## SPECIES: Centaurea maculosa



# INTRODUCTORY

SPECIES: Centaurea maculosa



AUTHORSHIP AND CITATION:
Zouhar, Kris. 2001. Centaurea maculosa. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2007, September 24].

FEIS ABBREVIATION:
CENMAC

SYNONYMS:
*Centaurea biebersteinii* DC. [82]
*Centaurea stoebe* L. ssp. *micranthos* (Gugler) Hayek [137]

NRCS PLANT CODE [212]:
CEBI2

COMMON NAMES:
spotted knapweed

TAXONOMY:
The scientific name for spotted knapweed is *Centaurea maculosa* Lam. (Asteraceae) [45,67,217,233]. Oschmann [137] suggests that in North America, the name *Centaurea maculosa* has been misapplied to *Centaurea stoebe* ssp. *micranthos*. The taxonomy of spotted knapweed is discussed in Ochsmann [137] and on the Centaurea website.

Oschsmann [136] also cites evidence of hybridization between spotted and diffuse knapweed (*Centaurea diffusa*) in at least 7 U.S. states. The hybrid is named *Centaurea* × *psammogena* Gayer.

LIFE FORM:
Forb

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
Spotted knapweed has been declared a noxious or restricted weed in at least 15 states in the U.S. and 4 Canadian provinces [213]. See the Invaders or Plants databases for current information.

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# DISTRIBUTION AND OCCURRENCE

SPECIES: Centaurea maculosa

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GENERAL DISTRIBUTION:
Spotted knapweed is native to eastern Europe, though it now occurs in western and central Europe. It was introduced to North America, probably as a contaminant in alfalfa (*Medicago sativa*) seed and/or ship's ballast, in the late 1800s [115,137,161]. In 1920, the distribution of spotted knapweed in North America was limited to the San Juan Islands, Washington. By 1980 it had spread to 48 counties in the Pacific Northwest. Between 1980 and 1998, the known range of spotted knapweed included 326 counties in the western United

States, including every county in Washington, Idaho, Montana, and Wyoming [175]. Although it is reported to occur in 45 of the 50 states [82,211], spotted knapweed is found primarily in the northwestern states and southwestern Canada. The PLANTS database
provides a map of spotted knapweed's distribution in the United States. The following table reflects estimates of spotted knapweed acreage as reported by state or province in 1988 and again in 2000 (from [33]):

| State/Province | 1988 | 2000 |
|---|---|---|
| Arizona | not reported | 1,800 |
| California | not reported | 5 |
| Colorado | 2,500 | 2,500 |
| Idaho | 2,293,000 | 2,300,000 |
| Montana | 4,721,069 | 3,818,450 |
| Nevada | not reported | 5000 |
| New Mexico | not reported | 500 |
| North Dakota | 0 | 1,160 |
| Oregon | 3,000 | 784,000 |
| South Dakota | 2,500 | 1,898 |
| Utah | 500 | 2,000 |
| Washington | 29,070 | 500,000 |
| Wyoming | 100 | 15,000 |
| Alberta | 0 | scattered |
| British Columbia | not reported | 50,000 |
| Total | | 7,482,313 |

The decrease in acreage reported in Montana is attributed to improved inventory methods during the past decade. Although inventories are more common and more accurate, 50% of these states reported only 50% accuracy, while 31% reported 51 to 75% accuracy, and 2 states reported 75 to 100% accuracy [33]. Watson and Renney [221] reported that spotted knapweed was abundant in British Columbia, common in Ontario, Quebec and the Maritimes, and observed in southern Alberta in 1974.

Information on the distribution of spotted knapweed is limited for most North American states and provinces in which it occurs. It is commonly listed as occurring on roadsides and other disturbed areas in the Adirondacks [93], New England [170], the Northeast [45], Michigan [217], Illinois [125], Nebraska [165], the Great Plains [48], the Blue Ridge region of North Carolina, Tennessee, and Virginia [231], West Virginia [197], the Carolinas [149], and Florida [5,233].

Specific information on the plant communities in which spotted knapweed occurs is also limited outside its primary area of occurrence. The following lists reflect ecosystems and cover types in which spotted knapweed is commonly found, although the lists are not exhaustive.

ECOSYSTEMS [43]:
FRES10 White-red-jack pine
FRES11 Spruce-fir
FRES13 Loblolly-shortleaf pine
FRES14 Oak-pine
FRES15 Oak-hickory

FRES17 Elm-ash-cottonwood
FRES18 Maple-beech-birch
FRES19 Aspen-birch
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES22 Western white pine
FRES23 Fir-spruce
FRES25 Larch
FRES26 Lodgepole pine
FRES28 Western hardwoods
FRES29 Sagebrush
FRES34 Chaparral-mountain shrub
FRES35 Pinyon-juniper
FRES36 Mountain grasslands
FRES37 Mountain meadows
FRES38 Plains grasslands
FRES39 Prairie
FRES42 Annual grasslands

STATES:

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AB | BC | YK | NB | NS | ON | PE | PQ |

BLM PHYSIOGRAPHIC REGIONS [15]:
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 [92] PLANT ASSOCIATIONS:
K005 Mixed conifer forest
K008 Lodgepole pine-subalpine 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
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
K038 Great Basin sagebrush
K047 Fescue-oatgrass
K048 California steppe
K050 Fescue-wheatgrass
K051 Wheatgrass-bluegrass
K055 Sagebrush steppe
K056 Wheatgrass-needlegrass shrubsteppe
K063 Foothills prairie
K064 Grama-needlegrass-wheatgrass
K066 Wheatgrass-needlegrass
K067 Wheatgrass-bluestem-needlegrass
K068 Wheatgrass-grama-buffalo grass
K074 Bluestem prairie
K075 Nebraska Sandhills prairie
K081 Oak savanna
K082 Mosaic of K074 and K100
K095 Great Lakes pine forest
K100 Oak-hickory forest
K104 Appalachian oak forest
K106 Northern hardwoods
K109 Transition between K104 and K106

SAF COVER TYPES [36]:
1 Jack pine
14 Northern pin oak
15 Red pine
16 Aspen
20 White pine-northern red oak-red maple
21 Eastern white pine
42 Bur oak
43 Bear oak
44 Chestnut oak
50 Black locust
51 White pine-chestnut oak

52 White oak-black oak-northern red oak
53 White oak
55 Northern red oak
64 Sassafras-persimmon
109 Hawthorn
206 Engelmann spruce-subalpine fir
210 Interior Douglas-fir
211 White fir
212 Western larch
213 Grand fir
215 Western white pine
217 Aspen
218 Lodgepole pine
220 Rocky Mountain juniper
222 Black cottonwood-willow
224 Western hemlock
227 Western redcedar-western hemlock
228 Western redcedar
229 Pacific Douglas-fir
233 Oregon white oak
235 Cottonwood-willow
236 Bur oak
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
249 Canyon live oak
250 Blue oak-foothills pine

SRM (RANGELAND) COVER TYPES [180]:
101 Bluebunch wheatgrass
102 Idaho 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
210 Bitterbrush
215 Valley grassland
216 Montane meadows
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
411 Aspen woodland
412 Juniper-pinyon woodland
413 Gambel oak
420 Snowbrush
421 Chokecherry-serviceberry-rose
422 Riparian
504 Juniper-pinyon pine woodland
601 Bluestem prairie
602 Bluestem-prairie sandreed
603 Prairie sandreed-needlegrass
607 Wheatgrass-needlegrass
608 Wheatgrass-grama-needlegrass
609 Wheatgrass-grama
610 Wheatgrass
612 Sagebrush-grass
613 Fescue grassland
614 Crested wheatgrass
615 Wheatgrass-saltgrass-grama

HABITAT TYPES AND PLANT COMMUNITIES:
Montana is the center of distribution for spotted knapweed in the United States. There it tends to favor ponderosa pine (*Pinus ponderosa*)/Douglas-fir (*Pseudotsuga menziesii*), and adjacent foothill prairie habitats (previously dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), rough fescue (*F. altaica*), and needle-and-thread grass (*Hesperostipa comata*)) [24,25,127,161,162], although it is said to grow in nearly every habitat type west of the Continental Divide in Montana [126]. On undisturbed sites (e.g. Glacier National Park) additional associates may include slender wheatgrass (*Elymus trachycaulus*), prairie junegrass (*Koeleria macrantha*), timber oatgrass (*Danthonia intermedia*), Richardson needlegrass (*Achnatherum richardsonii*), western yarrow (*Achillea millefolium*), northern bedstraw (*Galium boreale*), field chickweed (*Cerastium arvense*), silky lupine (*Lupinus sericeus*),

and cryptogams [208]. On disturbed sites, old hayfields, and pastures, common associates are Kentucky bluegrass (*Poa pratense*), smooth brome (*Bromus inermis*), timothy (*Phleum pratense*), and cheatgrass (*B. tectorum*) [159,177]. Spotted knapweed is found in the Idaho fescue/bluebunch wheatgrass and bluebunch wheatgrass/blue grama (*Bouteloua gracilis*) habitat types, and the antelope bitterbrush (*Purshia tridentata*) series in Montana, as described by Mueggler and Stewart [127]. Spotted knapweed occurs along roadsides in Montana and North Dakota in shortgrass prairie types with blue grama; in mixed-grass with wheatgrass (Triticacea), needlegrass (*Achnatherum*, *Hesperostipa*, and *Nassella* spp.) and little bluestem (*Schizachyrium scoparium*); in foothill grassland with bluebunch wheatgrass, Idaho fescue, and rough fescue; and in ponderosa pine, Douglas-fir, and subalpine fir (*Abies lasiocarpa*) forest types. Spotted knapweed tends to escape the roadside disturbance area and penetrate less disturbed communities in the shortgrass, mixed-grass, and foothill grassland environmental types as described by Meier and Weaver [123]. Other Montana associates may include common snowberry (*Symphoricarpos albus*), Oregon-grape (*Mahonia repens*), basin wildrye (*Leymus cinereus*), green needlegrass (*N. viridula*), whitetop (*Cardaria draba*), long-leaved aster (*Aster chilensis*), spreading dogbane (*Apocynum androsaemifolium*) [51], pinegrass (*Calamagrostis rubescens*), elk sedge (*Carex geyeri*), thistles (*Cirsium* and *Carduus* spp.), and kinnikinnick (*Arctostaphylos uva-ursi*) [219]. Spotted knapweed is also found in pinyon-juniper (*Pinus-Juniperus* spp.) communities in the Intermountain West [199].

