

Ecology and Management of Spotted knapweed (*Centaurea maculosa* Lam.)

Abstract

Populations of spotted knapweed have been recorded in every county of Montana making this noxious weed one of the more widespread invasive plant species in the state (see Figure 1). In addition, it is one of the more economically destructive non-native invaders in western North America where it infests about ten million acres. Large-scale, monotypic infestations can reduce livestock and wildlife forage, are associated with reduced plant diversity, and can increase surface water run-off, soil erosion, and stream sedimentation.

Spotted knapweed is a tap-rooted, short-lived perennial. The average age of plants in the Bitterroot Valley, Montana, was estimated at three to four years and the oldest plants were nine years old. Plants grow each year from perennial buds on the root crown at the soil surface, do not produce rhizomes or stolons, and therefore the persistence and spread of populations is dependent on seeds which can remain viable and dormant in the soil for eight or more years. Auxin-type herbicides including 2,4-D, aminopyralid, clopyralid, dicamba, picloram, and

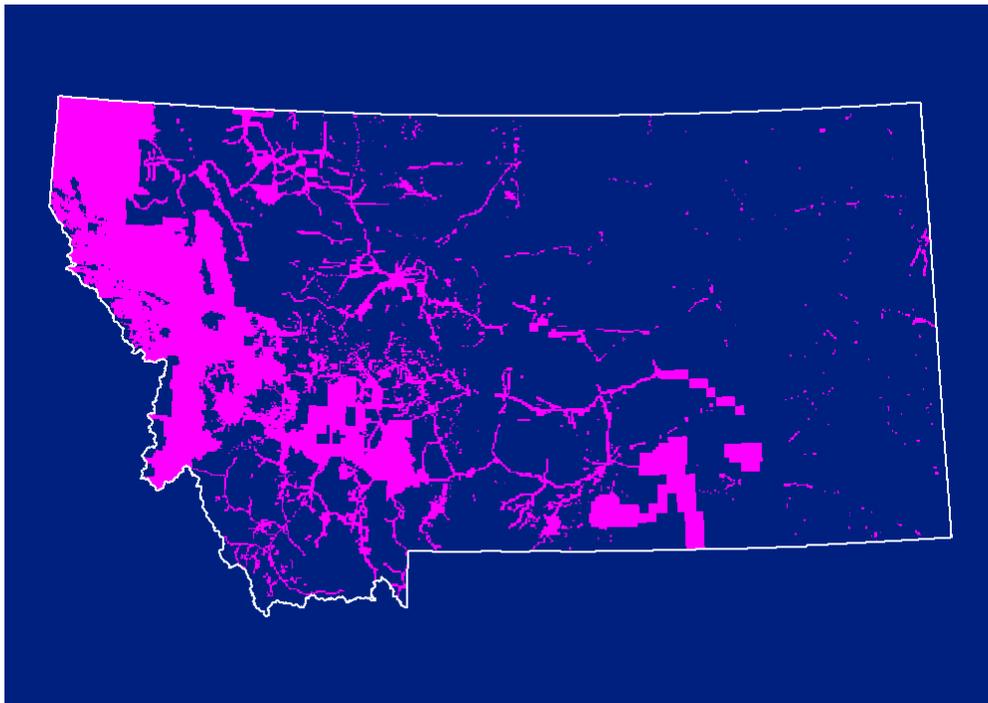


Figure 1. Spotted knapweed infestations (magenta) reported in Montana in 2001. Each magenta dot on the map represents one section reporting spotted knapweed. Permission to use this map was granted from Diana Cooksey, Adjunct Instructor, MSU-LRES and Coordinator of Montana Agricultural Potential System (MAPS). Additional information about section based maps can be found at: <http://www.montana.edu/places/mtweeds/databasedev.html>.

triclopyr are effective at killing spotted knapweed plants when applied at recommended rates and timings. Sulfonylurea herbicides such as metsulfuron and trisulfuron, and imazipic do not kill spotted knapweed at label recommended rates. Currently, there are eight flower-head insects and five root-boring insects that have been approved and released for biological control of spotted knapweed. In addition, sheep and goat grazing have been used to reduce seed production and population densities. Cultural control methods including hand pulling, tilling, irrigation, and re-vegetation are effective when combined with chemical, biological, or grazing control. Cultivating a desirable, competitive plant community is the key to sustainable management of spotted knapweed regardless of the population control methods used.

