knapweed [128].

SITE CHARACTERISTICS:
Semiarid rangeland and dry open forest sites in the northwestern U.S. are subject to invasion by diffuse knapweed, especially with disturbance. In British Columbia, density of diffuse knapweed was significantly ($p<0.05$) correlated with degree of soil disturbance, but not with any soil chemical properties [129]. Disturbance also allows diffuse knapweed to invade a wide range of habitats [16,85], where it can rapidly establish dense, often monotypic, stands. Disturbances may be as small as rodent activity or a single hailstorm [50] and may not be recent [85]. Typical disturbed sites subject to diffuse knapweed invasion include transportation corridors, water ways, gravel pits, and industrial areas [88]. Diffuse knapweed is also capable of invading well-managed rangeland [11,50,99].

Diffuse knapweed is tolerant of a wide range of total precipitation and temperature conditions but does best in semiarid and arid conditions, and is most competitive in areas receiving between 12 and 17 inches (305-432 mm) of annual precipitation [11,36,87,128]. Diffuse knapweed is susceptible to flooded or waterlogged conditions, and infestations stop abruptly with an increase in soil moisture near temporary and permanent streams. Irrigation can also eliminate diffuse knapweed [68]. Diffuse knapweed is not competitive in moist microsites such as gullies, depressions, and poorly drained soils [11,85]. Diffuse knapweed seeds require conditions near field capacity for at least 4 days to begin germination. Seedling root growth in diffuse knapweed may be sensitive to saline conditions (electrical conductivity of 4 dS m^{-1}). Seedling root growth may also be sensitive to and germination delayed by water stress (osmotic potential of -0.5 mP or less) [45].

In eastern Washington, diffuse knapweed grows on all aspects and slope positions, from flat to over 60% [85,87,115]. In the Gilpin range, British Columbia, knapweed is commonly found on south-facing slopes below 3,000 feet (900 m) [63]. The following table provides some elevation and precipitation ranges as reported by state or province:

Location	Elevation range	Annual precipitation range	Mean annual temperature range	References
Arizona	up to 7,000 ft (2,134 m)	----	----	[138]
Washington	0-5,000 ft (0-1,500 m)	6-35 inches (150-900 mm)	----	[85,115]
British Columbia	500-3,000 ft (150-900 m)	----	45-49 °F (7-9 °C)	[128,129]

Diffuse knapweed is commonly found on well-drained soils such as sandy or gravelly loams or loamy fine sands, with coarse fragments from 0 to over 80% [86,87]. It is less competitive on shallow soils (< 15 inches (38 cm) deep) and very coarse textured soils such as sand or loamy coarse sand, although it may thrive on these sites when disturbance removes other vegetation [87]. It grows best on fertile, well-watered Cryoborolls, mesic Argiudolls, and mesic Hapludolls in open and uncultivated sites with summer drought [36,99].

SUCCESSIONAL STATUS:
Diffuse knapweed is an early successional species that establishes best on disturbed ground. Although diffuse knapweed seeds can germinate in the dark [69,107], diffuse knapweed plants do not grow well in dense shade [85]. Diffuse knapweed can dominate a site over time and persist in monotypic stands [100].

SEASONAL DEVELOPMENT:
The phenology of individual diffuse knapweed plants is highly variable and dependent on climatic and site conditions such as moisture, temperature, and plant density. Diffuse knapweed seedlings usually emerge under favorable conditions in spring and/or fall and develop into rosettes. Most root development occurs during this stage [128]. Rosettes respond to a period of cold temperature (vernalization) and bolt when a critical size or stage of development is reached [80,116]. Diffuse knapweed plants that complete their juvenile growth by fall and overwinter as rosettes usually bolt in early May. Plants that do not complete the juvenile stage by the end of fall remain as rosettes through the 2nd year and may bolt during the 3rd year. Flower buds are formed in early June. Flowering occurs July through September [18,128] or later as permitted by adequate moisture and mild temperatures [85]. Mature seeds are usually formed by mid-August, followed by death of the plant. Dead plants break off at ground level in the spring and tumble with the wind, spreading seed as they roll [128].

Powell [80] found that under conditions of severe crowding, a plant might not flower for 5 or more years. Other exceptions include plants that germinate in early spring that may flower the 1st year (<1% observed) [93], and plants that continue to grow after producing seed to flower again the following year, behaving as short-lived perennials [85].

FIRE ECOLOGY

SPECIES: Centaurea diffusa

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:
Fire adaptations:
Information on the fire ecology and adaptations of diffuse knapweed to fire is lacking in the literature. Diffuse knapweed has a large, perennial taproot that may survive fire if the root crown is not killed. It also produces large quantities of seed that may survive fire.