Spotted knapweed is listed as a "dominance type" in Montana riparian areas and is found primarily on upper terraces of major river courses, relatively dry, disturbed sites, and gravel bars. Associated species are affected by the degree of past disturbance. On relatively undisturbed sites it may be found with bluebunch wheatgrass, redtop (*Agrostis* spp.), silver sagebrush (*Artemisia cana*), Idaho fescue and Wood's rose (*Rosa woodsii*). On more disturbed sites likely associates include Canada bluegrass (*Poa compressa*), Kentucky bluegrass, bulbous bluegrass (*P. bulbosa*), slender cinquefoil (*Potentilla gracilis*), crested wheatgrass (*Agropyron cristatum*), and Canada thistle (*Cirsium arvense*) [57]. It may occur with other species associated with frequent disturbance such as common tansy (*Tanacetum vulgare*), creeping bentgrass (*Agrostis stolonifera*), and widely scattered seedlings of sandbar willow (*Salix exigua*) and black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) [55]. Hansen and others [56] list spotted knapweed occurring in 24 riparian habitat types in Montana. Dominant associates include red-osier dogwood (*Cornus sericea*), black cottonwood, grand fir (*Abies grandis*), ladyfern (*Athyrium filix-femina*), spruce (*Picea* spp.), Douglas-fir, Rocky Mountain juniper (*Juniperus scopulorum*), ponderosa pine, quaking aspen (*Populus tremuloides*), narrowleaf cottonwood (*P. angustifolia*), Geyer willow (*Salix geyeriana*), sandbar willow, Wood's rose, thinleaf alder (*Alnus incana* ssp. *tenuifolia*), water birch (*Betula occidentalis*), shrubby cinquefoil (*Potentilla fruticosa*), chokecherry (*Prunus virginiana*), western snowberry (*Symphoricarpos occidentalis*), water sedge (*Carex aquatilis*), Baltic rush (*Juncus balticus*), and reed canarygrass (*Phalaris arundinacea*).

In Washington state, spotted knapweed is found in openings in ponderosa pine/bunchgrass or Douglas-fir/shrub forests, especially on coarse, gravelly glacial soils [163]. Spotted knapweed is competitive in disturbed forest types in Washington (primarily northeastern), including ponderosa pine with bunchgrass, snowberry (*Symphoricarpos* spp.), or ninebark (*Physocarpus malvaceus*); or Douglas-fir with snowberry or ninebark [164].

Plants associated with spotted knapweed in British Columbia are characteristic of dryland range and pioneer sites including bluebunch wheatgrass, rough and Idaho fescue, bluegrass (*Poa* spp.), and many others [221]. Bluebunch wheatgrass communities in British Columbia are especially susceptible to spotted knapweed infestation [2]. In west-central British Columbia, an infestation of spotted knapweed occurred along the railroad with Kentucky bluegrass, red fescue (*Festuca rubra*), timothy, smooth brome, and clover (*Trifolium* spp.) [236]. In open forests of British Columbia, spotted knapweed may be found with ponderosa pine, Douglas-fir, ninebark, Saskatoon serviceberry (*Amelanchier alnifolia*), mock orange (*Philadelphus lewisii*), toadflax (*Linaria dalmatica*), pinegrass, and Idaho fescue [124]; or with lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), subalpine fir, huckleberry (*Vaccinium* spp.) and fireweed (*Epilobium angustifolium*) [148].

Information on plant communities invaded by spotted knapweed in other parts of the country is very limited. In North Dakota spotted knapweed is found primarily along roads and sometimes in adjacent grasslands [17]. In Michigan oldfields it is found growing with blackberry (*Rubus alleghaniensis*), poverty oatgrass (*Danthonia spicata*), and broomsedge (*Andropogon virginicus*) [40]. In Shenandoah National Park, Virginia, spotted knapweed was found growing along a trail in the bigfruit hawthorn (*Crataegus macrosperma*)/shrub forest with black raspberry (*R. occidentalis*) and dwarf cinquefoil (*Potentilla canadensis*) [54]. Spotted knapweed is said to be widespread in California, occurring in disturbed areas up to 6,600 feet (2,012 m) [67,185]. In Yellowstone National Park it is found in a campground in a big sagebrush (*Artemisia tridentata*)/bluebunch wheatgrass habitat type [4].

# MANAGEMENT CONSIDERATIONS

SPECIES: Centaurea maculosa



IMPORTANCE TO LIVESTOCK AND WILDLIFE:
The importance of spotted knapweed to livestock and wildlife depends upon the size and density of the infestation, the availability of other forage plants, and the season. Large-scale infestations of spotted knapweed can impede access to more desirable forage for livestock and wildlife, especially when the presence of old, dried knapweed stems creates a dense and spiny overstory [221]. Large reductions in available forage [60] and wildlife use [10,175] have been reported on knapweed-infested range. Reports of forage losses for elk vary, and probably do not consider the possibility of elk using spotted knapweed as forage [11,232]. In fact, the perception that spotted knapweed has minimal forage value and may even be toxic [110] has changed since studies have shown that it has good nutritional value [89], and it is eaten by both livestock [26] and wildlife [109,229].

Several reports from western Montana indicate some use of spotted knapweed by livestock. In general, use of spotted knapweed by livestock is highest during spring and early summer when plants are green and actively growing in the rosette and bolt stages [96,160]. Use declines as spotted knapweed matures, and protein and digestibility decrease [89], although flowerbuds and seedheads may be grazed in the late summer [26,96,110]. Domestic sheep may also graze rosettes when present (from regrowth and late season germination) in the fall [26]. Cox [26,27] observed domestic sheep eating large quantities of spotted knapweed in the spring and early summer in preference to grasses and other forbs. Olson and Wallander [141,142] also report sheep readily grazing spotted knapweed in an infested pasture, although they grazed other plants as well and did not consistently graze one plant more than the others. Sheep grazed spotted knapweed leaves and avoided stems. In sagebrush steppe rangeland in southeastern Idaho, spotted knapweed was readily consumed by domestic sheep throughout the year. Grasses were consumed in amounts similar to spotted knapweed, but native forbs were most commonly used [108]. Sheep grazing has been proposed as a potential control method for spotted knapweed [27,53,108] (see "Management Considerations" below).

Reports on wildlife use of spotted knapweed are also varied. Bedunah [11] cites several studies suggesting large potential losses of elk range to spotted knapweed, though he indicates that quantifying the effects of infestation on elk populations is complicated by their mobility. Spotted knapweed infestation is considered more detrimental to elk than to deer because spotted knapweed replaces grasses that are preferred by elk, while deer have a diet of predominantly shrubs and conifers that spotted knapweed does not replace [109,229]. Elk use increased following removal of spotted knapweed with herbicides on sites in Montana [157,200]. In a study in western Montana on 2 game ranges in the Bitterroot Valley, Willard and others [229] report minimal use of spotted knapweed dominated sites by elk and mule deer. When used, mule deer consumed knapweed flowerheads from December through April, while elk consumed knapweed flowerheads only during winter. Spotted knapweed was preferred by deer and elk over other plant species on sites with dense knapweed cover [109,229]. It was suggested that deer and elk did not frequently use the spotted knapweed sites in this study because cervid densities were relatively low and other forage was available [232]. On spotted knapweed infested bunchgrass range in the Selway-Bitterroot Wilderness, Idaho, Wright and Kelsey [232] report that elk, mule deer, and white-tailed deer used spotted knapweed infested range as much as or more than uninfested bunchgrass range from 1 December through 25 April. All cervid species consumed both rosettes and seedheads of spotted knapweed, with seedhead consumption greatest during periods of snow cover. The authors suggest that when estimating carrying capacity of a cervid range, spotted knapweed can be considered a potential food source, because when animal densities are high and food choices are limited, elk and deer will consume spotted knapweed [232]. In British Columbia, deer and elk forage on diffuse and spotted knapweed rosettes in late fall and early winter, and again when snow cover recedes and spring green-up commences. Knapweed rosettes and bluegrass comprised 90% of mule and white-tail deer diets in February and early March [124].

In the Gilpin range, British Columbia, California bighorn sheep utilized diffuse and spotted knapweed seedheads as primary forage when snow depth was in excess of 8 inches (20 cm). As snow cover receded in January and February, knapweed basal rosettes were the largest component (80%) of their diet. Rocky Mountain bighorn sheep also utilized knapweed seedheads and basal rosettes throughout the year in the Robson/Syringa Park area, British Columbia [124].

Spotted knapweed is a nectar source for the endangered Karner blue butterfly in Wisconsin [52]. Rodent utilization of spotted knapweed seed has been suggested [221]. Deer mice have been observed eating larvae and seeds from spotted knapweed flowerheads infested with seedhead flies (introduced biocontrol agents) [145].