PLANT BIOLOGY

Taxonomy

Centaurea maculosa (Lam.) is the most widely used taxonomic name of the species commonly referred to as spotted knapweed in North America. It is in the Asteraceae (sunflower) family. In its native range of western, central, and eastern Europe, two sub-species have been identified; *Centaurea stoebe* spp. *stoebe* is biennial, and subspecies *C. stoebe* spp. *micranthos* is perennial. The perennial subspecies is considered more invasive in Europe than the biennial subspecies. The invasiveness of the North American taxon, *C. stoebe* spp. *micranthos*, has been ascribed to it being perennial because it can tolerate dense vegetation once it has become established, whereas the biennial is more dependent on disturbance. Spotted knapweed has also been referred to as *Centaurea biebersteinii*. *Centaurea* is appropriately derived from the Greek word for Centaurs, *kentaruion*, which were the mythical creatures with human head, arms, and chest, and the rest of the body like that of a horse. The unruly Centaurs that lived in herds around Mount Pelion in Thessaly, Greece, were a plague to people around them.

Life history and Identification

There are four relatively distinct and measurable life history stages of spotted knapweed; seeds, seedlings, rosettes, and flowering plants. Spotted knapweed populations maintain and spread by the sexual reproduction of seeds. Seed production of spotted knapweed in western Montana ranged from 1,000 to 7,800/m² on an Idaho fescue habitat-type, and has been reported as high as 40,000/m² in Washington. In Montana, viable seeds were recovered from soil that had no seed inputs for eight years. Seeds are 1/8-inch (3mm) long, oval, brown to black, and bear a short, persistent pappus of simple bristles. Seedlings are first year emergents and are difficult to distinguish from seedlings of other forb species. Spotted knapweed can persist for an entire growing season in the seedling stage. Rosettes can develop from seedlings within one growing season, and can be identified, in most cases, by the distinctive pinnatifid, oblong-lobed leaves (see Figure 2). In addition, plants that flower in one year may persist in the following year as rosettes. Flowering plants are distinguished by the production of an upright (except when heavily grazed or repeatedly mowed) paniculate inflorescence with few to many branches and reaching heights of eight inches to four feet depending on the environmental conditions (see Figure 3). Development of flowering plants from seedlings in one growing season is common. Flower heads develop on branch ends and are distinguished by the comb-like fringed, black-tipped involucre bracts and the pink to light purple flowers (see Figure 4). Each flower head can have as many as 30 flowers each producing one seed. Sensitivity analysis of life history stages and calculated transitions has identified early summer rosette survival, the transition from the rosette stage to the flowering plant stage, flowering plant survival, and seeds produced per

flowering plant as life history stages and transitions critical to spotted knapweed population fitness.



Figure 2. Spotted knapweed rosette showing the pinnatifid, oblong lobes on the leaves.



Figure 3. Spotted knapweed inflorescence showing the paniculate branching. The characteristic shape of the inflorescence can be used to locate spotted knapweed infestations in the winter.



Figure 4. Spotted knapweed flower heads showing the black-tipped involucre bracts and the light purple flowers.

Spread

Spotted knapweed spreads by seed, however, entire plants can be transported in soil and on the root balls of horticultural trees and shrubs. Radial expansion of populations through peripheral enlargement of existing stands can be as much as a few meters per year. Seeds can be transported long distances when they become embedded in the fur of animals, by rodents that cache flower heads for food, and by birds, livestock and wildlife that consume the seed heads and pass the seed through their digestive tract. Flower heads attached to the undercarriages of vehicles and equipment, seeds in mud attached to equipment, and seeds that drop into shoes of hikers can be transported long distances. Spotted knapweed seeds spread in the currents of rivers and streams, and through contaminated crop seed and hay.

