Restoration and Reclamation Review
Student On-Line Journal
Vol.6, No.1, Fall 2000
Department of Horticultural Science
University of Minnesota, St.Paul, MN

Centaurea maculosa: Invader of Western U.S. Grasslands

Catherine Neu

Introduction

Centaurea maculosa (spotted knapweed) is a Eurasian perennial weed that invades grasslands throughout the Western United States and Canada. It was introduced to North America in the late 1800's as a contaminant in *Medicago sativa* L. (alfalfa). Today it has expanded from the Pacific Northwest throughout the states of Washington, Oregon, Idaho, Montana, and Wyoming, and into portions of neighboring states (Sheley *et al*. 1998). Due to its competitive advantage over native vegetation and its disruption of the inherent balance of the invaded system, *C. maculosa* can cause increased soil erosion, increased water runoff, reductions in wildlife and livestock forage, as well as reductions in biodiversity. *C. maculosa* has become a serious threat to intermountain grasslands and rangelands in the West.

Grassland restoration sites are target landscapes of *C. maculosa* due to soil disturbance during site preparation and recovery. Extensive research has gone into developing control techniques for *C. maculosa*. It is essential to analyze these techniques as they pertain to ecological restoration in grassland areas throughout the western regions of North America. This paper will focus on minimizing the effects of *C. maculosa* in restored ecosystems. By studying the life history, geography and biology of *C. maculosa*, as well as the most effective management techniques that are used to control it, one will understand that, due to the diversity in restoration projects, there is not one solution for management. Integrated management techniques are therefore needed to reduce the disastrous effects of *C. maculosa* invasions in restored sites. Studies often involve the comparison of *C. maculosa* to a similar species, *Centaurea diffusa* (diffuse knapweed). Due to its wider distribution and its spreading behavior, *C. maculosa* is the focus of this paper.

Fig. 1. *Centaurea maculosa*, photo taken from USDA, NRCS Plants Database for educational purposes

Centaurea maculosa and its Effects

History and Geographic Distribution

C. maculosa is native to central Europe, central Russia, Caucasia, and western Siberia. In Europe, *C. maculosa* is most aggressive in the forest steppe, and can form dense stands in moist areas, as well as in drier sites (Sheley *et al*. 1998). The first record of *C. maculosa* in North America was in Victoria, British Columbia, in 1883 (Groh 1944 in Sheley and Petroff 1999). The geographic spread of *C. maculosa* up to 1980 was documented using herbarium records (compiled by Forcella and Harvey 1980) and the current distribution has been documented using weed authorities and interviews. Since 1980, *C. maculosa* has spread rapidly from 48 counties to 326 counties in the western United States, including every county in Washington, Idaho, Montana, and Wyoming. In these western regions, *C. maculosa* has been able to gain a competitive advantage over native species due to its ability to germinate over a wide range of environmental conditions. *C. maculosa* can exist at elevations from 1,900 to more than 10,000 feet (580 to 3048 m), and in varying precipitation zones, ranging from 8 to 79 inches (20 to 200 cm) annually (Sheley *et al*. 1998).

Biology and Impacts

The inherent morphology, spreading behavior, germination and allelopathic characteristics of *C. maculosa* all contribute to its aggressiveness. It is important to examine the biology of *C. maculosa* to understand its impacts on the site and in the ecosystem.

Identification, Morphology and Life Cycle: *C. maculosa* is a taprooted, rosette-forming plant in the Asteraceae family that is capable of living up to nine years (Sheley and Petroff 1999). Rosettes are deeply divided into oblong lobes on either side of the center vein. Its branches divide on the upper half of the stem, and contain alternate leaves. The purple to pink flower heads are ovate, and terminate the numerous branch ends (Fig. 2). The flower heads usually stay on the plant after reaching maturity (Gleason and Cronquist 1991; Sheley *et al.*1998). The flowers bloom from June to October, and during this time the plant is capable of producing 5,000 to 40,000 seeds per m^2 per year depending on site conditions and precipitation. These seeds are spread by a wind-induced flicking action that can send them up to a meter from the parent plant (Watson and Renney 1974). Seeds germinate in the fall and early spring, and may become seed-producing adults in one year (Shirman 1981 in Sheley and Petroff 1999). *C. maculosa*'s rosette growth habit, unpalatable foliage and spiny heads all contribute to their aggressiveness. Grazing animals are not attracted to them and chemical control may be hindered in some cases, since pubescent features do not allow for penetration (Watson and Renney 1974).