PALATABILITY:
It has been suggested that the bitter tasting sesquiterpene lactone, cnicin, found primarily in the leaves of spotted knapweed, may make it unpalatable to mammalian herbivores [88,113]. Wright and Kelsey [232] were unable, however, to correlate changes in cnicin levels to changes in the amount of spotted knapweed consumed by mule deer, white-tailed deer, or elk. Furthermore, observations by Cox [27] suggest that spotted knapweed is more palatable to domestic sheep than orchardgrass (*Dactylis glomerata*), timothy, quackgrass (*Elytrigia repens*), Kentucky bluegrass, sainfoin (*Onobrychis viciifolia*), or birdsfoot trefoil (*Lotus* spp.). In a cafeteria trial, domestic sheep readily consumed spotted knapweed in all growth stages, although they preferred rosette and bolting stages somewhat to the flowering stage [108]. Robbins [160] also observed cattle readily grazing spotted knapweed in the spring, though cattle prefer grasses when available [97]. Mature spotted knapweed plants (with stems) are eaten less frequently than young plants (rosettes), and may be less palatable due to spininess and high fiber content [24,176].

NUTRITIONAL VALUE:
Spotted knapweed has substantial nutritional value that compares favorably to the native plants with which it is commonly associated. By traditional measures of forage nutritive value (e.g. crude protein (CP), neutral detergent fiber (NDF), in-vitro dry matter digestibility (IVDMD), and total nonstructural carbohydrates (TNC)), spotted knapweed (especially leaves and flowerheads) is more nutritious than Idaho fescue [142]. The following table provides measurements of nutritive value of spotted knapweed, harvested before flowering, as reported by Kelsey and Mihalovich [89]:

| CP (%) | NDF (% dry wt) | IVDMD (%) | TNC (%) | ash (%) | ether extract (%) | gross energy (cal/g) |
|---|---|---|---|---|---|---|
| 6.2 - 18.2 | 24.2 - 53 | 53.2 - 61.8 | 11 - 27.5 | 4.9 - 9.3 | 3.1 - 9 | 4,088 - 4,539 |

Values vary with season, plant part, age, and site. Nutritional value declines as summer progresses [142,232], with crude protein and nonstructural carbohydrates most concentrated during the spring. Spotted knapweed becomes more fibrous, with lower protein and carbohydrate levels, as stems mature over the summer [89]. Seedheads are less nutritious than rosettes, but may be available above the snow [232]. Willard and others [229] measured crude protein, fiber, and lignin content in spotted knapweed flowers and recorded average values of 6.6%, 45.6%, and 14.5%, respectively. Crude protein was similar for open and forested sites, while fiber and lignin values were higher on forested sites than on open sties [229]. Jones and others [80] provide a detailed study of the forage value of spotted knapweed from a sagebrush/grassland site in southeastern Idaho, comparing different parts of mature and immature plants from May through September.

Secondary compounds in spotted knapweed, such as cnicin, can negatively affect activity and growth of anaerobic rumen microorganisms in domestic sheep, reducing digestibility of spotted knapweed [138,140].

COVER VALUE:
No information

VALUE FOR REHABILITATION OF DISTURBED SITES:
Watson and Renney[221] noted that "the rapid establishment of (spotted knapweed) cover in the form of rosettes on barren soil prevents soil erosion and leads to accumulation of organic matter." Kelsey [86] points out that "this characteristic is of marginal utility since the plants inhibit further succession and are difficult to replace with more desirable species." Furthermore, spotted knapweed establishment provides a seed source for invasion of adjacent lands and potential for reduction of native plant diversity [207]. Lacey and others [100] determined that surface water runoff and stream sediment yield were 56 and 192% higher, respectively, and infiltration rates lower, for spotted knapweed-dominated sites compared to bunchgrass-dominated sites.

OTHER USES:
Kelsey and Locken [88] cite studies indicating that the compound cnicin has antimicrobial properties, as well as being active against some human carcinoma cells and L-1210 leukemia. Knapweeds provide substantial pollen and nectar for domestic bees in interior British Columbia [221], the Intermountain West [86], and Michigan [35]. Kelsey [86] recommends short-term research to utilize spotted knapweed biomass for commercial products.

OTHER MANAGEMENT CONSIDERATIONS:
Spotted knapweed is considered a serious threat to rangelands in Montana, Washington, Idaho, Oregon, Wyoming, and British Columbia. Because of its affinity for the climate of western Montana, Chicoine and others [25] predicted that spotted knapweed had the potential to invade 37 million acres (15 million ha) in that state alone, and Bedunah [11] speculated that the foothill grasslands in western Montana (the primary habitat for spotted knapweed) are becoming an endangered vegetation type. The ill effects of spotted knapweed are manifold. Spotted knapweed infestations have been associated with reductions in forage production [60,221], plant species richness and diversity [205,207], cryptogam cover [206], soil fertility [65,138,232], and wildlife habitat [10], as well as increases in bare ground [207], surface water runoff, and stream sedimentation [100]. Lesica and Shelly [111] also found that spotted knapweed reduced seed germination and seedling establishment of a rare Montana endemic forb, Mt. Sapphire rockcress (*Arabis fecunda*).

Experimental evidence suggests that spotted knapweed gains dominance in part by its ability to out-compete native grasses for nutrients such as nitrogen [139] and phosphorus [65]. Other evidence suggests that as succession proceeds and nutrients become less available, the competitive advantage shifts from spotted knapweed to native plants such as bluebunch wheatgrass [91]. Allelopathy, primarily from the compound cnicin, has been suggested as a growth inference mechanism in spotted knapweed [19,88]. However, because cnicin concentration in soil is lower than that found to be toxic in in-vitro experiments, allelopathy was not considered as important as resource competition in determining the ecological success of spotted knapweed [87,113]. Allelopathic activity of cnicin may be enhanced, however, when large quantities of stem and leaf tissue from live or dead spotted knapweed plants come in direct contact with the soil surface, as when plants are trampled or mowed. This allelopathic activity could be minimized by burning or removing plant material before it comes in contact with the soil surface [113]. More recent experimental evidence suggests that knapweed's advantage over its North American neighbors could be attributed to differences in the effects of its root exudates and how they, in turn, affect competition for resources [19], thus linking allelopathy and resource competition.

In many areas, eradication of spotted knapweed is no longer an option. Perhaps small patches can be eradicated with cultural practices or herbicides. Large infestations must be controlled or suppressed with cultural and biological methods, perhaps in conjunction with herbicides, to contain the weed and slow its spread. Before management plans for the control of spotted knapweed can be designed, land use objectives must be defined. A generalized objective may be to develop a plant community that is weed resistant and meets other land-use objectives. Desired plant communities can be designed to maximize niche occupation with desirable species that compete intensely, grow rapidly, and grow during much of the season [73,178]. It is important that the successional effects of spotted knapweed control are considered in this manner to avoid replacing spotted knapweed with another weedy species [69,178,230].

Spotted knapweed control requires a sustained, site-specific commitment over a period of several years [96,207]. Economic considerations for spotted knapweed control have been investigated [50,138], and Griffith [49] provides a procedure for performing an economic evaluation for noxious weed management on rangeland, with spotted knapweed as an example.

Integrated weed management: Managers are encouraged to integrate different control methods that can complement one another in a given situation. Integrated management includes considerations of not only killing the target weed, but also of establishing desirable species and maintaining weed-free systems over the long-term. Factors to be addressed before a management decision is made include inventory and assessment to identify the target weed and determine the size of the infestation(s); assessment of non-target vegetation, soil types, climatic conditions and important water resources; and an evaluation of the benefits and limitations of control methods [131]. Components of any integrated weed management program are sustained effort, constant evaluation, and the adoption of improved strategies [175].

Conceptual models can be developed to determine the probability that the weed management strategy will result in the desired plant community, based on the life histories and population dynamics of the species in the existing plant community [73,178]. A weed management strategy may include designed disturbance (e.g. cultural or chemical control), controlled colonization (e.g. planting competitive species), and controlled species performance (e.g. biological control) [178,230]. Management strategies may include several approaches designed to disrupt the stages in a weed's life cycle that are most vulnerable to stress or control [175]. Jacobs and Sheley [73] identified juvenile, the transition from juvenile to adult, and adult as critical phases in the life history of spotted knapweed. The key processes associated with these stages are competition, growth, and reproductive allocation. Successful control practices must target one or more of these processes. Sheley and others [178] provide examples of ecologically based spotted knapweed management systems.

Prevention: Prevention of spotted knapweed establishment is the most cost-effective control strategy [31]. Prevention practices begin with the maintenance of healthy, desirable vegetation that is resistant to weed establishment. This includes minimizing soil disturbance in all activities and reestablishing desirable vegetation promptly whenever soil disturbance leaves areas of bare ground, with continued monitoring and immediate follow-up treatment of colonizing weeds, and/or revegetation with desirable species

[31,207,208,210]. In areas where it is critical to maintain native vegetation (e.g. national parks, nature preserves, wilderness), avoid building new roads and trails, since this is the primary habitat for many invasive species including spotted knapweed [3,123,207,208]. Carefully monitor the intensity, frequency, and season of grass defoliation in grazing prescriptions so that grasses can tolerate grazing and resist weed invasion. One greenhouse study suggests that even moderate defoliation of competing grasses (30%) may allow greater spotted knapweed growth on Idaho fescue rangeland [72]. Another study found that spring defoliations increased spotted knapweed cover compared to summer defoliations; that grass defoliation greater than 60% caused an increase in spotted knapweed cover and density; and that more than one grass defoliation in a year increased spotted knapweed cover. The researchers suggest that a single, annual grass defoliation of 60% or less, regardless of the season, will not increase spotted knapweed invasion on rangeland [78]. Rangeland managers must also consider the potential for livestock to introduce spotted knapweed seed in their feces or fur.