Fire regimes:
Diffuse knapweed occurs primarily in bunchgrass and open ponderosa pine forest community types in the northwestern United States and southern British Columbia. The historical fire regimes of these communities were relatively frequent, low-severity surface fires. Diffuse knapweed did not occur in these communities at the time in which these fire regimes were functioning, but has established since fire exclusion began. It is unclear how this type of fire regime might affect diffuse knapweed populations. It is also unclear how the presence of diffuse knapweed might affect these fire regimes, though it has been observed that closely related species, such as spotted knapweed, do not carry fire as readily as grasses [61,134]. If this holds true for diffuse knapweed, dense infestations may change the fire regime by changing the fuel characteristics and reducing the fire return interval at a given site.

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

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
grand fir	*Abies grandis*	35-200 [7]
sagebrush steppe	*Artemisia tridentata/Pseudoroegneria spicata*	20-70 [75]
basin big sagebrush	*A. t.* var. *tridentata*	12-43 [92]
mountain big sagebrush	*A. t.* var. *vaseyana*	15-40 [8,12,62]
Wyoming big sagebrush	*A. t.* var. *wyomingensis*	10-70 (40**) [124,135]
desert grasslands	*Bouteloua eriopoda* and/or *Pleuraphis mutica*	5-100
plains grasslands	*Bouteloua* spp.	< 35
blue grama-needle-and-thread grass-western wheatgrass	*B. gracilis-Hesperostipa comata-Pascopyrum smithii*	< 35
grama-galleta steppe	*B. g.-Pleuraphis jamesii*	< 35 to < 100
cheatgrass	*Bromus tectorum*	< 10
western juniper	*Juniperus occidentalis*	20-70

Rocky Mountain juniper	*J. scopulorum*	< 35 [75]
Engelmann spruce-subalpine fir	*Picea engelmannii-Abies lasiocarpa*	35 to > 200 [7]
pinyon-juniper	*Pinus-Juniperus* spp.	< 35 [75]
Rocky Mountain lodgepole pine*	*P. contorta* var. *latifolia*	25-300+ [6,7,89]
Colorado pinyon	*P. edulis*	10-49 [75]
Jeffrey pine	*P. jeffreyi*	5-30
western white pine*	*P. monticola*	50-200
Pacific ponderosa pine*	*P. ponderosa* var. *ponderosa*	1-47
interior ponderosa pine*	*P. p.* var. *scopulorum*	2-10 [7]
mountain grasslands	*Pseudoroegneria spicata*	3-40 (10**) [6,7]
Rocky Mountain Douglas-fir*	*Pseudotsuga menziesii* var. *glauca*	25-100
California mixed evergreen	*P. m.* var. *m.-Lithocarpus densiflorus-Arbutus menziesii*	< 35
western redcedar-western hemlock	*Thuja plicata-Tsuga heterophylla*	> 200
mountain hemlock*	*T. mertensiana*	35 to > 200 [7]

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

POSTFIRE REGENERATION STRATEGY [109]:
Caudex/herbaceous root crown, growing points in soil
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: Centaurea diffusa

- 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:
Although experimental evidence is lacking, a single, low-severity fire will probably not kill diffuse knapweed unless it is severe enough to kill the root crown. A low-severity fire will also probably not kill diffuse knapweed seeds stored in the soil. It is unclear what effects a severe fire would have on diffuse knapweed plants and seeds. Research in this area is needed.

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
No entry

PLANT RESPONSE TO FIRE:
Diffuse knapweed may sprout from the root crown and/or establish from seed after fire [85]. It is unclear how diffuse knapweed populations may respond to fire. Reports in the literature are scarce and based primarily on speculation and second-hand information, with little experimental evidence available. It can be assumed that the response of diffuse knapweed to fire will vary with the nature of the prefire plant community, the timing and conditions of the burn, and the conditions of the postfire environment.

Harrod and others [40] suggested that fire might reduce the ability of diffuse knapweed to produce seed in the current year, since many bolting stems appeared to be reverted back to a rosette stage after fire. This might allow grasses (which appear to be stimulated by fire) to gain a competitive advantage [40]. A single fire in northern Washington, however, increased the cover and density of both diffuse and spotted knapweed without enhancing desired species [97,99]. Roche and Roche [85] suggest that diffuse knapweed can resprout even after intense wildfire at bolting or flowering stages, although they provide no experimental evidence for this assertion. They further suggest that fire may damage desirable residual species while stimulating knapweed (*Centaurea* spp.) populations.

Reproduction by abundant seed gives diffuse knapweed an advantage in fire-prone environments. Spotted knapweed seeds demonstrate some resistance to high temperatures [1]. This may also be true for diffuse knapweed. Diffuse knapweed seeds may persist in the soil and germinate after fire. Where diffuse knapweed plants are left standing, seeds may be present above ground as well. This "aerial seed bank" may or may not be an advantage after fire, depending upon the characteristics of the fire. Renney and Hughes [84] suggest that burning shows some promise for diffuse knapweed control, especially since the viability of seeds held above ground in the seedhead is considerably reduced by heat, though they give no reference to experimental evidence for this conclusion. Watson [129] notes that seed collected from diffuse knapweed plants in an area burned by a mid-August wildfire was not viable.