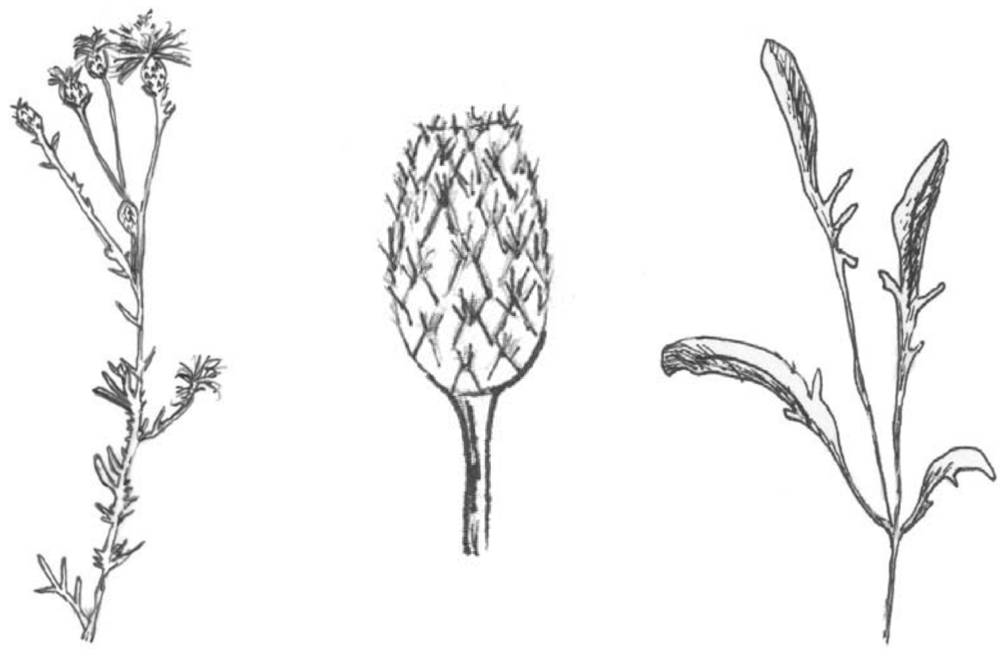

Figure 2. *Centaurea maculosa* plant, flower head and rosette, adapted from Sheley *et al* 1998

Spreading: *C. maculosa* seeds are spread by wind, through rivers, in crop seed and hay, and by attachment to the undercarriage of vehicles and equipment (Watson and Renney 1974). Due to this problem, Thomas of Bitterroot Restoration, Inc., stresses the importance of cleaning equipment before project installation (Thomas 2000, personal communication). *C. maculosa* also establishes rapidly on disturbed soils: the greater the disturbance, the higher the density of the weed (Watson and Renny 1974). Disturbance encourages the establishment of *C. maculosa* and its spread because its seedlings, rosettes, and adults are able to inhabit different soil rooting zones and occupy all available niches (Sheley and Larson 1996 in Sheley and Petroff 1999). These populations are then extended through peripheral enlargement of existing stands, out-competing native vegetation (Watson and Renney 1974).

Germination: The aggressive tendencies of *C. maculosa* are strengthened by its ability to germinate over varying environmental conditions. Watson and Renney found that germination might occur at temperatures ranging from 45° to 93° F (7° to 34° C) with optimum germination at about 66° F (19° C). Optimum seedling emergence occurs at the soil surface level and rarely below 5-cm depth, which is an important consideration when using cultivation methods of control.

C. maculosa has extremely long-lived seeds. The soil seed bank of the weed decreases by 95% over a seven-year period, but the number of viable seeds remains high: 98,800 seeds/acre (244,139 seeds/ha) (Davis *et al*. 1993 in Sheley and Petroff 1999). In addition, up to 22% of *C. maculosa* seeds can remain viable after passing through the digestive tract of sheep and mule deer (Wallander *et al*. 1995 in Sheley and Petroff 1999).