Regular removal of newly established spotted knapweed plants at trailheads, campsites and along road corridors is critical to prevent their spread into adjacent natural areas [95,117]. Monitor for weed emergence annually, especially in areas where there is vehicle or livestock movement, in riparian areas, areas of wildlife concentration, public use areas, and locations where sand, gravel, or fill materials have been imported, soil has been disturbed, or vegetation or overstory has been removed [210]. When spotted knapweed plants are found, remove them immediately.

The introduction of spotted knapweed seeds from infested areas to recently disturbed and/or uninfested areas can be limited by monitoring vehicle, livestock, and wildlife movement [207,208,210]. Encourage public land users to avoid driving vehicles through or scheduling livestock use in existing spotted knapweed infestations when seeds are present, to inspect and clean vehicles of weeds and their seeds, to brush and clean animals, tack, and equipment before entering public lands, and to minimize soil disturbance by stock. Regulations promoting minimum impact camping and the use of weed-free feed, hay, straw, and mulch in natural areas may reduce spotted knapweed infestations [117,210]. Encourage the use of certified weed-free feed for several days before entering backcountry [131,208,210,220].

A key component of prevention practices is education and awareness of managers, land owners, and public land users [31,86,131,210]. In Montana, programs have been implemented such as a trust fund for weed research and weed management efforts, organized cooperative weed management programs for landowners [98,131], a curriculum for educating school children [133], and bounty programs [175]. Examples of successful cooperative spotted knapweed control efforts have been reported in Canada [3] and Wyoming [224].

Weed prevention and control can be incorporated into all types of management plans, including logging and site preparation, management of grazing allotments, recreation management, research projects, road building and maintenance, and fire management [210]. See the "Guide to noxious weed prevention practices" [210] for specific guidelines in preventing the spread of weed seeds and propagules under different management conditions. When prevention fails, or spotted knapweed populations already exist, several management approaches can be used to eradicate small populations or to control larger infestations including cultural, biological and chemical control methods, or some combination of methods timed in such a way as to be complementary. Tu and others [202] provide a comprehensive review of weed control methods that are applicable for use in natural areas. The information is also available online (Weed Control Methods Handbook).

Physical and mechanical control: Manual control techniques may be preferred in some areas with spotted knapweed infestations. For example, on the Salmon River watershed in the Klamath National Forest in California, it is recognized that manual control methods offer less risk to the high quality waters and high value fisheries than do chemical applications. A cooperative effort among the local residents and land management agencies, orchestrated by the Salmon River Restoration Council (SRRC), has successfully employed the use of several manual control approaches including propane torching of seedlings early in the season, hand digging with small tools, mulching with black plastic, and mowing with weed eaters [167]. For a detailed description of their knapweed control program see the SRRC website.

Spotted knapweed does not persist under annual cultivation or in irrigated alfalfa. This, however, does not present a widely applicable solution for infested wildland, rangeland or prairie [60]. Mowing, hand-pulling, planting competitive species, and good range management may reduce the spread of spotted knapweed, but may not eliminate well established stands [86]. Tillage can reportedly lead to the spread of spotted knapweed [31]. This is especially likely in mature stands since tillage creates an ideal weed seed bed from which individuals in the seed bank may emerge. Tillage may be more successful if followed by seeding with a strongly competitive grass-legume mixture [151].

Consistent hand pulling can control spotted knapweed, although it is time and labor intensive. Entire plants must be removed before they produce seeds each year, and flowering plants should be removed from the site so no seeds are dispersed [175]. In greenhouse studies, only severe defoliation reduced spotted knapweed root, root crown, and aboveground growth. Some spotted knapweed plants produced flowers even when clipped monthly from June through September [90]. Mowing diffuse and spotted knapweed in Canada at the bud stage, flowering stage, or once at bud stage and again at flowering, reduced the number of plants producing seed by 77, 99, and 96% compared to unmowed plants. The latter 2 treatments also reduced germination of the seeds by approximately 79% [221]. Rinella and others [159] found that a single mowing at the flowering or seed stage resulted in an 83-85% decrease in adult spotted knapweed density at 2 sites in western Montana. This reduction was as much as any treatment consisting of repeated mowing at both sites. The long-term effects on spotted knapweed densities are unknown, but Rinella and others [159] hypothesize that repeated annual mowing may shift the competitive balance in favor of desired grasses. Rolling plots with a pasture roller, burning, mowing, or harrowing treatments had no effect on the spotted knapweed seedbank at 2 sites in Montana [23].

Burning: For information on fire management considerations for spotted knapweed, please see the "Fire Management Considerations" segment of the "Fire Effects" section of this report.

Biological control: The aim of biological control is to stress spotted knapweed and shift the competitive advantage away from the weed to desirable grasses and forbs [31,130,175,230]. Biological control efforts for diffuse and spotted knapweed have been underway in North America since 1970. Wilson and McAffrey [230] provide a discussion of considerations and safety issues in developing and implementing a biological control program. The objective of biological control efforts is to propagate and redistribute sufficient insect populations to hold spotted knapweed to population levels similar to their populations in Europe [209]. It is believed that 4 agents are necessary to affect 1 plant species, and that 6 established agents would help control both diffuse and spotted knapweeds since most agents attack both plants [60]. To date, 13 Eurasian insects have been introduced for the control of these knapweeds, several of which are demonstrating some impact against 1 or both species. Of these, 8 of the insects attack the flower heads, while 5 attack the roots [195]. The idea is that these agents will work together to reduce viable seed production and stunt the overall growth and strength of the plants [209]. In this sense, there is an additional ecological niche to be filled, since no agents attack the rosette foliage or root crown. These structures are vulnerable to attack for at least 1 year before the plant can reproduce [182].

Story and Piper [195] provide a current assessment of the status of biocontrol agents on spotted knapweed. On sites in Montana where *Urophora affinis* and *U. quadrifasciata* coexist, spotted knapweed seed production is reduced by at least 50% [194,195], and Harris [59] reports a 92% reduction in spotted knapweed seed production at locations in British Columbia. He also notes that *Agapeta zoenga* and *Cyphocleonus achates* are causing noticeable reductions in density and vigor of spotted knapweed at several locations in western Montana [195]. Success has not been dramatic, and has not developed as expected [171]. One partial explanation for the limited success of introduced biocontrol agents may be that biocontrol agents came from

*C. maculosa*, which is native to central Europe, while it has been suggested that the plant that is invasive in North America is actually *Centaurea stoebe* ssp. *micranthos*, which is native to eastern Europe [182]. Climatic analyses indicate that the climate of western Montana is more similar to the area in eastern Europe, from which *Centaurea stoebe* ssp. *micranthos* originated, than the area from which the bulk (12 of the 13) of biocontrol agents came. It is therefore suggested that future explorations in the area of origin of the target plant are necessary to find agents that are adapted to colder climates and a more vigorous plant [171,182].

Biological control efforts may also be hindered by indirect effects of herbivory on nontarget species. Callaway and others [20] found that herbivory on spotted knapweed had substantial negative, indirect effects on Idaho fescue under 2 very different sets of experimental conditions. They hypothesized that moderate herbivory may have stimulated compensatory growth in spotted knapweed, induced the production of defense chemicals that also had allelopathic effects, or stimulated root exudates that altered the relationship between knapweed and Idaho fescue via soil microbes [20].

Additional indirect affects of biological control of spotted knapweed have been observed in west-central Montana [145]. Gall fly larvae (*Urophora* spp.) released as biological control agents for spotted knapweed are the primary food item in native deer mouse diets for most of the year and made up 84-86% of their winter diet. The implications of these findings include the possibility that deer mice and other predators may reduce *Urophora* populations below a threshold to effectively control knapweed; the unknown effects on deer mouse population dynamics and subsequent effects on food chains; and the effects on seed dispersal, since 9% of deer mouse stomachs also contained knapweed seeds during the period following seed dispersal [146].