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
No entry

FIRE MANAGEMENT CONSIDERATIONS:
Fire as a control agent:
With very few examples in the literature of the effects of fire on diffuse knapweed, it is not surprising to find mixed opinions on the potential effectiveness of fire to control the plant. Control of diffuse knapweed with a single fire is likely to be only temporary [85], because it is a perennial species that produces abundant seed that spreads by tumbleweed action [84]. It is commonly suggested that fire may be used to remove plant debris and improve herbicide efficacy, but again, there is no experimental evidence to support this [22,85].

Others suggest that burning may be an effective means of controlling diffuse knapweed in areas where seasonal or occasional fires are part of the natural ecosystem [16]. Watson and Renney [128] cite Popova (1960) as reporting that fire provides effective control of diffuse knapweed, with vigorous grass regrowth after burning in the Crimea. Additionally, repeated burning of prairie and dune sites in Michigan has proven to encourage growth of native vegetation and reduce spotted knapweed density [61]. Repeated burns may also prevent new seed production and eventually deplete the seed bank.

Postfire colonization potential:
Diffuse knapweed has the potential to invade an area following fire. Fire provides an ideal seedbed by removing shade and exposing mineral soil. Therefore, if diffuse knapweed was present on or near the site prior to the fire, there is potential for its establishment. It is a good idea to survey the surrounding area for diffuse knapweed skeletons that may contain seed that could be dispersed through tumbleweed action. Diffuse knapweed is 1 of the introduced species mentioned as "taking over large tracts of logged, burned, or otherwise disturbed lands in British Columbia" [119].

The USDA Forest Service's "Guide to Noxious Weed Prevention Practices" [120] provides several fire management considerations for weed prevention in general that apply to diffuse knapweed. Wildfire managers might consider including weed prevention education and providing weed identification aids during fire training; avoiding known weed infestations when locating fire lines, monitoring camps, staging areas, helibases, etc., to be sure they are kept weed free; taking care that equipment is weed free; incorporating weed prevention into fire rehabilitation plans; and acquiring restoration funding.

When planning a prescribed burn, inventory the project area and evaluate the cover and phenology of any diffuse knapweed present on or adjacent to the site, and avoid ignition and burning in areas at high risk for diffuse knapweed establishment or spread due to fire effects. Avoid creating soil conditions that promote weed germination and establishment. Discuss weed status and risks in burn rehabilitation plans.

To prevent infestation, 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. Monitor the burn site and associated disturbed areas after the fire and the following spring for emergence of diffuse knapweed, and treat to eradicate any emergent diffuse knapweed plants. Regulate human, pack animal, and livestock entry into burned areas at risk for weed invasion until desirable site vegetation has recovered sufficiently to resist weed invasion. Additional guidelines and specific recommendations and requirements are available [120].

MANAGEMENT CONSIDERATIONS

SPECIES: Centaurea diffusa

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Diffuse knapweed replaces traditional wildlife and livestock forage on range and pasturelands [19,63,68], and reports of its use by grazing animals vary. Watson and Renney [128] report that while it is not poisonous, the presence of diffuse knapweed in hay or on rangeland can decrease feeding value to livestock and wildlife species. They also note that in situations of overgrazing or drought, when fewer forage species are available, the flower shoots are sometimes grazed while immature rosettes are not [128]. Although rosettes of the 1st year's growth are nutritious and edible, they are difficult for cattle to eat because they are closely appressed to the ground (Popova 1960 as cited by [99]). Mature knapweed plants are coarse and fibrous and the spines on the bracts can be very irritating [99] or may even cause injury to the mouths and digestive tracts of grazing animals [128]. Diffuse knapweed is grazed by deer and domestic sheep [99], and by elk and cattle, at least through the bolting stage [85].

Miller [63] observed California and Rocky Mountain bighorn sheep, white-tailed deer, mule deer, and elk consuming diffuse and spotted knapweed in the Gilpin range, and in the Robson/Syringa Park area in British Columbia. Knapweeds are important forage for these animals in the winter and early spring. In the Gilpin range, knapweed rosettes comprised 80% of the diet of California bighorn sheep as the snow receded in January and February, and knapweed seedheads were the most common component of their diet when snow depth exceeded 8 inches (20 cm). When snow did not restrict availability, knapweed rosettes and bluegrass comprised 90% of the diet of mule and white-tailed deer during February and early March. In the Robson/Syringa Park area, Rocky Mountain bighorn sheep utilized knapweed seedheads and basal rosettes throughout the year, while local deer and elk populations foraged on knapweed rosettes in late fall/early winter, and again when snow cover receded and spring greenup commenced. The impact of knapweed consumption on the welfare of these animals, and the effects of heavy utilization of rosettes need further examination [63]. Harris [34] notes that deer in British Columbia began eating knapweed seedheads as winter browse after the establishment of the *Urophora* spp. seedhead flies, and that almost all the nutrition in these seedheads comes from these insect larvae.