Allelopathy: *C. maculosa* contains an allelopathic compound, cnicin, in its leaves and shoots. This chemical has been shown to reduce germination in *Agrpyron cristatum* L. Gaertn. (crested wheatgrass), *Pseudoroegneria spicata* (bluebunch wheatgrass*)*, and *Festuca altaica* Trin. (rough fescue) (Kelsey and Locken 1987 in Sheley *et al*. 1998). As an inhibitor to growth of these native plants, *C. maculosa* threatens biological diversity in the west. This chemical also has mechanical management implications since its release may cause abrasions on skin when pulling the weeds. Certain studies have also addressed the possibility that cnicin may have carcinogenic traits, but currently this is unresolved (Wyoming Department of Health 2000).

Overall Impacts: *C. maculosa* reduces livestock and wildlife forage, is detrimental to water and soil resources, and inevitably reduces biological diversity. The decrease in *P. spicata* due to *C. maculosa* invasions reduces elk foraging use by 98%, since elk prefer *P. spicata* to *C. maculosa*. These infestations have been predicted to cause a loss of 220 elk from winter range in Montana annually (Sheley and Petroff in Hakim 1979; Spoon *et al.* 1983). In addition, surface water runoff and stream sediment yield are higher on *C. maculosa*-dominated sites than on those dominated by *P. spicata* (Sheley and Petroff 1999).

Management Techniques

C. maculosa is particularly successful due to its seed longevity and its prolific seed production. In disturbed landscapes, like restoration sites, it can form solid stands and expand its populations rapidly. These characteristics become problematic for management when restoring a site. Due to the complexity of *C. maculosa* infestations, integrated strategies may be the only way to manage it effectively. It is important to understand the many techniques adopted by different weed specialists to arrive at the most successful control method.

Chemical Control

Picloram, clopyralid, dicamba and 2,4-D are common herbicides that have been used successfully to control *C. maculosa* on grasslands and rangeland. All of these herbicides are growth regulators used for broadleaf species. Studies have shown that plant diversity can be sustained and enhanced with certain herbicide treatments of picloram, clopyralid, and 2,4-D, all which have high efficacy when applied properly (Rice *et al* 1992). However, reapplication is usually necessary. Picloram, for example, is lost from the soil after four years, after which, *C. maculosa* seeds may begin to germinate again (Maddox 1982). Picloram is used for its effective control of broadleaf plants, and has been successful in the reduction of *C. maculosa*. In an eight-year study by Davis (1990), picloram at 0.25 lb/acre (0.28 kg/ha) provided close to 100% control of *C. maculosa* for three to five years. During this period of control, other grasses increased by 200% to 700% (Sheley and Petroff 1999 in Davis 1990). Picloram is not toxic to grazing animals and does not affect the germination of *Buchloe dactyloides*, *Bouteloua curtipendula,* and *Panicum virgatum*, which are important native plants of western Montana. According to Harris and Cranston (1979), restoration of heavily infested rangeland requires eradicating *C. maculosa* completely, usually with picloram, followed by seeding of competitive vegetation. This vegetation may consist of a diverse group of species (i.e. *Pseudoroegneria spicata*, *Bouteloua curtipendula*, *Panicum virgatum*) that together, will occupy all niches. The tolerance of picloram by most native grass species seems to make it a good option for management of *C. maculosa.* It is important to consider however, that the residual character of picloram can create considerable health hazards. Its existence in soil and surface runoff may have adverse impacts on water quality as well as on native species that cannot tolerate it for long periods of time.

Clopyralid can provide control similar to that of picloram when applied during bolt or bud growth stages. The amounts of clopyralid used are usually 0.24 lb/acre (0.27 kg/ha) and 0.20 lb/acre (0.22 kg/ha). It is then applied with 2,4-D at 1 lb/acre (1.1 kg/ha). However, when this combination is applied at rosette, flowering, or after flowering growth stages, the percent control declines to below 83% (Lacey *et al* 1995 in Sheley and Petroff 1999).Dicamba and 2,4-D can be used together for chemical control of *C. maculosa*. These herbicides are less dependable and must be applied annually until the seed bank is depleted (Sheley and Petroff 1999). These chemicals are most effective when applied at the bud stage.