Allelopathy

Two allelochemicals are produced and exuded by the roots of spotted knapweed, nicin and catechin. These chemicals have been found to suppress the growth of some plants and may give spotted knapweed a competitive advantage when growing with them. The role of allelochemicals in spotted knapweed invasiveness has not been determined because it is difficult to separate competition for water and nutrient from allelochemical suppression. Both nicotine and catechin are believed to be short lived in the soil and break down soon after spotted knapweed has been removed.

MANAGEMENT

Herbicidal Control ^{1/}

Short-term control of spotted knapweed is effective using herbicides. Table 1 lists herbicides, rates, soil half life, and ecotoxicity for chemicals commonly used to control spotted knapweed. The length of control (i.e. the time the population regenerates from seeds in the soil) will depend on the soil residual activity of the herbicide, soil texture, precipitation, and the competitiveness of the plant community. Picloram applied at one pint product per acre (0.25 pounds active ingredient/acre) is the standard recommendation for herbicidal control of spotted knapweed and can provide 90 percent population reduction for three or more years on loamy soils with a well-maintained grassland community. However, picloram is a restricted-use herbicide and cannot be applied near surface water or where there is a high water table. It is water soluble, mobile, and will leach quickly from the rooting zone in sandy soils. Picloram also breaks down in sunlight which reduces its residual activity. Because of the residual activity, timing of picloram application is not as critical as with other herbicides with less residual activity (indicated by half life in Table 1). Spring, early summer, and fall applications result in the greatest control. Application during the hot and dry part of the summer should be avoided because uptake into the plant is limited when plants are dormant and the active ingredient breaks down rapidly in the sun.

An economical alternative to picloram is 2,4-D a broadleaf selective herbicide, which can be applied to sensitive areas or where the use of picloram is prohibited. The timing of 2,4-D application is important to maximize control because this herbicide has brief residual soil activity (see Table 1). To have the greatest reduction of spotted knapweed populations, 2,4-D should be applied after most of the seeds have germinated and before plants flower, generally at the late bud stage but before flowers appear. This timing will target early summer rosettes, prevent the transition from rosette to flowering plant, and eliminate seed production. As mentioned above, these are life history stages and transitions that are most important to spotted knapweed population fitness. Repeated annual applications of 2,4-D may be necessary to maintain control of plants that regenerate from the soil seed bank. However, reapplication will depend on the degree of seedling suppression by competitive plants.

Other herbicides available for control of spotted knapweed in sensitive areas include products that contain dicamba, clopyralid, or triclopyr. These herbicides are more expensive than 2,4-D but clopyralid and triclopyr do not injure as many non-target forb species as 2,4-D, which makes them an option where preserving the forb community is important to management objectives. These chemicals have residual activity that is greater than 2,4-D but less than picloram (see Table 1). Timing of application for these herbicides for optimum control of spotted knapweed is similar to the timing recommended for 2,4-D.

Aminopyralid is a recently developed chemical that is effective for controlling spotted knapweed. Its chemistry is very similar to that of picloram, clopyralid, and triclopyr. The mobility of aminopyralid in the soil is very high, however because of low application rates and

^{1/}Any mention of products in this publication does not constitute a recommendation by the NRCS. It is a violation of Federal law to use herbicides in a manner inconsistent with their labeling.

short soil half life (see Table 1), most of the chemical remains within the upper 12 inches of the soil profile. Aminopyralid can be used to treat ditch banks and other channels that do not carry water used for irrigation or drinking. There are few studies of the effectiveness of aminopyralid on spotted knapweed control. Trials in plant communities with competitive, well-maintained grasses indicate that control of spotted knapweed using aminopyralid is similar to control using picloram.