Diffuse knapweed is a source of pollen and nectar for honey bees during mid- to late summer when other sources are in short supply, and it is sometimes eaten by pest grasshoppers during outbreaks [25,85]. At high densities, grasshoppers may consume large amounts of knapweed and reduce seed production [25]. Birds and rodents, including chipmunks, use diffuse knapweed seeds for food [86,129]. Chipmunks probably cache some seed for later use [86].

PALATABILITY:
Fielding and others [25] observed that diffuse knapweed had low palatability to 2 generalist herbivore grasshoppers, and suggested that this may confer a competitive advantage to diffuse knapweed over other rangeland plants. They suggested that diffuse knapweed palatability may be related to varying concentrations of the compound cnicin in different plant parts during different times of year.

Palatability of diffuse knapweed to a foraging animal is probably more closely related to its availability relative to other forage plants [85,129].

NUTRITIONAL VALUE:
Nutritional value of diffuse knapweed varies with the developmental stage of the plant and the season. Crude protein levels of diffuse knapweed were measured at 18% in the rosette stage, 11% in the bolt stage, 8% during bud and flowering stages, and 7% at seed-ripe stage [85]. In the Gilpin range, British Columbia, nutritional value of diffuse knapweed was comparable to associated grasses in the area, with crude protein levels higher than crude protein in associated grasses at that time [63]:

	Crude protein (%)			Digestible crude protein (%)	Acid-detergent fiber (%)		Dry matter (%)	
sample date	30 Jan.	20 Mar.	15 Dec.	20 Mar.	30 Jan.	15 Dec.	30 Jan.	15 Dec.
seedheads	7.5	6.98	8.3	1.26	50.8	23.8	71.8	78.9
rosettes	16.9	20.4	17.3	9.27	31.8	23.8	24.2	16.9

COVER VALUE:

No information

OTHER USES:
Diffuse knapweed provides nectar and pollen for honey bees [128,129]. In laboratory tests, some extracts from diffuse knapweed inhibited larval growth of variegated cutworms [91], while other extracts inhibited the growth of various plants [106], suggesting a potential to develop pesticides and herbicides from these extracts.

IMPACTS AND CONTROL:
Impacts:
Many environmental and economic losses have been attributed to diffuse knapweed infestations. Examples include replacing wildlife and livestock forage on rangeland and pasture [19,36,63,68,101,128], depleting soil and water resources [19,85,101], displacing native species on wildlands [137], reducing biodiversity [19,101], reducing land value [19,85], and disflavoring milk [59].

The presence of knapweeds may be a symptom of range degradation. Diffuse knapweed fills niches created by soil disturbance and can also invade good condition range in the absence of grazing [50,68,100]. Diffuse knapweed invasion can be insidious or rapid and conspicuous [50].

In a study conducted in British Columbia, neither diffuse nor spotted knapweed inhibited the growth or survival of conifer seedlings (lodgepole pine and Douglas-fir) [79]. Similarly, diffuse knapweed did not affect seed weight in antelope bitterbrush at British Columbia and northern Washington sites [47]. Diffuse knapweed does, however, possess several traits that give it an advantage over perennial grasses such as intense competitiveness, rapid growth rates, large seed output, and extended growing periods. Continuous seed rain and sequential seedling emergence allow diffuse knapweed to occupy more microsites for seed germination, and to maximize site dominance and eventually form monotypic stands [100]. Even under good range conditions, bluebunch wheatgrass may offer little resistance to knapweed invasion. Diffuse and spotted knapweed growing at moderate densities among bunchgrasses in British Columbia were more vigorous than when growing alone. Inhibition of the bunchgrasses may not occur until threshold densities of knapweed are reached [2].

Diffuse knapweed may suppress other vegetation by allelopathy [16,26]. Diffuse knapweed contains varying concentrations of phytotoxic secondary compounds [64,91,106]; however, the importance of allelopathy has been challenged since concentrations of these compounds in soil are usually below phytotoxic levels [44,73]. Allelopathy may be part of a more complex interference strategy that includes other specialized mechanisms unknown to the plant communities that it invades [14,15].

Control:
Lasting control of diffuse knapweed requires proper land management to maintain desired vegetation. It is important to define land use objectives before developing management plans for invasive plants. Killing the target plant is not usually an adequate objective. An understanding of basic diffuse knapweed biology (see the "Botanical and Ecological Characteristics" section of this report) will help land managers choose appropriate control tools and determine proper timing of their application according to the plant's life cycle, as part of a long-term control program [83]. More information on diffuse knapweed's requirements for litter cover, soil moisture, and nutrient needs for establishment and spread can enable managers to develop more effective integrated management programs [57].