Chemical control is one of the most effective methods currently in use on restoration sites. However, it is important to analyze site conditions and management capabilities due to the long-term commitment of the technique. Health considerations will also need to be taken into account, since runoff of chemicals may lead to hazardous conditions.

Biological Control

A variety of biological control methods have been used to reduce the seed production of *C. maculosa*. Due to marginal returns from herbicidal control, many studies have focused on natural enemies to minimize the effects of invasive species. The advantage of using insects over chemicals is that they are self-perpetuating, more target specific, and they afford a favorable cost-to-benefit ratio (Maddox 1982). A major disadvantage to using biological control however is that the insects that combat *C. maculosa* are non-native species in North America. Wildlife reserves, wilderness areas, national parks, and state parks often have strict regulations against the introduction of non-native species. For example, restorationists cannot use biological control methods on wildlife reserve projects in Montana (McAdoo 2000, personal communication). The Nature Conservancy does not use biological control for their many preserves, either. Gaining approval to overturn stringent regulations that restrict the introduction of non-native species into federally protected land would be a difficult task (Mauer *et al* 1999). Furthermore, predatory insects work too slowly for the normal timeline of a restoration project; it could take up to 30 years before there is a visible impact on the site (McAdoo 2000, personal communication).

Three seedhead-feeding insects (*Urophora affinis*, *Urophora quadrifasciata* and *Metzneria paucipunctella*) are commonly used to reduce seeds on knapweed flower heads; *Urophora affinis* is the most effective. In a study conducted in Montana and Idaho by Story and Anderson (1978), this species was reported to reduce seed production by 50% and their galls were found 50 m from the release point after a 2-yr period. Records show that the fly population had established, dispersed, and increased (Maddox 1982).

Four root-mining insects have been used to control *C. maculosa*. Larvae of these insects bore into the root of the plant, reducing flowering and production. *Agapeta zoegana* L., a Eurasian root moth and *Cyphocleonus achates*, a root weevil, have been able to damage roots of *C. maculosa* plants. The release of *A. zoegana* has caused reductions in biomass, height, number of stems, and number of capitula in *C. maculosa* (Story *et al*. 2000). Two other moths, *Pelochrista medullana* and *Pterolonche inspersa* (more specific to *Centaurea diffusa*), have been released in Montana, and are currently being studied.

These studies suggest that, given sufficient time for biological control to become fully effective, certain biocontrol agents could reduce the density and aggressiveness of *C. maculosa*. However, on a shorter timeline, they do not effectively eradicate populations unless they are integrated with other control techniques.

Cultivation

Cultivation may be one of the most effective ways to control *C. maculosa*. McAdoo (2000, personal communication) emphasizes the importance of cultivation on restoration sites. He recommends plowing up soils, allowing 4 to 6 weeks for regermination of *C. maculosa*, and then repeating the process for one growing season. If there is a large establishment of weeds already on the site, herbicide application may be necessary before disking begins. This management process takes time, so it is dependent on the limits of the project objectives (budget, timeline, etc.). Cultivation to 7 inches (17.8 cm) has been reported as an efficient depth for eliminating *C. maculosa* and encouraging grass growth (Popova 1960 in Sheley and Petroff 1999).

Revegetation with Competitive and Native Plants

Using the appropriate plant vegetation is a key component of a restoration project. It is often suggested as a means of minimizing non-indigenous plant invasions since it maximizes niche occupation (Jacobs and Sheley 1999). According to Sheley (2000, personal communication), "establishing competitive plants is essential for the successful management of knapweeds and the restoration of desirable plant communities." It is necessary to choose the right species and densities that are site-appropriate in order to achieve a successful project.

It is essential to use a seed mix of desirable native grasses, including sod-forming, fast-growing species in order to create a good cover that will allow for full native plant establishment (McAdoo 2000, personal communication). If it is possible, irrigation should also be a part of the seeding process. Since *C. maculosa* prefers drought-like conditions, the moisture will preclude it from establishing, and will ultimately favor the native grasses. One could also install a nurse cover crop of a fast-growing species like wheat, which can shade the soil and prevent *Centaurea* infestation. A sterile cover crop mix like Regreen will not emerge the following year, ensuring that native grasses will appear the next spring in place of the cover crop. Depending on the target species, one could also establish a shrub or tree canopy to shade the soil. Since *C. maculosa* prefers full sun, this method would discourage its growth. Preferable shade-tolerant grass species will emerge instead of *C. maculosa*.