The following table shows insects that have been established in North America for the control of spotted knapweed, and the states or provinces in which they have been established or recovered, and additional references pertaining to each [105,175,191,195,203]:

| Agent | type | States established or recovered | References |
|---|---|---|---|
| Sulfur knapweed moth (*Agapeta zoegana*) | root -boring moth | CO, MN, MT, NV, OR, SD, UT, WA, WY | [62,128,129,184] |
| Broad-nosed seedhead weevil (*Bangansternus fausti*) | seedhead weevil | MT, OR, UT | [62] |
| Knapweed peacock fly (*Chaetorellia acrolophi*) | seedhead weevil | CO, MN, MT, OR | [195,203] |
| Knapweed root weevil (*Cyphocleonus achates*) | root-boring/gall weevil | CO, MN, MT, OR, SD, UT, WA, WY | [62,184,228] |
| Lesser knapweed flower weevil (*Larinus minutus*) | seedhead weevil | ID, MN, MT, NV, OR, SD, UT, WA, WY | [83,104] |
| Blunt knapweed flower weevil (*Larinus obtusus*) | seedhead weevil | MT, WA, WY | [195,203] |
| Spotted knapweed seedhead moth (*Metzneria paucipunctella*) | seedhead moth | CO, ID, MN, MT, OR, VA, WA | [46,62,116,120] |
| Brown-winged root moth (*Pelochrista medullana*) | root-boring moth | MT | [62] |

| | | | |
|---|---|---|---|
| Gray-winged root moth (*Pterolonche inspersa*) | root-boring moth | establishment not yet confirmed | [195,203] |
| Bronze knapweed root borer (*Sphenoptera jugoslavica*) | root beetle | MT, OR | [195,203] |
| Green clearwing fly (*Terellia virens*) | seedhead fly | MN, MT, OR, SD, WY | [195,203] |
| Banded gall fly (*Urophora affinis*) | seedhead fly | AZ, CA, CO, ID, MI, MN, MT, ND, NE, NV, NY, OR, PA, SD, UT, VA, WA, WI, WY, PQ | [61,62,103,116,120,135,226] |
| UV knapweed seedhead fly (*Urophora quadrifasciata*) | seedhead fly | AZ, CA, CO, CT, ID, IN, MA, MI, MN, MD, MA, MT, ND, NE, NH, NJ, NV, NY, OR, PA, RI, SD, UT, VA, VT, WA, WI, WV, WY, BC | [61,62,70,103,135,225,226] |

In addition to insect control agents, several microorganisms have been considered for potential control of spotted knapweed including the fungi *Sclerotinia sclerotiorum* [76,175], *Fusarium avenaceum* [28] and *F. oxysporum* [79], and the bacteria *Pseudomonas syringae* [84]. A phytotoxin isolated from the black leaf blight fungus (*Alternaria alternata*), maculosin, was found to be the active ingredient in this host-specific pathogen of spotted knapweed, and was synthesized in the laboratory [187,198]. Maculosin appears to be highly toxic only to spotted knapweed and was being researched for potential field efficacy in 1993 [130], though no work has been completed to date [33].

Grazing: Low to moderate levels of grazing of spotted knapweed by cattle, domestic sheep, and domestic goats have been observed in Montana [175]. Of these, sheep seem to have the most promise for control of spotted knapweed through prescribed grazing [27,53,108,142,143]. Others suggest that livestock grazing is not likely to seriously reduce spotted knapweed populations in native bunchgrass communities because of its many other competitive attributes [90,101].

Two consecutive years of sheep grazing in May to early June and again in late summer on 40 acres (16 ha) in western Montana heavily infested with spotted knapweed completely eliminated spotted knapweed seed production, and the sheep were healthy [26,86]. Olson and others [143] observed that 1- and 2-year-old spotted knapweed plants were effectively controlled by sheep grazing in Montana. Sheep grazing when grasses are dormant can reduce potential negative impacts on associated grass species [143] and reduces density of very young spotted knapweed seedlings, thereby limiting seedling recruitment [31,175]. Timing of grazing is important, as sheep were observed to pass viable seed of spotted knapweed up to 7 days after consumption [220].

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. If chemical control is used it must be incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations [18]. Use of herbicides may be limited in natural areas. 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 spotted knapweed can be effective in some cases, but may be cost prohibitive because repeat applications are usually necessary to exhaust the seedbank, and because spotted knapweed often infests large tracts of marginal rangeland and rough terrain [50,168,209]. It is important to consider not only the efficacy of the herbicide for control of spotted knapweed, but also its effects on non-target organisms (plants, animals, aquatics, and invertebrates), the environmental persistence of the chemicals used, their decomposition products, and the environmental effects of chemical contaminants and other additives found in herbicide preparations. Chemical control methods are the focus of considerable research. The following summary is current as of July 2001: Clopyralid, dicamba, picloram, and 2,4-D, alone and in combination, can effectively control spotted knapweed on rangeland [175]. Each chemical or combination of chemicals provides different degrees of control for varying periods of time [12,13,14,22,37,42,97,106,114,151,154,173,227], has different effects on non-target organisms [10,12,13,107,152,153,154,155,156,173] (including biocontrol agents [60,77,121,193,215]), and has different degrees of environmental persistence [222]. Rate and timing of application and site conditions (e.g. soil texture and precipitation) will affect the degree of control, the impacts on non-target organisms, and the persistence of the chemicals in the environment.

Germination of spotted knapweed seeds was not affected by the application of wheat gluten meal at any rate [47]. Fertilization trials in western Montana using variable rates of nitrogen fertilizer suggest that N fertilization alone is an impractical control approach, and would likely contribute to an increase in spotted knapweed [194].

Prescribed burning in combination with herbicide application may increase the efficacy of the herbicide and stimulate growth from competitive species. See the "Fire Management Considerations" segment of the "Fire Effects" section of this report for more information. A study examining the effect of the timing and frequency of grass defoliation on spotted knapweed reinvasion in areas treated with picloram and fertilizer combinations found increased densities of spotted knapweed at intermediate fertilizer applications rates, and better grass growth at higher rates. Also, alternating spring/fall defoliation resulted in higher spotted knapweed density and biomass than did annual spring or fall defoliation, while fall defoliation alone appeared to be the best for minimizing spotted knapweed. The site with residual understory of smooth brome and timothy was more responsive to picloram treatments than the site which had a residual understory of Kentucky bluegrass, which was more affected by fertilizer and clipping treatments [75].

Competition: Reducing spotted knapweed density on wildlife ranges without filling the empty niches with more desirable forage and/or native species may encourage the proliferation of other exotics that are less palatable and more toxic, spiny, or otherwise noxious than spotted knapweed [130,232]. Temporary control of spotted knapweed is an attainable objective; however, the subsequent establishment of a healthy community of desirable plants is required for a more permanent solution [69,174,178]. In a container study, competition with grass had a more negative effect on spotted knapweed growth than did either root herbivory or nitrogen shortage [184]. A healthy, weed-resistant plant community consists of a diverse group of species that occupy diverse niches [74,178]. Establishing desirable species with diverse above- and belowground growth can enhance resource capture by desirables on the site and may limit exotic invasion. In a growth chamber study of competition between spotted knapweed, bluebunch wheatgrass and northern sweetvetch (*Hedysarum boreale*), Jacobs and Sheley [74] found evidence to support the idea that maintaining taprooted forbs along with grasses increases niche occupation and may be more effective in minimizing invasion of taprooted weeds than grasses alone.

Due to the limited availability of seed from native species that are capable of rapid development under stress conditions [69], natural revegetation of spotted knapweed infested rangelands often fails [216]. The initial level of spotted knapweed reduction necessary to shift the competitive relationship between spotted knapweed and bluebunch wheatgrass varies with location, plant densities, and the initial composition and density of the suppressed grasses [76,174]. Jacobs and others [76] provide evidence that establishment of bluebunch wheatgrass on spotted knapweed infested rangeland may be improved by combining the fungus *Sclerotinia sclerotiorum*
with dense grass seeding, although the fungus has not been approved for use as a biocontrol agent to date.

In areas without a residual understory of desired plants, artificial revegetation is required for effective control of spotted knapweed [175,178,216]. Revegetation of aggressive species has been shown to inhibit reinvasion by spotted knapweed [71,175,216]. In a controlled environment experiment, Lindquist and others [112] found that smooth brome (an invasive species itself) is capable of suppressing the growth of spotted knapweed, with the degree of suppression increasing with increasing nitrogen levels. Bluebunch wheatgrass and Idaho fescue had no impact on spotted knapweed growth [184]. Vigorous grass (especially crested wheatgrass) slow knapweed invasion; however, the drought tolerance and high seed production of spotted knapweed enable it to rapidly occupy dryland range, especially if grass vigor is reduced by grazing [60]. Both 'Durar' hard fescue (*Festuca trachyphylla*) and 'Covar' sheep fescue (*F. ovina*) are fairly aggressive competitors with spotted knapweed in the Columbia River Basin, although both are introduced grass species [63]. Reseeding may be limited by the challenge of achieving adequate seed coverage, which is usually achieved by drilling and not feasible on most rangelands [69]. Some specific approaches to controlling spotted knapweed by planting competitive species are given by Sheley and others [175] and Velegala and others [216]. Combining herbicide treatments with reseeding and/or fertilizer applications has met with some success [71,162,177].

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# BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Centaurea maculosa

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- GENERAL BOTANICAL CHARACTERISTICS
- RAUNKIAER LIFE FORM
- REGENERATION PROCESSES
- SITE CHARACTERISTICS
- SUCCESSIONAL STATUS
- SEASONAL DEVELOPMENT

GENERAL BOTANICAL CHARACTERISTICS:
Spotted knapweed is a non-native, perennial forb that can live at least 9 years. Older plants (>7 years of age) may have high incidence of root rot, indicating senescence [16]. Once established, spotted knapweed is able to form monotypic stands because its age class hierarchy allows it to occupy all available niches [175].

Spotted knapweed has a deep, stout taproot and basal rosette leaves that grow up to 8 inches (20 cm) long and 2 inches (5 cm) wide. Beginning usually the 2nd year, each spotted knapweed plant produces 1 to 6 flowering stems (15 or more on older plants) that stand 8 inches to 4 feet (0.2 - 1.2 m) tall. Leaves are alternate and grow smaller near the tops of the stems. Stems branch in the upper half and bear terminal flowerheads that are 0.25 inch (6 mm) wide and 0.5 inch (12 mm) long. Flowerheads are solitary or borne in clusters of 2 or 3, with 25-30 flowers per head, and up to 60 flowering heads per plant [221]. Achenes are oval, 1/8 inch (3 mm) long, bearing a pappus of simple bristles which are less than the length of the seed (~1-2 mm) and persistent [176]. Most stems remain erect after drying, with leaves and flowerhead bracts attached [87].