For diffuse knapweed, a biennial or short-lived perennial that reproduces by seed, control is very effective during the 1st season of growth when the plant is in the rosette stage and prior to the development of viable seed. A plan to prevent new seed production (e.g. killing the plant or destroying the aboveground portion prior to seed set) can contain existing infestations. To deplete the existing seed bank, areas must then be monitored 2 to 3 times a year, for several years, and any new rosettes destroyed. It is important to document the location and densities of any diffuse knapweed stands or individual plants in order to record the rate of spread of the infestation and to know where to look for emerging seedlings and rosettes in following years [16,137]. Steps must then be taken to prevent reinfestation by cooperating with managers of adjacent land, and land along shared transportation and water corridors, and by being aware of and preventing potential seed dispersal vectors. For instance when diffuse and spotted knapweed were first found in Alberta in 1974, an eradication program was launched that included cooperation between provincial and local government agencies and landowners. By 1985, the infestation was reduced to scattered plants and remains so, to date. Early detection and public awareness were keys to their success [4,5].

Integrated weed management (IWM):
The use of multiple control methods is important when implementing any weed management system [83], because multiple approaches can create a cumulative stress on the plant, thus reducing its ability to flourish and spread. A combination of methods also provides some redundancy, in case 1 type of control treatment is ineffective [16]. With combinations of treatments, timing is critical and must be customized to the plant community, present and desired, and to site conditions [21]. Procedures that increase bare ground on rangeland without replacement by desirable species are not recommended [22].

IWM is more than just combining 2 or more methods to control a weed population; it is a long-term commitment to replace weed-infested plant communities with more desirable plant communities in a way that is complementary to the ecology and economics of the site. IWM is a multidisciplinary, ecological approach for containing or controlling undesirable plant species using all available methods, including education, prevention, physical or mechanical methods, biological control agents, herbicides, cultural methods and other land management practices. The methods selected for control of diffuse knapweed on a specific site will be determined by the land use objectives, environmental factors, economics, the extent and nature of the infestation(s), and the effectiveness of the control techniques on diffuse knapweed [83]. Sheley and others [102] suggest using a generalized objective such as developing an ecologically healthy plant community that is weed resistant and meets other land-use objectives such as livestock forage, wildlife habitat, or recreation. A weed-resistant plant community is comprised of diverse species that occupy most of the niches [22]. 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 [98].

Prior to deciding which control measures are most appropriate, a land manager should: 1) inventory and assess the land to determine the size of the infestation(s); 2) assess non-target vegetation in the management area; 3) determine soil types, climatic conditions, and important water resources; and 4) determine the limitations of various control methods [83]. Also necessary for a successful IWM program is cooperation between all private and public landowners and government agencies that manage land in the area [22]. Additional components in any integrated weed management program are sustained effort, monitoring and evaluation for several years, and the adoption of improved strategies [99].

Some examples of combined approaches 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.

Prevention:

Preventing the spread of diffuse knapweed is the most economically and ecologically effective management strategy [99]. Prevention is achieved by minimizing soil disturbance on range and other noncrop lands, early detection and treatment of newly established plants, eradication of small infestations before they spread, containing large infestations, and preventing seed dispersal. Seeding desirable perennial grass species on areas disturbed by logging, fire, construction, mining or other activities can help prevent diffuse knapweed invasion [22]. Renney and Hughes [84] suggested in 1969 that much of the knapweed infestation could be contained if transportation corridors (highways, roads and trails) could be rid of the plants.

Proper grazing management is essential to the maintenance of a competitive, desirable plant community that can slow diffuse knapweed encroachment [22,57]. To minimize weed invasion, grazing systems should alter the season of use, rotate or combine livestock types and pastures, and allow grazed plants to recover before being regrazed [22]. In eastern Washington, the establishment of diffuse knapweed was enhanced when defoliation of bluebunch wheatgrass exceeded 60%, suggesting that defoliation above this level reduced the competitiveness of the grass. Diffuse knapweed density did not initially increase on a similar crested wheatgrass site, but after a year it increased when crested wheatgrass was defoliated by 80-100%. Although this study indicates that moderate defoliation does not accelerate diffuse knapweed invasion, disturbances associated with grazing, such as trampling and exposed mineral soil, were not examined [101].

Public awareness of the identity and characteristics of diffuse knapweed and support of local weed management programs can help prevent seed dispersal. Driving, walking, biking and trailing animals through infested areas must be avoided. When vehicles have been in weed-infested areas, it is important to wash the undercarriage before driving through uninfested areas [22]. Additionally, use only certified weed-seed free seed and hay for livestock before entering the backcountry, and avoid grazing livestock on knapweed-infested sites during flowering and seeding. When this cannot be avoided, it is important to hold livestock for 7 days before moving to uninfested pastures [22,127,138].

Physical or mechanical:

Physical and mechanical approaches to diffuse knapweed control include hand pulling, digging, tilling, disking, and cutting or mowing. Physical removal of, or damage to diffuse knapweed plants may offer some degree of control depending on the timing and frequency of treatment, the condition of desired vegetation and the degree of soil disturbance imposed by the treatment itself. The Salmon River Restoration Council provides an example of nonchemical spotted and diffuse knapweed control in the Salmon River watershed in northern California, using physical and mechanical control techniques such as hand pulling and digging, propane torching, mulching with black plastic (solarization), and mowing [46]. See their website, SRRC, for detailed information on this program.