There are risks associated with herbicidal control of spotted knapweed that should be balanced against the resulting benefits, and the risks of alternative management actions, including the no action alternative, when making weed management decisions. Potential risks include human and environmental health, and economic costs.

The risks to human and environmental health can be minimized by strict adherence to application requirements defined on the herbicide label. The relative risks of chemicals can be compared by their ecotoxicity evaluations (see Table 1). Generally, the chemicals listed pose a low risk to human and environmental health. However, the degree of risk is dependent on dose and frequency of exposure. Frequency of exposure can be minimized by integrating non-herbicidal population regulation to reduce the number of herbicide reapplications. This will also reduce economic risk.

Introduced grasses inter-seeded into herbicide controlled spotted knapweed stands can provide competition and long-term suppression of recurring infestations if properly managed. Maintaining competitive grasses can reduce the number of herbicide applications needed to suppress spotted knapweed and therefore reduce environmental risk.

The greatest environmental risk of herbicidal control of spotted knapweed is injury to plants other than spotted knapweed, which is limited in most cases to forbs. While the functional role of forbs in ecosystems is not completely understood, we can assume the risk is significant where forbs, other than spotted knapweed, make up most of the plant community. Where grasses or spotted knapweed dominate the plant community, this risk will be minor.

Table 1. Chemical and product name, recommended application rate, soil residual half life, and ecotoxicity of herbicides commonly used to control spotted knapweed.

Chemical name	Product name	Rate per Acre	Half life (days)	Ecotoxicity (LC ₅₀ /EC ₅₀)
2,4-D	Many names	1 to 2 qts.	7	1-10 mg/L
Aminopyralid	Milestone	5 to 7 oz.	30	>100 mg/L
Clopyralid	Stinger	1/3 to	40	>100 mg/L
	Transline	1-1/3 pts.		
Dicamba	Banvel	1 to 3 pts.	10	>100 mg/L
	Clarity			
Picloram	Tordon	1 pt.	90	10-100 mg/L
Clopyralid+2,4-D	Curtail	2 to 3 qts.	40	0.1-1 mg/L
Clopyralid+triclopyr	Redeem	1 to 2 qts.	40	0.1-1 mg/L

Biological Control

Pathogenetic control of spotted knapweed using fungi, bacteria, or viruses has had limited success in field applications. *Sclerotinia sclerotiorum* is a common native soil fungus that is very effective in killing spotted knapweed in laboratory experiments. In field situations, mortality of spotted knapweed from *Sclerotinia* is most often associated with damage caused by root boring insects. *Sclerotinia* is pathogenetic to a wide range of plant species including many crops.

Currently there are eight flower-head insects and five root-boring insects that have been approved and released for biological control of spotted knapweed in the United States (see Table 2 below). Most of these insects are available commercially or through state, federal, or private programs. Once insects are established they can be collected on site and redistributed. Bio-control insects may reduce spotted knapweed populations where competitive plants are available, but they will not eradicate the population.

Table 2. Biological control insects for management of spotted knapweed, the site of attack on the plant, insect life stage and time of collection, and the collection method for redistribution.

Insect	Type	Site of attack	Collection	Collection method
<i>Agapeta zoegana</i>	Moth	Root	Larvae/rosette	Hand pick
<i>Bangasternus fausti</i>	Weevil	Flower head	Adults/bud	Sweep net
<i>Chaetorellia acrolophi</i>	Fly	Flower head	Larvae-pupae/seed heads(fall-winter)	Whole plant bouquets
<i>Cyphocleonus achates</i>	Weevil	Root	Adults/flowering	Sweep net, hand pick
<i>Larinus minutus</i>	Weevil	Flower head	Adults/flowering	Sweep net
<i>Larinus obtusa</i>	Weevil	Flower head	Adults/flowering	Sweep net
<i>Metzneria paucipunctella</i>	Moth	Flower head	Larvae-pupae/seed heads (fall-winter)	Whole plant bouquets
<i>Pelochrista medullanda</i>	Moth	Root	Larvae/late winter or adults/flowering	Hand pick or sweep net
<i>Pterolonche inspersa</i>	Moth	Root	Larvae/late winter or adults/flowering	Hand pick or sweep net
<i>Spenoptera jugoslavica</i>	Beetle	Root	Adults/flowering	Sweep net
<i>Terellia virens</i>	Fly	Flower head	Larvae-pupae/seed heads (fall-winter)	Whole plant bouquets
<i>Urophora affinis</i>	Fly	Flower head	Larvae-pupae/seed heads (fall-winter)	Whole plant bouquets
<i>Urophora quadrifasciata</i>	Fly	Flower head	Larvae-pupae/seed heads (fall-winter)	Whole plant bouquets