According to Sheley and Petroff (1999), revegetation involves a late-fall cultivation, followed by a dormant seeding of grasses. A diverse seed mix that is appropriate for the site is essential. The next spring, *C. maculosa* will emerge first at which point glyphosate (a nonselective herbicide used as foliar spray) may be applied before grass seedlings emerge. If the grass seedlings survive until mid-summer, a reduced rate of 2,4-D or mowing could be applied to weaken *Centaurea* plants. This application may need to be repeated.

Other Control Methods

Burning: Fire has not been effective at totally eradicating *C. maculosa* because it is not hot enough to prevent resprouting from crowns or reestablishment from viable seeds in the soil. *C. maculosa* has even increased after a controlled fire, which indicates that its colonization may benefit from the disturbance (Sheley and Petroff 1999).

Hand-Pulling: Hand-pulling may be beneficial on small sites, along streams and in sensitive areas. However, due to the spreading methods of knapweeds, their crowns must be completely removed from the soil. The entire plant should be pulled before it produces seed. Due to its allelopathic chemicals, *C. maculosa* may produce hand sores after continuous weeding. Possible carcinogenic traits are also a concern, as addressed earlier.

Mowing: Watson and Renney (1974) found that mowing at the flowering stage or at both the flowering and bud stage reduced germination of *C. maculosa*. Mowing in the flowering stage and mowing twice during the growing season both reduced the percent germination even further. Overall, mowing can be an effective way to combat *C. maculosa*, but should not be the only method used.

Analysis of Management Techniques: The Best Control of *Centaurea maculosa*

Integrated Management

Restoration projects vary widely. Each project contains specific site objectives, including a timeline, budget, target species, and cultural needs. A control technique may work on one site, and not on another, depending on the nature of the site. An integrated approach is essential for a successful restoration project on any site. This approach requires adequate plant competition with native plants as described earlier, and a mixture of other site-appropriate management techniques.

The integrated approach uses options from the examined management methods. It should always incorporate a proper native plant species list that is site-specific and that involves target species. Depending on the timeline and budget of the project, as well as the pre-existing nature of the site, one or more of the following should be incorporated into the management plan: *herbicide application*, *cultivation*, *irrigation*, *cover crops*, and possibly *biological control*. Since restoration projects are diverse, it is necessary to determine one's goal. Taking an inventory of the infested lands, calculating densities, soil and range types, as well as analyzing the degree of infestation will help one to develop a practical management program (Sheley 2000, personal communication). Here are a few examples of the integration of various techniques depending on the goals of the project (all of these options include using the appropriate species list):

Goals of the Project	Integrated Approach
1. quick solution at a low cost	1. herbicide application and irrigation
2. intermediate timeline, low cost and labor available	2. cultivation over 1 growing season, cover crop, irrigation
3. intermediate timeline, non-native species & chemical restrictions	3. irrigation and cultivation
4. long timeline, no herbicide treatment wanted	4. biological control

Conclusion

Centaurea maculosa is one of the most invasive plants in western North America. Research into effective management techniques is extensive, but little is published on the invasive qualities as they relate to ecological integrity and restoration methods. Currently, interviewing individuals who work in the restoration field is the best way to analyze the effects of the many techniques.

Restoration involves continuous trial and error. After evaluating a site, restorationists develop and use management plans to guide the installation plans and future requirements of the site. By using an integrated management approach, a restorationist will be able to craft the management techniques to the site, encouraging a balance between goals and limitations. An integrated management approach, if conducted efficiently, will inevitably lead to a successful restoration project, whereby *Centaurea maculosa* is controlled before, during, and after project installation.

References

Callaway, Ragan M., Thomas H. DeLuca, and Wendy M. Belliveau. 1999. Ecology 80(4): 1196-1201.

Chicoine, Timothy K. 1984. *C. maculosa* (*C. maculosa* L.): Control, Seed Longevity and Migration in Montana. MS Thesis Montana State University.

Davis, E.S. 1990. *C. maculosa* (*C. maculosa* Lam.) seed longevity, chemical control, and seed morphology. M.S. Thesis. Montana State University, Bozeman, MT.