Control of diffuse knapweed by hand pulling is feasible for scattered diffuse knapweed plants or in areas where other control methods are not feasible and sufficient hands are available. It is important to remove the entire taproot with as little soil disturbance as possible [137]. Diffuse knapweed rosettes cut just below the crown regrew 38% of the time, while only 4% of those cut 2 to 4 inches (5-10 cm) below the crown resprouted [85]. Pulling works best when done 3 times per year. Begin by removing diffuse knapweed plants in spring, taking care to get a "lethal portion" of the root. This is easiest done when soil is moist. Pull again in June to remove bolting plants before they flower and set seed. Finally, pull plants just before seed dispersal, taking care to remove plants from the site and dispose of them in a manner that ensures seeds are not dispersed [137]. After 5 years of this regimen using volunteers in Oregon to control small populations of diffuse knapweed scattered amongst native plants, average density of diffuse knapweed plants was reduced 98%. About 10 personhours are then required each season to monitor and remove the few dozen plants that sprout from the seed bank. For larger infestations, a combination of chemical and mechanical control can be used. In Oregon and Colorado, diffuse knapweed was sprayed with picloram in the spring, followed later in season by mechanical removal of plants that were missed with herbicides, with good results [96,136]. In some cases, however, hand pulling may not be effective. On a Colorado rangeland, hand pulling twice a year failed to control diffuse knapweed probably because the root tended to break off near soil surface. Additionally, plants on nearby experimental plots were allowed to seed, and just a few diffuse knapweed plants can repopulate a large area [95]. Hand pulling twice for 2 consecutive years in west-central Colorado was expensive and provided only 0 to 35% diffuse and spotted knapweed control, respectively, after 3 seasons, and increased bare ground [21].

Mowing diffuse knapweed can reduce seed production or alter phenological development, and can reduce weed competition during establishment of newly seeded grasses. A long-term program in which only bolted plants are cut for several consecutive years can reduce number and cover of diffuse knapweed plants, or in some cases it can severely damage or disturb surrounding vegetation and make the area more susceptible to knapweed infestations [16,95,128,138]. Because diffuse knapweed is an obligate outcrosser, seed production can be greatly reduced when diffuse knapweed is mowed prior to flowering [40]. Mowing diffuse knapweed in British Columbia at the bud stage and again at flowering reduced the number of plants producing seed by 77 to 99% compared to unmowed plants. Mowing treatments also reduced germination of seeds by about 79%. Energy remaining in the cut plants may be adequate for seeds to develop. Plants mowed early in the growing season produce few viable seeds; however, mowed plants usually resprout and flower again [128]. Seeds are then produced late in the season and are, therefore, likely to escape attack by biocontrol insects. In Washington state, 22% of plants mowed to a 2-inch (5 cm) height each month of the growing season (April through October) were still growing 4 years later [85].

Diffuse knapweed is intolerant of cultivation and irrigation and is generally not considered a problem on cultivated land [36,108,112,128,129]. Cultivation in combination with reseeding competitive perennial grasses may minimize reinvasion by the knapweeds [22,55].

Fire: See Fire Management Considerations.

Biological control:
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 [38,67,90,118,133] and the Weed Control Methods Handbook [117] for background information on biological control.

Biological control efforts for diffuse and spotted knapweed began in 1970, and since that time 13 biocontrol agents have been released in North America [54]. Several introduced biological control agents occur in high numbers at sites in Washington, Oregon, and Montana, where diffuse knapweed populations appear to be decreasing [105]. The combined effects of 2 knapweed seedhead flies (*Urophora* spp.) on diffuse knapweed has reduced the dry weight of the attacked plants by 74%, reduced the average seed weight by 18%, and reduced seed production by 95% [3,118]. At 1 site in British Columbia, the combined attack by the 2 *Urophora* species and the root beetle *Sphenoptera jugoslavica* resulted in a 98% reduction in seed numbers [37]. Although the insects reduce seed numbers, diffuse knapweed plants still produce enough seed to maintain population levels [3,137]. Throughout the northwestern United States, *S. jugoslavica* is well established on diffuse knapweed and causes noticeable stunting of plants, but no measurable impact on plant density, while the weevil *Larinus minutus* is having a serious impact on plant growth and density at many locations [111]. It appears that none of these agents, alone or in combination, effectively controls diffuse knapweed populations. They may, however, be useful in integrated control programs by weakening the plants and/or reducing seed output enough to make the plants more susceptible to herbicides, prescribed fires, or other control techniques [16,81,83].

Site characteristics may be an important consideration in the successful establishment of biocontrol agents [113]. For example, seedhead flies may be most effective under site conditions that are marginal to diffuse knapweed survival [11]. Infection of diffuse knapweed by mycorrhizal fungi increased the suitability for infestation by *S. juogoslavica* [35]. Other considerations for biological control include not only the potential effects on nontarget plant species, but also the complex indirect effects agents can have on native communities, as exemplified by the case study of spotted knapweed gall flies and deer mice [76]. For more detail, see spotted knapweed.