The *Urophora* seed-head flies were released over 20 years ago in Montana and they are well established throughout most of the spotted knapweed-infested areas in the western United States.

These species have been observed to reduce seed production by 50 percent or more. Other flower-head feeding insects are not as well distributed, but may be as effective as the *Urophora* fly. The *Larinus* flower-head weevils and *Metzneria* seed-head moth are established in Montana and believed to be effective in reducing seed production. *Larinus* species prefer hot dry sites and *Metzneria* does best on sites with winter snow cover. The *Bangasternus* seed-head weevil feeds primarily on diffuse and squarrose knapweed and is not reported in Montana. However, it is reported to consume up to 100 percent of the seeds per flower head where it is established.

While the number of seeds produced per flowering plant has been identified as important to spotted knapweed population fitness, seed-reducing insects applied alone are usually not effective in reducing populations because of the perennial nature of the plants. Spotted knapweed seed reduction is greatest where more than one insect is established, however, some species will attack and destroy larvae of other flower-head feeding species. Poor establishment of the *Chaetorellia* and *Terellia* flies is believed to be the result of competition with other flower-head insect species.

Of the root feeding insects, the *Agapeta* root moth, *Cyphocleonus* root weevil, and *Sphenoptera* root borer are well established in parts of Montana. These species prefer hot, dry, open sites. The *Pelochrista* root moth first released in Montana in 1984 has been slow to establish for unknown reasons. The *Pterolonche* root moth was released and established in Oregon in 1986 but has not been recovered since 2000 presumably because of the dramatic control of diffuse knapweed (another host for this species) by the seed-head weevils.

Reductions in spotted knapweed biomass and density have been noted ten years after the release of root-boring weevils. Observations suggest that the *Cyphocleonus* root weevil reduces the longevity of spotted knapweed plants making their duration more biennial than perennial, and thus less competitive with perennial grasses. This observation is supported by taxonomic information about spotted knapweed plants in Europe.

Dramatic reductions in spotted knapweed densities have been observed in southwestern Montana after the release of flower-head and root-feeding biological control insects. In most cases, two or more insect species attack the spotted knapweed population. Ten years after the release and establishment of *Cyphocleonus achates* (see Figure 5) and *Larinus spp.* in large scale and dense populations of spotted knapweed, three different plant communities were observed depending on management treatments. Where the biological insects were released and no other management was used, the plant community remained dominated by spotted knapweed. Where picloram was applied and the biological control insects established on spotted knapweed regenerating from the seed bank, cheatgrass was the dominant plant in the plant community. However, where picloram was used to establish perennial grasses and the insects established, the perennial grasses dominated the plant community. These observations illustrate how plant community composition was important in influencing the outcome of management actions.



Figure 5. A spotted knapweed root with a *Cyphocleonus* root weevil gall. This root supported three weevil larvae. The gall is the enlarged portion of the root below the base of the plant. One newly emerged adult can be seen on the lower side of the root gall above the center of the clippers. One larva can be seen on the paper bag below the root and above the soil residue.