Galatowitsch, Susan. 2000. Associate Professor, Department of Horticulture, University of Minnesota. Personal Communication. November 13, 2000.

Gleason, Henry A. and Arthur Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada, Second Edition. The New York Botanical Garden. 615 p.

Harris, P. and Cranston, R. 1979. An economic evaluation of control methods for diffuse and *C. maculosa* in Western Canada. Canadian Journal of Plant Science 59: 375-382.

Jacobs, James S. and Roger L. Sheley. 1999. Competition and Niche Partitioning Among *Pseudoroegneria spicata*, *Hedysarum boreale*, and *C. maculosa*. Great Basin Naturalist Volume 59(2): 175-181.

Jacobs, James S., Roger L. Sheley, and Bruce D. Maxwell. 1996. Effect of *Sclerotinia sclerotiorum* on the Interference between Bluebunch Wheatgrass (*Agropyron spicatum*) and *C. maculosa* (*C. maculosa*). Weed Technology 10: 13-21.

Maddox, Donald M.1982. Biological Control of Diffuse Knapweed (*Centaurea diffusa*) and *C. maculosa* (*C. maculosa*). Weed Science. Volume 30: 76-82 pp.

Mauer, Teresa, Mary J. Russo, and Margaret Evans. 1999. Element Stewardship Abstract for Centaurea maculosa, *C. maculosa*. The Nature Conservancy. September 8, 2000. <http://tncweeds.ucdavis.edu/esadocs/documnts/centmac.html>

McAdoo, David. Restorationist, Bitterroot Restoration, Inc. Personal Communication. October 26, 2000.

Powell, George W., Brian M. Wikeem, and Allen Sturko. 2000. Biology of *Agapeta Zoegana* (Lepidoptera: Cochylidae), Propagated for the Biological Control of Knapweeds (Asteraceae). The Canadian Entomologist 132: 223-230.

Rice, Peter, Donald J. Bedunah and Clinton E. Carlson. 1992. Plant Community Diversity after Herbicide Control of *C. maculosa*. United States Department of Agriculture.

Sheley, Roger L. Associate Professor, Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT. Personal Communication. October 12, 2000.

Sheley, Roger L. and James S. Jacobs, and Michael F. Carpinelli. 1998. Distribution, Biology, and Management of Diffuse Knapweed (*Centaurea diffusa*) and *C. maculosa* (*C. maculosa*). Weed Technology 12: 353-362.

Sheley, Roger L. and Janet K. Petroff. 1999. Biology and Management of Noxious Rangeland Weeds. Oregon State University Press.

Story, J. Entomologist, Montana Agricultural Experiment Station, Corvallis, MT. Personal Communication. September 25, 2000.

Story, J.M., W.R. Good, L.J. White, and L. Smith. 2000. Effects of the Interaction of the Biocontrol Agent *Agapeta zoegana*L. (Lepidoptera: Cochylidae) and Grass Competition on *C. maculosa*. Biological Control 17: 182-190.

Story, J. M. and N.L. Anderson. 1978. Release and establishment of *Urophora affinis* (Diptera: Tephritidae) on *C. maculosa* in western Montana. Environmental Entomologist 7: 445-448.

Thomas, M.2000. Restorationist, Bitteroot Restorations, Inc. Corvallis, MT.

USDA. 2000. Not All Alien Invaders are from Outer Space. United States Department of Agriculture and Animal and Plant Health Inspection Service. Program Aid number 1665.

USDA. 1994. Biological Control of Spotted and Diffuse Knapweeds. United States Department of Agriculture. Program Aid number 1529.

USDA. 2000. USDA Natural Resources Conservation Service Plants Database. <http://plants.usda.gov/plants/cgi_bin/topics.cgi> November 21, 2000.

Watson, A.K. and A.J. Renney. 1974. The Biology of Canadian Weeds. 6. *Centaurea diffusa* and *C. Maculosa.* Canadian Journal of Plant Science 54: 687-701.

Wyoming Department of Health. Wyoming Cancer Surveillance Program: Monitor Investigate, Prevent. News Release <http://wdhfs.state.wy.us/cancer/knapweed.htm> May 8, 1998 (Accessed 18 August 2000).