Story and Piper [111] provide brief information, and Turner and others [118] provide more detailed information on individual insect control agents for diffuse knapweed:

Agent	Type	States established or recovered on diffuse knapweed [111]	Additional references
knapweed moth (*Sulfur knapweed moth (Agapeta zoegana)*	root-boring moth	CO, MT, UT, WY	[65]
Broad-nosed seedhead weevil (*Bangansternus fausti*)	weevil	CA, OR	[111,118]
Broad-nosed seedhead weevil (*Bangansternus fausti*)	root-boring/gall weevil	CO, MT, OR, UT, WA, WY	[105,132]
Lesser knapweed flower weevil (*Larinus minutus*)	seedhead weevil	CA, CO, MT, NV, OR, UT, WA, WY	[43,53,85]
Spotted knapweed seedhead moth (*Metzneria paucipunctella*)	seedhead moth	MT, OR, WA	[111,118]
Gray-winged root moth (*Pterolonche inspersa*)	root-boring moth	OR	[17]
Bronze knapweed root borer (*Sphenoptera jugoslavica*)	root beetle	CA, CO, ID, MT, OR, UT, WA, WY, BC	[37,78,83,105]
Banded gall fly (*Urophora affinis*)	gall-forming seedhead fly	CA, CO, ID, MT, OR, UT, WA, WY, BC	[3,33,37,52,81,105,111,130]
UV knapweed seedhead fly (*Urophora quadrifasciata*)	gall-forming seedhead fly	CA, CO, ID, MT, OR, UT, WA, WY, BC	[3,33,37,52]

In addition to insect agents, 2 fungal pathogens are known to damage diffuse knapweed under certain conditions. *Puccinia jaceae* attacks the leaves, and *Sclerotinina sclerotiorum* attacks the crowns of diffuse knapweed [77]. These fungi are still being studied and are not cleared as biocontrol agents [28,104,105].

Grazing: The use of grazing animals to control invasive rangeland species is discussed by Olson [72]. Control of diffuse knapweed populations with grazing has received little attention. It is often suggested that grazing is not effective for diffuse knapweed because diffuse knapweed is unpalatable [138] and because ground disturbance created by grazing animals creates ideal seedbeds for further invasion [16]. Piper and others [77] suggest that livestock grazing of diffuse knapweed in early spring can reduce seed production. One study in Colorado found that cattle readily grazed diffuse knapweed and negatively influenced diffuse knapweed population dynamics [9]. Diffuse knapweed is more likely to be grazed by domestic sheep during the rosette through bud stage (when it is green and succulent), or when it is the only plant available (when associates are dormant) [85].

Roche and Roche [85] suggest that methods of utilizing diffuse knapweed can be patterned after programs designed for spotted knapweed and yellow starthistle. Timing relative to the development stages of both the weed and associated vegetation is critical to achieve the desired selectivity. Early and late-season grazing appear to be most effective for spotted knapweed control with sheep (early season to reduce flower production and late season to reduce density of young plants) [31]. Olson and others [74] found that 3 summers of repeated sheep grazing negatively impacted spotted knapweed but minimally affected the native grass community.

Chemical:
Herbicides are effective in gaining initial control of a new invasion or a severe infestation of diffuse knapweed, but are rarely a complete or long-term solution to weed management [13]. Herbicides are more effective on large infestations of diffuse knapweed when incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations [13,22]. Control with herbicides is temporary, as it does not change conditions that allow infestations to occur [137]. See the Weed Control Methods Handbook for considerations on the use of herbicides in natural areas and detailed information on specific chemicals.

Diffuse knapweed plants are easily killed by any of several properly used herbicides. However, because diffuse knapweed produces abundant, long-lived seed, the impact of nonresidual herbicides is reduced in the long-term [86]. As of 1999, several herbicides are registered for control of diffuse knapweed on rangeland, with varying degrees of residual activity for control of later germinants. In order of decreasing residual effects, the following herbicides control diffuse knapweed: picloram, clopyralid, clopyralid + 2,4-D, and 2,4-D [85], and glyphosate. The effectiveness of a residual herbicide varies with application rate and method, soil texture, soil organic matter, and precipitation pattern [86]. Best results from herbicides are usually when the knapweed is in the rosette stage [16,85]. Backpack sprayers or wick applicators are recommended over spray booms or aerial applicators to minimize damage to nontarget plants [16].

Several researchers have compared different rates, application times and combinations of herbicides for diffuse knapweed control [84,94,95,125,131]. Others have examined herbicide use combined with reseeding of desirable plants [24,36,41,60], effects on nontarget plants [96], as well as herbicide compatibility with biocontrol agents [67,81] and grazing [60]. Some researchers recommend mowing or burning prior to herbicide application to increase rates of efficacy [22,95,96].

Fertilizer may effectively stress diffuse knapweed by enhancing competition where conditions are drier than optimal; it may not be effective under moister conditions [11,128]. It has also been suggested that inducing bolting under field conditions by application of gibberellic acid can be timed so that fewer seeds are produced and winter kill is increased. Gibberellic acid can also be used to synchronize the appropriate stages in the life cycles of diffuse knapweed and biocontrol agents. However, induction of bolting of this type under field conditions remains to be demonstrated [123].