As with herbicidal management, there are risks associated with releasing biological control insects that include potential human and environmental health, and economic risks. The risk of non-target attack is controlled, but not eliminated, by host specificity testing. Many of the insects released will attack more than one species of *Centaurea*, however there have been no reported occurrences of insects released for spotted knapweed management attacking individuals of native plant species populations. Considering the abundance of host plants where insects have been released, there is currently little pressure for insects to adapt to alternative hosts. Other than hand pulling, biological control insects are the most target-specific management available for spotted knapweed.

Increases in mouse populations have been documented in spotted knapweed infestations where the larvae of flower head insects have established and provide a new energy source for mice. Increased mouse populations may increase risk of mouse-borne diseases to humans; however there has been no increase in human disease associated with spotted knapweed or biological control insects.

Establishment, Collection, and Redistribution of Bio-Control Insects

The minimum number of insects needed to establish a sustainable population is 200 insects, but more is better. The spotted knapweed infestation should be at least two acres in area and moderately dense to very dense (three or more knapweed plants per square yard). Sites should be open and not forested. Insects collected for redistribution, should be released on the new site as soon as possible after they are collected, and kept cool (but not frozen) during collection, transport and storage. Collected insects should be kept in breathable containers that allow air

flow and where condensation does not form. Non-wax ice cream containers work well, paper bags will work if they are not crushed or saturated when iced, and pillow cases are convenient for collecting and transport. Do not use plastic bags. Including some fresh knapweed in the container gives the insect something to congregate and feed on.

Release sites may be marked with a steel post to help relocate the site for monitoring. Whole plant bouquets can be tied directly to the post or to fence posts. Weevils, moths and flies should be released on the ground within three feet of the marking post. The best time to release insects is during the cool times of the day in the morning or evening. The post can be used as a photo point to monitor any change in the weed population and plant community after release.

It may take two to three years for an insect population to establish. High release numbers will reduce the time of establishment.

Grazing Control

Sheep and goats have been used to reduce the biomass and density of spotted knapweed, and other forb-eating livestock may also utilize this weed. An advantage of this management is that it results in a commodity while providing control of the weed. The degree of spotted knapweed population regulation will depend on the timing, intensity, and frequency of spotted knapweed utilization by these animals.

The nutritional content and palatability of spotted knapweed will vary during the growing season and affect the way grazing animals use spotted knapweed. Spring and early summer rosettes, and bolting plants are most palatable and nutritious to livestock. These life history stages were identified in sensitivity analysis as important stages to target in management to reduce spotted knapweed population fitness. When plants dry in the summer, nutrition and palatability are reduced and livestock select stem leaves, flower heads of spotted knapweed, and other more palatable forage plants.

The diet of sheep is generally divided equally between forb and grass species, or in proportion to their availability. When spotted knapweed is more abundant than grasses, sheep will tend to consume a greater proportion of it than grasses if palatability is equal. One strategy that has been applied is to graze an area first with cattle to utilize the grass followed by sheep grazing to clean up the knapweed. The resulting grazing pressure on desirable grasses and the weed is equal under this management.

The intensity of sheep grazing on spotted knapweed can be increased by fencing sheep on infestations (see Figure 6). Portable electric fencing has been used successfully to target specific problematic infestations. Webbed electric fencing also helps reduce losses to small predators including fox, coyotes, and domestic dogs.



Figure 6. A fence line comparison of sheep utilization of spotted knapweed (right) and no control of spotted knapweed (left). On the right side, 20 ewes and one ram were held on 0.1 acre plot for one to four days twice annually for five years.

A single grazing during bloom may reduce spotted knapweed seed production, however multiple, repeated grazing over a number of years is needed for sheep or goats to reduce spotted knapweed biomass and density. In a five year study, annual intensive grazing of spotted knapweed when plants bolted in late May, and repeating the treatment after one month rest when plants re-initiated bolting, was effective in reducing spotted knapweed density. Grazing spotted knapweed one time with sheep resulted in an increase in spotted knapweed density.