Early and deep fine root development, and the colonization of spotted knapweed roots by arbuscular mycorrhizal fungi, may contribute to its competitive dominance over native grasses [118,119] by allowing for greater resource acquisition. Chemical allelopathy of spotted and diffuse knapweeds has been suggested as a mechanism of interference of the growth of other herbaceous species [19,88,113].

RAUNKIAER [150] LIFE FORM:
Hemicryptophyte

REGENERATION PROCESSES:
Spotted knapweed reproduces almost entirely from seed. Plants are also able to extend lateral shoots below the

soil surface that form rosettes adjacent to the parent plant, and multiple rosettes on a single spotted knapweed root crown are common [176,221].

Flowering and pollination: Spotted knapweed plants may remain in the rosette stage for 1 to 4 years, producing flowering stems the 2nd year [221] or later [16,207]. Flowering during the year of seedling emergence is rare [168]. Boggs and Story [16] observed the percentage of flowering plants increasing with age up to 5 to 7 years, with little or no flowering in the 1st and 2nd years, in Montana. Flowers are pollinated by insects [221], and spotted knapweed is heavily visited by several species of bees [35,64,221]. Large pollen counts in late July and early August in the Missoula Valley, Montana, suggest that spotted knapweed is also wind pollinated [44]. Fertilization in spotted knapweed requires cross-pollination between flowers on different plants (obligately xenogamous). This can limit the reproductive success of isolated individuals, but it also promotes genetic diversity, and may thereby improve competitive ability [64].

Seed production: The number of seeds produced by an individual knapweed plant or a population of plants is highly variable between plants, sites, and years. Reported averages of seed production per plant range from about 65 seeds per plant in Montana [73] to 400-900 seeds under range conditions in British Columbia [221], and about 2,000 seeds per plant, averaged across diverse sites in Washington and Idaho [168]. A population of plants may produce about 5,000 to 40,000 seeds/m$^2$/year [176,207]. Schirman [168] reported an average of 23.8 to 61.1 flowerstems per m$^2$, 11.2 to 16.8 seedheads per stem, and 24.3 to 33 seeds per head, producing 11,300 to 29,600 seeds per m$^2$
in Washington and Idaho. Similar stem and seed densities were observed in Glacier National Park, Montana [207]. Only about 0.1% of the seed produced under these conditions would be needed to maintain the size of the stands observed [168].

The following data were collected on Idaho fescue-bluebunch wheatgrass habitat types in Montana [73]:

| | adults/m$^2$ | seeds/plant | % viability | total # seeds/m$^2$ | viable seeds/m$^2$ |
|---|---|---|---|---|---|
| Site 1-1994 | 99 | 21 | 60% | 2062 | 1237 |
| Site 1-1995 | 10 | 140 | 71% | 1405 | 998 |
| Site 1-1996 | 54 | 61 | 79% | 3312 | 2617 |
| Site 2-1994 | 177 | 62 | 71% | 11,007 | 7815 |
| Site 2-1995 | 151 | 55 | 82% | 8519 | 6986 |
| Site 2-1996 | 89 | 51 | 78% | 4524 | 3529 |

The number of seeds produced may vary with site conditions (available moisture, nutrient availability and competition), herbivory and seed predation, and age of plants. Site conditions and precipitation during the growing season probably have the greatest effect on the number of seeds produced each year, with more seeds produced during wet years [168,176] and on wetter sites [73]. Schirman [168] reported a reduction in the number of viable seeds per head in dry years and an increase in the number of flowerheads per stem in wet years. On an irrigated site, spotted knapweed produced an average of 25,260 seeds per plant, compared to about 680 seeds per plant under range conditions in British Columbia [221]. Adult density also appears to be sensitive to spring precipitation [73]. Maternal treatment (control, herbivory, herbivory + nutrient shortage, and herbivory +nutrient shortage + grass competition) affected physiology, morphology, growth, and size of maternal plants and the numbers of seeds produced, but did not affect the mass or quality of seeds and offspring produced [223]. In Glacier National Park, seed production is 3 to 4 times higher in plants immediately adjacent to the road than in plants on adjacent grassland [207].

Seed predation may be an important factor in seed production. The seed production numbers reported by

Schirman [168] in 1973 through 1976 were measured before the introduction of *Urophora affinis* and *U. quadrifasciata*. Jacobs and Sheley [73] reported in 1998 that 90% of the seedheads collected in their study were infested with larva of these insects. Shirman [168] consistently found 2 to 10 times the seed production in his study, compared with Jacobs and Sheley [73]. Differences in seed production may be attributable to differences in precipitation and/or seed predation between sites and years [73]. Harris [62] reports similar findings and notes that prior to the release of biocontrol agents in British Columbia, Watson and Renney [221] reported an average of 26.6 seeds per head, whereas in 1986 Harris [62] observed an average of 15.4 seeds/head.

Seed dispersal: As soon as bracts open, any movement of the stem (e.g. by wind or passing animals) expels the loosely held seeds from the head with a flicking action. The seeds usually land within 3 to 4 feet (0.9-1.2 m) of the parent plant [132,175,221]. In this way, spotted knapweed populations spread outward and downwind from the perimeter of existing stands [161,176,221]. Dispersal of achenes over long distances is facilitated by animals and birds. Wallander and others [220] show that both domestic sheep and mule deer excrete viable seeds of spotted knapweed in their feces for 7 to 10 days after consumption, respectively. Seeds mixed with soil and mud may be carried by vehicles or other equipment that, in turn, create an ideal seedbed for spotted knapweed establishment [161,176,221]. Spread of seeds on logging trucks, off-road vehicles, and trail bikes has contributed greatly to the spread of knapweed into new areas in British Columbia [196]. Spotted knapweed seeds can also be transported in rivers and other watercourses, and in crop seed and hay [175].

Seed banking: Spotted knapweed seeds are known for their longevity and durability. They have a thick, durable pericarp that protects the seeds but does not restrict water imbibition or water loss [30]. Nolan and Upadhyaya [132] determined that a portion of the spotted knapweed seed population requires exposure to red light to germinate. This light requirement may permit buried seeds to remain dormant for an extended period of time [29,30]. Experimental evidence indicates that spotted knapweed seeds can remain viable but dormant after 5 years of burial [29]. Perez and others [147] observed evidence of seed banking of spotted knapweed in the Nebraska sandhills prairie.

The following data were collected on 2 Idaho fescue-bluebunch wheatgrass habitat types near Bozeman, Montana [73]:

| | adults/m$^2$ | total seed bank (#/m$^2$) | viable seed bank (based on tetrazolium tests) (#/m$^2$) |
|---|---|---|---|
| Site 1-1994 | 99 | 51,850$\pm$30,600 | 3,825$\pm$1,285 |
| Site 1-1995 | 10 | 47,000$\pm$7,900 | 34$\pm$43 |
| Site 2-1994 | 177 | 60,690$\pm$13,133 | 8,466$\pm$3,060 |
| Site 2-1995 | 151 | 60,350$\pm$13,023 | 646$\pm$850 |

When seed production was controlled with herbicide treatments at 2 other heavily infested spotted knapweed sites in Montana, the spotted knapweed seed bank decreased by 72 to 81% after 15 months [23]. After 7 years, only 5% of the original seed bank remained, leaving about 160,000 viable seeds per acre (400,000 seeds/ha, or about 4 viable seeds per 0.09 m$^2$) [29,30]. Seedlings showed a decline in vigor associated with length of burial [23].

Germination: Spotted knapweed seeds have the potential for germination shortly after maturity, and approximately 90% are viable upon dispersal [34,168]. However, many studies indicate a dormancy period for some portion of the annual seed crop. For example, Watson and Renney [221] observed an increase in germination from 40 to 80% after 25 days of dry storage. Similarly, reports of low germination and emergence under field conditions range from 65 to 85% of the seed crop ungerminated but viable the year following dispersal [23,34,168]. This period of dormancy may be released by seed aging, cool-moist stratification, freezing [34], or exposure to red light [132]. Nolan and Upadayaya [132] describe 3 distinct types of germination behavior in spotted knapweed seed, a phenomenon that distributes seed germination over time by facilitating the incorporation of seeds into a seed bank.

Spotted knapweed seeds germinate whenever moisture and temperature are suitable, and both fall and spring seedling emergence is common. Optimal temperatures for germination range from 45 to 93 degrees Fahrenheit (7-34 °C), and germination is best at 66 degrees Fahrenheit (19 °C) [221]. Spotted knapweed seeds required at least 55% soil moisture to initiate emergence. Germination increases with increased soil moisture, and 65-70% soil moisture content is optimum for germination [183]. Dormancy may prevent germination at higher temperatures when soil moisture status is fluctuating, and at lower temperatures when germination in late fall may make seedlings susceptible to winter kill. Germination after cold stratification provides a strategy for spring emergence and avoidance of environmental extremes [34]. Canopy cover had no effect on emergence rate, with spotted knapweed germinating equally well over a range from 0-100% canopy cover, as simulated in a laboratory experiment [183]. Spotted knapweed seeds can germinate in light and dark, with maximum germination in alternating light and dark periods. Optimum germination occurs with the seeds at the soil surface, and decreases with depth, with little germination below 2 inches (5 cm) [183,221]. Because of the bare interspace areas between plants and seasonal periods of drought, bunchgrass rangeland provides favorable microsites for spotted knapweed seed germination [132].