A study designed to compare 5 control treatments on diffuse knapweed (burning, cultivation, picloram, seeding of smooth brome (*Bromus inermis*) (another weedy, exotic species), and nitrogen fertilization, alone and in combination) in northeastern Washington was carried out for 8 years. When precipitation was at or above normal, the combination of herbicide and fertilizer produced maximum weed control and forage production, whereas fertilization alone stimulated both grass and knapweed, producing more knapweed than grass. Picloram alone decreased diffuse knapweed for 2 years, with knapweed returning the 3rd year, and grass production remaining higher on all sprayed plots through the 5th year. As single treatments, burning and cultivation provided only fleeting control of diffuse knapweed, with weed production equal to or greater than untreated controls after the 1st year. When all 5 treatments were combined, grass production peaked the 3rd year after treatment and then declined during 3 subsequent drought years. Diffuse knapweed reestablished completely on all of the plots 8 years after treatments, in the absence of grazing or clipping. The authors attribute reinvasion to 3 years of drought and to small plot size, which allowed reseeding from adjacent plots [85]. In a similar study in west-central Colorado, researchers compared hand pulling, mowing, herbicides, and the root weevil *Cyphocleonus achates*
alone and in combination for the control of spotted and diffuse knapweeds. The only increases in grass cover were with treatments including herbicides. Herbicides provided the most cost effective and efficacious control of the knapweeds over multiple years with the greatest increase in grass cover. Insects alone and combined with herbicides may prove cost effective for long term management of knapweed if insects establish and maintain suppression of weed populations [21].

Cultural:
No matter what method is used to kill diffuse knapweed plants, reestablishment of competitive plant cover is imperative for long-term control [22,85]. Fertilization and reseeding with competitive, adapted species is often necessary in areas without a residual understory of desirable plants [83]. Revegetation with aggressive desirable species has been shown to inhibit reinvasion of knapweeds [22], especially with the help of effective biological control agents and carefully prescribed grazing practices [85]. Vegetative suppression is applicable both after knapweed control and before knapweed establishment [108,110].

No single species will suppress diffuse knapweed on all sites at all times. Species effectiveness depends on site conditions including soil type, moisture, slope, and aspect [22]. Species that remove water from the rooting zone of diffuse knapweed during seedling establishment are most effective [16,108]. Larson and McInnis [55] found some wheatgrasses (Triticeae) capable of decreasing knapweed density in northeastern Oregon. On British Columbia rangeland, 11 years after treatment with picloram, diffuse knapweed density was high in non-seeded plots, moderate (1/3 density of control) in plots seeded to Russian wildrye (*Psathyrostachys juncea*), and very low in plots seeded to crested wheatgrass (*Agropyron cristatum*) [11]. Hubbard [41] also found crested wheatgrass effectively suppressed the invasion of diffuse knapweed. In a 2-year study in Oregon, a diffuse knapweed infestation was disked in the spring and seeded to 'Covar' sheep fescue (*Festuca ovina*), 'Ephraim' crested wheatgrass, 'Paiute' orchardgrass (*Dactylis glomerata*), and 'Critana' thickspike wheatgrass (*Elymus lanceolatus*). Orchardgrass and thickspike wheatgrass controlled knapweed establishment during both years of the study [56]. At one site in northeastern Washington, 'Durar' hard fescue (*Festuca trachyphylla*) limited diffuse knapweed reinvasion more effectively than did smooth brome or orchardgrass [85]. A long-term study to identify the species best suited to seeding semiarid rangeland sites in northeast Washington indicated that hard fescue was the most aggressive competitor, and that crested wheatgrass taxa provided the highest yields [32].

While these aggressive species can be effective at suppressing diffuse knapweed, it is important to consider the implications of using 1 exotic to suppress another. Native species may be best for maintaining or achieving biodiversity that is site specific. Unfortunately, there is little success reported for suppressing invasive species with native species. Idaho fescue seedlings were planted on preserve land in Oregon; however, survival was low, and the low density plantings failed to further reduce knapweed numbers [137].

The same cultural practices will have different effects on knapweed suppression under different climatic regimes. Crested wheatgrass provided very good long-term suppression in a region of British Columbia that receives 8 inches (200 mm) mean annual precipitation, but poor suppression on a site with 13 inches (330 mm) mean annual precipitation [11]. Site preparation prior to seeding will also affect results. Fagerlie [24] suggests that treatment with picloram in association with grass seeding is more successful for grass establishment than disking for seedbed preparation. Herbicide selection is also an important consideration, since seeded species will vary in susceptibility to different chemicals [24]. Maxwell and others [60] found spraying with picloram to be successful at controlling knapweed, while interseeding had little impact on knapweed cover and grazing negated treatment effects.

Centaurea diffusa: References

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FEIS Home