Sheep grazing may be combined with other management to improve control of spotted knapweed. Irrigation followed by repeated sheep grazing has been used to boost the production of perennial grasses and reduce spotted knapweed production. Applying this treatment for three to five years followed by a single application of 2,4-D resulted in long-term suppression of spotted knapweed.

Spotted knapweed seed can pass through the digestive system of grazing animals and remain viable. Sheep, goats, and other animals that have grazed in spotted knapweed infestations and may have consumed seeds should be held for at least five days before being moved to weed free areas to prevent spreading the weed *via* feces. Grazing weeds with sheep should be timed to avoid contact with, and disease spread to, wild sheep.

Cultural Control

Cultural methods including hand pulling, mowing, tilling, irrigation, and re-vegetation are effective in managing spotted knapweed in certain situations and when combined with other control actions.

Hand Pulling. Hand pulling that extracts the root crown is an effective method to temporally reduce spotted knapweed on small-scale infestations. Pulling or grubbing the root crown is most easily accomplished when the soil is moist and a shovel is used to pry-up the tap root. When the soil is dry the plant tends to break-off above the root crown enabling it to regenerate. If flowering plants have been pulled, they should be sealed in plastic bags and disposed of in the trash to prevent seed spread. Wearing gloves while pulling spotted knapweed will protect against potential skin irritation from chemicals produced by knapweed.

Mowing. Spotted knapweed seed production can be reduced by mowing. Mowing when plants have bolted to produce a flower, but before flowering, will reduce energy reserves and seeds produced. Repeated mowing may be needed if plants reinitiate bolting after the first mowing. After repeated mowing, spotted knapweed has been observed to produce flower heads below the height of the mower blade. Mowing has not been shown to reduce population densities but may prevent population spread by reducing seed production. Consecutive years of mowing followed by an herbicide application may improve long-term control of spotted knapweed because of reduced seeds to regenerate the population. Washing mowing equipment after mowing spotted knapweed will help prevent spread of this weed if the equipment is subsequently used on weed free areas.

Tilling. Shallow tilling that severs the tap root below the root crown has been effective in reducing spotted knapweed populations. This treatment may, however, increase regeneration of spotted knapweed from the seed bank by exposing buried seeds. Multiple tilling or tilling followed by application of herbicide to target establishing seedlings can be used to exhaust the supply of viable seeds in the soil. Tilling is only recommended in combination with seeding perennial competitive plants. As with any mechanical treatment, equipment should be washed after working spotted knapweed infestations and before it is used on weed-free areas to prevent the spread of spotted knapweed.

Irrigation. Irrigation can be used as part of a spotted knapweed management program. Irrigation can stimulate the germination of spotted knapweed seeds thus reducing viable seeds in the soil. When followed by a control treatment such as herbicide application or sheep grazing, populations can be reduced. Irrigation can be used to increase the production of many pasture plant species and increase their competitiveness with spotted knapweed. If mature, competitive spotted knapweed plants are controlled using herbicides, sheep grazing, or biological control insects, the competitive pasture plants may suppress young and establishing spotted knapweed plants.

Prescribed Burning. In Montana, prescribed fire generally results in increased spotted knapweed populations and is not used as a control treatment. The effect of fire on plants is strongly influenced by the timing of burning. Most fires are prescribed in the spring or fall in Montana. In Michigan, annual prescribed fire in the summer reduced spotted knapweed on restored warm-season grass prairies. Burning spotted knapweed infested pastures or rangeland in the summer in Montana poses a high risk of wildfire and is generally not recommended.

Fertilization. Fertilization can be used to boost the competitiveness of grasses with spotted knapweed when applied in combination with herbicidal or other suppression of spotted knapweed. Non-native pasture grasses respond to fertilization with greater biomass production than native grasses. Fertilization can also be used to stimulate the growth of re-vegetation plants. Fertilization by itself stimulates spotted knapweed growth and reproduction.