Seedling survival: Spotted knapweed seedling survival depends primarily on environmental conditions at the time of emergence and establishment. Seed weight was positively correlated with initial growth, but its influence decreased over time and disappeared after 8 weeks. Competition (with meadow ryegrass (*Lolium pratense*)) did not influence growth of spotted knapweed seedlings during early weeks, but strongly suppressed growth after 9 weeks [223]. Spotted knapweed seedling survival is poor when conditions are dry following emergence [221], and survival is enhanced if precipitation coincides with the time of seedling emergence [168]. Seedling mortality averages 12%, but can be as high as 55% under dry conditions [176,221]. Seedlings emerging in April in Idaho and Washington had a high rate of survival, with most plants flowering the following growing season. Seedlings emerging after May 15 had a very low survival rate and almost no flowerstem production the following season [168].

SITE CHARACTERISTICS:
Spotted knapweed establishes and dominates on dry, disturbed sites, especially along roads [161,169,208,217,221]. In western Montana, the success of spotted knapweed increases with site disturbance and soil moisture stress. Disturbance intensity has the greatest influence in habitat types moister than the Douglas-fir group, with coarse soil texture and steep slopes adding to success. In grass and shrub habitat types, south aspect and disturbance intensity are important variables for spotted knapweed success [229]. Spotted knapweed is well adapted to open forested areas, especially after logging or other disturbances [39].

Spotted knapweed is found on soils with a wide range of chemical and physical properties [25,221], and often on poor soils [217]. It does especially well in coarse-textured soils [123,164] that are well-drained with low water holding capacity [57]. Spotted knapweed is well adapted to Montana rangelands with "light-textured" soils that receive summer rainfall. In northeastern Washington, it is usually found on glacial till and outwash soils [161]. Spotted knapweed is poorly adapted to irrigated pastures where saturated soil is common [30,221], and does not compete well with vigorously growing grass in moist sites [60]. However, in central Washington spotted knapweed thrives in irrigated land, although it is also found growing on compacted soil in a 10 inch (254 mm) precipitation zone [161].

Spotted knapweed has been observed at elevations ranging from 1,900 to 9,975 feet (578-3,040 m) and in precipitation zones ranging from 7 to 79 inches (200-2000 mm) [97]. Some general ranges by area are as follows:

| | Elevation range | Annual precipitation range | References |
|---|---|---|---|
| MT | 2,001 to 8,999 feet (610-2743 m) | 12 to 30 inches (310-760 mm) | [25] |
| WA | up to 6,800 feet (2,072 m) | 16 to 22 inches (406-559 mm) | [161,164] |
| BC | 98 to 3,937 feet (30-1,200 m) | 10 to 25.5 inches (251-648 mm) | [221] |

In Montana, spotted knapweed is most abundant between 4,000 and 6,000 feet (1,219-1,829 m) in elevation and 10 to 80 inches (250-2,030 mm) precipitation and in areas with 50-120 frost-free days [4,25]. In British Columbia, spotted knapweed is more common below 2,950 feet (900 m) on south-facing slopes [124].

Spotted knapweed not only readily occupies disturbed sites, but it also invades relatively undisturbed perennial native plant communities in the northern Intermountain region [31,102,175,207,208], and invades wilderness areas all over Montana [95]. In Glacier National Park, spotted knapweed colonized undisturbed rough fescue grasslands adjacent to roadside spotted knapweed infestations [207]. The frequent breaks in cover, which provide favorable light conditions for seed germination, and the warm-dry climate of these grassland ecosystems appear to facilitate invasion of spotted knapweed and other alien species [132,207].

SUCCESSIONAL STATUS:
Spotted knapweed usually emerges shortly after disturbance, especially when overstory species are removed. In western Montana, for example, when the dominant species from the ponderosa pine/red-osier dogwood or the black cottonwood/red-osier dogwood riparian site types have been removed, spotted knapweed invades [57]. Spotted knapweed seeds are able to germinate under full canopy [183], but mature plants are uncommon in shaded areas [221]. Spotted knapweed is typically found under open canopies [117,164,221]. In Yellowstone National Park, spotted knapweed was always found under <20% canopy cover, and 75% of its occurrence was under <5% canopy cover [4]. In a grand fir/queencup-beadlily (*Clintonia uniflora*) habitat type in the Selway-Bitterroot Wilderness, spotted knapweed occurred in a 15-year-old stand but not in a 185-year-old stand [181].

Hironaka [69] presents a replacement series of weedy species in the Intermountain Region in which summer annuals are replaced by winter annuals (e.g. Russian thistle (*Salsola kali*) is replaced by cheatgrass), and the earlier winter annuals are replaced by the later maturing ones (e.g. cheatgrass is replaced by medusahead (*Taeniatherum caput-medusae*) or knapweeds (*Centaurea* spp.)).

SEASONAL DEVELOPMENT:
Spotted knapweed seeds germinate in the fall and early spring and develop into rosettes, though most recruitment is between April and June [73]. Most root growth occurs during this stage [221].

Spotted knapweed overwinters as rosettes or as seeds. Rosette mortality may occur under extreme winter conditions. In the Intermountain West, rosettes that overwinter bolt in early May [176,221]. Seeds that overwinter germinate in early spring. Early spring growth gives spotted knapweed a competitive advantage over many natives for soil moisture and mineral nutrients [110]. Flowering buds are formed in early June and flowering occurs from July through September. Mature seeds are formed by mid-August. Spotted knapweed flowerheads that are not infested with larvae open after they dry, about 2 to 3 weeks after seeds mature, usually in late summer [161], from mid-August through mid-September [34,176]. Most seeds are shed upon maturity; very few overwinter in seedheads [176]. At 2 sites in Montana, seed rain occurred during August and September, with 30 to 62% of the seeds produced reaching the soil surface by October [73]. Rosettes that do not bolt die back to the root crown, which serves as the perennating part of the plant over winter [175].

In Virginia, flowering of spotted knapweed occurs from June through August or even in November, and fruiting occurs from mid-June to November [120]. In the Adirondacks, spotted knapweed flowers 19 July to 20 August [93].

# FIRE ECOLOGY

SPECIES: Centaurea maculosa

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:
Spotted knapweed has a large, perennial taproot and survives after fire if the root crown is not killed. It also produces large quantities of seed that can survive fire.

Spotted knapweed occurs primarily in bunchgrass and open ponderosa pine forest community types in the Intermountain West, especially Montana. The historical fire regimes of these communities were relatively frequent, low-severity surface fires. Spotted 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 spotted knapweed populations. It is also unclear how the presence of spotted knapweed might affect these fire regimes, though it has been observed that spotted knapweed does not carry fire as readily as grasses. Therefore, dense knapweed infestations can change the fire regime by changing the fuel characteristics and thus reducing the fire return interval at a given site [122,235].

The following table provides fire regime intervals for communities and ecosystems in which spotted knapweed most commonly occurs:

| Community or Ecosystem | Dominant Species | Fire Return Interval Range (years) |
|---|---|---|
| grand fir | *Abies grandis* | 35-200 [9] |
| sagebrush steppe | *Artemisia tridentata/Pseudoroegneria spicata* | 20-70 |
| plains grasslands | *Bouteloua* spp. | < 35 |
| western juniper | *Juniperus occidentalis* | 20-70 |
| Rocky Mountain juniper | *J. scopulorum* | < 35 [144] |
| western larch | *Larix occidentalis* | 25-100 |
| Engelmann spruce-subalpine fir | *Picea engelmannii-Abies lasiocarpa* | 35 to > 200 [9] |
| pinyon-juniper | *Pinus-Juniperus* spp. | < 35 [144] |
| Rocky Mountain lodgepole pine* | *P. contorta* var. *latifolia* | 25-300+ [6,9,166] |
| Colorado pinyon | *P. edulis* | 10-49 [144] |
| interior ponderosa pine* | *P. ponderosa* var. *scopulorum* | 2-10 [9] |
| red pine (Great Lakes region) | *P. resinosa* | 10-200 (10**) [32,41] |
| eastern white pine | *P. strobus* | 35-200 |
| eastern white pine-northern red oak-red maple | *P. strobus-Quercus rubra-Acer rubrum* | 35-200 [218] |
| mountain grasslands | *Pseudoroegneria spicata* | 3-40 (10**) [6,9] |
| Rocky Mountain Douglas-fir* | *Pseudotsuga menziesii* var. *glauca* | 25-100 [9] |

| | | |
|---|---|---|
| oak-juniper woodland (Southwest) | *Quercus-Juniperus* spp. | < 35 to < 200 [144] |
| northern red oak | *Q. rubra* | 10 to < 35 [218] |
| elm-ash-cottonwood | *Ulmus-Fraxinus-Populus* spp. | < 35 to 200 [32,218] |

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

POSTFIRE REGENERATION STRATEGY [186]:
Caudex/herbaceous root crown, growing points in soil
Ground residual colonizer (on-site, initial community)
Secondary colonizer (on-site or off-site seed sources)

# FIRE EFFECTS

SPECIES: Centaurea maculosa

- 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:
Low-severity fire will not kill spotted knapweed plants or seeds [172]. Fire will top-kill spotted knapweed and stress the plant, however the sturdy perennial taproot can survive and resprout. Severe burns may reduce germination of spotted knapweed seeds [1].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
In a greenhouse study using seeds from a spotted knapweed infested site in Michigan, germination of spotted knapweed seeds was significantly ($p<0.05$) reduced in seeds exposed to 200° C for 120 seconds or more, and for seeds exposed to 400° C for 30 seconds or more [1].

PLANT RESPONSE TO FIRE:
Fires are said to create the type of disturbance that promotes the colonization of knapweeds by creating areas of bare soil and increasing the amount of sunlight that reaches the ground surface [176]. Spotted knapweed plants present before burning may resprout from root crowns, and seedlings may emerge from the seed bank or invade bare ground from an off-site seed source following fire. Spotted knapweed is one of the introduced species mentioned as "taking over large tracts of logged, burned, or otherwise disturbed lands in British Columbia" [204]. Olson [138] observes that spotted knapweed is seldom negatively impacted by fire. For example, spotted knapweed cover and density increased and desirable species were unaffected after prescribed burning on mountain grassland in northeastern Washington [172,176]. Conversely, prescribed fire and spot-burning on prairie and dune sites in Michigan have been used successfully to stimulate native vegetation and reduce cover of spotted knapweed [122].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Differences in the observed response of spotted knapweed to fire may be regional, may differ with the density of the infestation, may be different in low fire severity versus high fire severity microsites, and in spring versus fall burns.

On prairie sites in Michigan with low to moderate spotted knapweed density and sufficient fine fuels to carry a fire, annual spring broadcast burning under severe conditions (when humidity and dead fine fuel moisture are as low as possible) serves to reduce spotted knapweed populations and increase the competitiveness of the native prairie vegetation. On some sites, 3 years of this regimen reduced spotted knapweed to the point where it could be controlled by hand-pulling individuals and increasing the fire return interval to 3-5 years. In dense infestations (>60 rosettes/$m^2$), broadcast burning is ineffective due to lack of adequate fuel to carry the fire. In this case, spotted knapweed plants can be killed with repeated spot- burning (using a propane torch) of individuals and resprouts 3 to 4 times during the growing season until root reserves are depleted. Top-killing individuals allows seedlings to emerge in the time between burning treatments, so they are also killed with subsequent burning, thus depleting the seed bank. This treatment does not seem to harm existing prairie natives, but newly-germinating natives may be at risk, and seeding after the last burning may help them to recover [122].

In Douglas-fir-ponderosa pine communities in western Montana, spotted knapweed cover increased after spring prescribed fires with both high and low fuel consumption following shelterwood cuts. Fuel moisture and duff characteristics of the fires were as follows [58]:

| | fuel moisture | | duff characteristics | |
|---|---|---|---|---|
| | lower duff | slash | initial depth | % reduction |
| Low consumption burn | 50% | 90% | 1.1 inch (2.8 cm) | 20% |
| High consumption burn | 16% | 40% | 1.4 inch (3.6 cm) | 40% |

Changes in spotted knapweed cover during the 4 years following treatments are as follows [8]:

| | Average percent cover of spotted knapweed | | | | |
|---|---|---|---|---|---|
| | Prefire | Postfire year 1 | Postfire year 2 | Postfire year 3 | Postfire year 4 |
| No burn | 0.3 | 0.4 | 0.6 | 1.4 | 1.9 |
| Low consumption burn | 0.5 | 1.0 | 3.4 | 4.9 | 5.9 |
| High consumption burn | 1.9 | 3.6 | 7.3 | 11.4 | 14.1 |

Spotted knapweed was present on these sites before treatments were carried out, probably as a result of soil scarification during logging activities, as well as big game and livestock use of the site prior to these studies. Also, the harvesting done as a part of this study resulted in scarification of about 11% of the area, which evidently encouraged spotted knapweed establishment. Burning, especially high consumption, seems to further encourage the spread of spotted knapweed. Severe wildfire (as might occur if fuels are allowed to accumulate) would also probably favor expansion of knapweed [8].

Spotted knapweed was reported on a Douglas-fir forest site 5 to 10 years after wildfire in western Montana, though it was not recorded 3 years after the fire. No information on prefire vegetation was given [201].

After fall prescribed burning at a western Montana site in a Douglas-fir/ninebark habitat type dominated by snowbush ceanothus (*Ceanothus velutinus*), spotted knapweed was not present in the 1st postfire year, but its volume doubled 2 years following the burn compared with preburn volume [134]. Characteristics of that fire are as follows:

| | upper slope | mid-slope | lower slope |
|---|---|---|---|
| Relative humidity | 30% | 23% | 18% |

| | | | |
|---|---|---|---|
| Dry bulb temperature | 59 °F (15 °C) | 69 °F (20 °C) | 70 °F(21 °C) |
| Wind velocity | 6-8 mi/h (10 km/h) | 8 mi/h (13 km/h) | 7-12 mi/h (11 km/h) |
| Rate of spread | 3716 feet/h (1,126 m/h) | 3386 feet/h (1,026 m/h) | 2657 feet/h (805 m/h) |
| Flame length | 10 ft (3 m) | 9 ft (3 m) | 8 ft (2 m) |

After a spring burn of lesser intensity on an adjacent site, no spotted knapweed was recorded before or after burning. Shrubs recovered faster and grasses increased on the spring burn, while herbaceous cover recovered faster and nongraminoid, herbaceous species increased on the fall burn [134].

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 spotted knapweed.

FIRE MANAGEMENT CONSIDERATIONS:
It is thought that fire has little potential for spotted knapweed control, because small areas are left unburned and fires are not usually hot enough to eliminate all of the viable seed in the soil or to prevent root crowns from resprouting [97,151,175]. Repeated burning of prairie and dune sites in Michigan was, however, successful at encouraging the growth of native vegetation and reducing spotted knapweed density [122]. Experimental evidence is, however, limited.

It has also been suggested that burning prior to herbicide application can increase the efficacy of the herbicide and stimulate new growth from competitive species [176]. A study in western Montana, where dry conditions following burning limited spring germination of knapweed prior to the herbicide application, did not support this assertion [21], while results from Washington state supported the efficacy of burning prior to herbicide treatment [172]. A more recent project was begun in the fall of 1996 on the Lolo National Forest in western Montana, in which herbicide treatments were coupled with prescribed burning to improve habitat for elk. Prescribed burning in April 1997, followed by aerial application of picloram in June 1997 resulted in a 95% decrease in weed biomass (primarily spotted knapweed with small amounts of common mullein (*Verbascum thapsis*) and leafy spurge (*Euphorbia esula*)), an 86% decrease in native forb biomass, and a 714% increase in grass biomass as of July 1998 [66]. The area was retreated in 1999 with a lower concentration of picloram that was successful in killing spotted knapweed plants missed in 1997 and in killing the young knapweed that had sprouted after the original treatments. The end results to date suggest that the treatments were successful at reducing spotted knapweed cover and increasing native grass cover, although native forb density decreased and compositional changes were not recorded [94].

Rice [157] suggests controlling weeds (including spotted knapweed) with herbicides before reintroducing fire for the restoration of native plant communities, to avoid increasing the weed problem by using fire alone. A study is underway in western Montana comparing different combinations and timing of prescribed burning and herbicide applications [158].

Prescribed burning of spotted knapweed can be difficult, especially if no fine grass fuels are present, because fire does not usually carry through spotted knapweed stems easily. Grass fuel models work poorly for spotted knapweed unless associated grasses exceed 40-50% cover [235]. Spotted knapweed fuel loading varies between sites, thus affecting fire behavior. Intense fires in spotted knapweed have been observed under some conditions, and prescribed burning in spotted knapweed for fire hazard reduction may be a consideration [234].

A fuel model for spotted knapweed and guidelines for prescribed burning are available [234,235]. Calculation of fuel load is based on knapweed plant height and percentage of ground cover (old, standing plants and new plants), and litter depth and cover (including sparse grasses) [234]. The model was developed for early spring burns, and is valid only under specific fine fuel loading conditions. It is offered as a guideline to help the user select environmental conditions (wind, dead fuel moisture) that allow safe and effective burns. Fire managers familiar with fire modelling can create their own site-specific models for knapweed infestations using this general knapweed fuel model as it is summarized by Xanthopoulos [234,235].

When prescribed burning in spotted knapweed for fire hazard reduction in spring, sustaining a fire that carries without interruption and without risk of escape generally requires a predicted flame length of at least 20 cm (using a fuel model that does not include standing knapweed), and a controllable flame length less than 120 cm (as predicted using a complete fuel model). Fire behavior problems caused by discontinuous and nonuniform fuels are similar to the ones found in big sagebrush. Use these models with caution, since they have been verified with few actual test burns in spotted knapweed [234].

The following seasonal moisture data for spotted knapweed were collected on a south-facing slope in the Missoula Valley, Montana [234]:

| Date | Mean moisture content (% of dry weight) | Development characteristics |
|---|---|---|
| 7/1/86 | 235 | Flowerheads in dough stage |
| 7/9/86 | 210 | Few flowers open; grasses drying |
| 7/15/86 | 170 | Approximately 20% of the flowers open; grasses mostly dry |
| 8/1/86 | 120 | 80% of the flowers open; <3% of flowers lost petals and dried; lower knapweed leaves turning yellow; grasses mostly cured |
| 8/6/86 | 93 | All flowers open; 5-10% of flowers lost petals; lower knapweed leaves mostly dry |
| 8/20/86 | 45 | Spotted knapweed plants look dry; most leaves crumbly and yellow; less than 10% of flowers retain petals |
| 8/27/86 | 30 | Plants with any green leaves very rate; less than 2% of flowers retain petals |

The USDA Forest Service's "Guide to Noxious Weed Prevention Practices" [210] provides several fire management considerations for weed prevention in general that apply to spotted knapweed. To prevent infestation, re-establish vegetation on bare ground as soon as possible using either natural recovery or artificial techniques as appropriate to site 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 spotted knapweed, and treat to eradicate any emergent spotted 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.

Additionally, when planning a prescribed burn, preinventory the project area and evaluate cover and phenology of any spotted knapweed present on or adjacent to the site, and avoid ignition and burning in areas at high risk for spotted 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. Also, 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. Additional guidelines and specific recommendations and requirements are available [210].

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