Re-vegetation. Sustainable suppression of spotted knapweed populations is less likely without desirable perennial plants to compete with spotted knapweed for water, nutrients, and light. On disturbed sites, and sites where the competitive vegetation has been lost, re-vegetation may be needed. Successful establishment of desirable vegetation can be improved by selecting a site adapted seed mix, preparing a firm weed-free seedbed, controlling weeds, and seeding at a time that optimizes moisture availability to establishing seedlings.

Species selected for re-vegetating disturbed sites and spotted knapweed infestations should be appropriate for management objectives, adapted to site conditions, and competitive with spotted knapweed. Management objectives will determine if forage species or native species are seeded and the species mixture. The environmental conditions of the site including precipitation, soil texture and depth, slope and aspect, will affect species establishment. A diversity of perennial grass and forb species that occupy many niches over time and space will most fully utilize resources and compete with spotted knapweed. Refer to [Montana Plant Materials Technical Note 46](#), 'Seeding Rates and Recommended Cultivars,' and Extension Bulletin EB19 'Dryland Pasture Species for Montana and Wyoming' for seeding rate guidance and re-vegetation species selection. State and area resource specialists can help determine the most appropriate, site-specific species mix and timing of seeding.

An ideal seedbed for re-vegetation is one that has pulverized soil on the surface with moderate amounts of mulch or plant residue, firm soil below seeding depth, and free of residual competitive plants. This may be practically prepared on agricultural land, however, on rangeland a no-till drill may be the best method to seed into spotted knapweed infestations that have been suppressed. On sites inaccessible to machinery, broadcast seeding with little or no seedbed preparation is often the only option. Increasing seeding rate can increase the establishment of seeded species that are broadcast. Weed infested sites burned by wildfire have been successfully re-vegetated using aerial seeding.

In most cases, herbicidal suppression of spotted knapweed is needed for re-vegetation of infested lands. The herbicides listed in Table 1 will control spotted knapweed and reduce competition during the establishment period with little or no injury to emerging grass seedlings. Picloram provides the longest spotted knapweed suppression of the herbicides listed in Table 1, and therefore provides the greatest window of competition-free establishment. This is especially important for species that are slow to establish like many of the native grasses. Picloram applied at the time of a fall-dormant drill-seeding in spotted knapweed/cheatgrass (*Bromus tectorum*) infestations has resulted in good stands of native and non-native perennial grasses (see Figure 7).



Figure 7. A comparison of a spotted knapweed infestation re-vegetated with bluebunch wheatgrass (left) and no re-vegetation (right) on adjacent sites. The grass was drill-seeded after a fall picloram application ten years prior to the time of the photograph. The *Cyphocleonus* root weevil and the *Larinus* flower head weevil are established on both sites.

Integrated Pest Management

Integrated Pest Management (IPM) is the application of multiple management actions that are mutually supportive, and should include actions that cultivate competitive desirable plants and actions that suppress weed populations. The goals of IPM beyond weed control include reducing the cost of weed management and reducing herbicide inputs. Keys to successful IPM include understanding the biology of the weed, understanding the ecology of the system, and careful planning. The biology of spotted knapweed important to IPM has been outlined above and can be used to time control actions to reduce early summer rosette, the transition from the rosette stage to the flowering plant stage, flowering plant survival, and seeds produced per flowering plant. Knowledge of the ecology of the system including climate, soil, and biotic community factors is important in designing biological, grazing, and cultural management.

Careful planning is based on three things that very often are not considered in weed management: overall management goals, measured threats or risk to management goals, and measured progress toward reaching management goals. Specific weed management goals will fit into one of the following categories: prevention, early detection and small-scale eradication, containment, and large-scale population reduction. Prevention is guided by how spotted knapweed spreads and its requirements for establishment. Early detection and small-scale eradication is achieved through persistent survey and herbicide application. Spotted knapweed populations are contained by herbicidal control of population borders and satellite populations, control actions that reduced seed production, and cultivation of competitive plants. Large-scale population reduction is achieved over the long-term by applying management actions that reduce the spotted knapweed population fitness and increase the fitness of desirable plant populations.

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