ELEMENT STEWARDSHIP ABSTRACT
for

Centaurea diffusa Lamarck
(synonym *Acosta diffusa* [Lam.] Sojak)

diffuse knapweed

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SPECIES CODE
PDAST1Y060

SCIENTIFIC NAME
Centaurea diffusa Lamarck
synonym: *Acosta diffusa* (Lam.) Sojak

The genus name *Centaurea* commemorates the centaur, the mythical creature of Hippocrates, half horse and half man (Allred and Lee 1996). The specific epithet *diffusa* refers to the open branching pattern of mature plants (Allred and Lee 1996).

COMMON NAMES
Diffuse knapweed is the most commonly used name in North America. Additional common names include spreading knapweed and tumble knapweed.

DESCRIPTION AND DIAGNOSTIC CHARACTERISTICS
Centaurea diffusa is a highly competitive herb of the aster (sunflower) family (*Asteraceae*). The plants first form low rosettes and may remain in this form for one to several years. After they reach a threshold size they will bolt, flower, set seed, and then die. Thus they may behave as annuals, biennials or short-lived perennials, bolting in their first, second, third, or later summer, respectively. Plants of this type are often called semelparous perennials or short-lived monocarpic perennials.

Stems are upright, 10-60 cm (4-24 in) tall from a deep taproot, highly branched, angled, with short, stiff hairs on the angles (Allred and Lee 1996). There are two types of leaves. The long, deciduous basal leaves, which form the rosette, are stalked and divided into narrow, hairy segments, 3-8 cm (1-3 in) long, and 1-3 cm (0.4-1 in) wide (Zimmerman 1997, Allred and Lee 1996). The stem, or cauline, leaves, which are alternately arranged on the stems, are smaller, less divided, stalkless, and become bract-like near the flower clusters (Zimmerman 1997, Allred and Lee 1996).

Flower heads are broadly urn-shaped, 1.5-2.0 cm (0.6-0.8 in) tall, solitary or in clusters of 2-3 at the ends of the branches (Allred and Lee 1996, Watson and Renney 1974). Bracts of the flower heads (phyllaries) are yellowish with a brownish margin, sometimes spotted, fringed on the sides, and terminating in a slender bristle or spine 1-5 mm (0.04-0.2 in) long (Allred and Lee 1996, Watson and Renney 1974). The heads contain two types of flowers, ray flowers around the edges surrounding tubular disk flowers. The petals are white, rose-purple, to lavender (Allred and Lee 1996, Watson and Renney 1974).

Achenes are 2-3 mm (0.08-0.1 in) long, light brown to black, bristles (pappus) generally absent or a mere fringe less than 1 mm (0.04 in) long (Watson and Renney 1974).

STEWARDSHIP SUMMARY
Centaurea diffusa is one of the most important rangeland weeds in North America (Muller-Scharer and Schroeder 1993). It infests an estimated area of over 1,264,000 hectares in the western United States, and the area infested is increasing an estimated 18 percent per year (Zimmerman 1997). Diffuse knapweed is a highly competitive and aggressive plant that forms dense colonies in pastures, over-grazed rangelands, croplands, and along riverbanks (Zimmerman 1997). It is especially adept at spreading along rights-of-way and farm roads, and can spread rapidly (Allred and Lee 1996). Disturbed or overgrazed lands are prime candidates for colonization, but diffuse knapweed will also invade undisturbed grasslands, shrublands, and riparian communities (although infestations are typically less dense) (Zimmerman 1997).

Diffuse knapweed suppresses other vegetation presumably by intense competition for limited soil water. However, associated grasses that remove moisture and nutrients from the rooting zone of diffuse knapweed (Allred and Lee 1996) can retard its spread through vegetated areas. Other non-native species, such as crested wheatgrass (*Agropyron cristatum*) have been shown to stress, and inhibit, diffuse knapweed invasion by limiting available soil moisture during the critical seedling growth stage (Berube and Myers 1982).

The most effective method for control of diffuse knapweed is to prevent its establishment. In areas already infested with diffuse knapweed, a successful management program should set a goal of reducing knapweed cover and/or density to below impact level on biotic diversity or ecosystem integrity. In some areas, reduction of knapweed to <5% cover may be necessary for adequate control (Muller-Scharer and Schroeder 1993), but in other areas, depending on the natural vegetation, soil types, and ongoing management activities, significant control may be achieved by reducing cover to 5, 10, or even 20%. Areas should be monitored two to three times a year (spring, summer, and fall) and any new rosettes should be destroyed. Established plants or stands of diffuse knapweed can be pulled or spot treated with picloram (Tordon). Burning may be an effective means of controlling *Centaurea diffusa* in areas were seasonal or occasional fires are part of the natural ecosystem (Zimmerman 1997). Crested wheatgrass can be seeded in drier areas to inhibit *Centaurea diffusa* seedlings, but the benefits of replacing one foreign species with another should be analyzed before hand.

At least nine biological control agents that attack *Centaurea diffusa* are established in parts of the United States. Unfortunately, it appears that none of these agents, alone or in combination, effectively controls diffuse knapweed populations. However, they may prove useful in integrated control programs by weakening the plants and/or reducing seed output enough to make the plants more susceptible to herbicides, prescribed fires or other techniques.

***** As a precaution, anyone working with diffuse knapweed or other knapweed species should wear protective gloves and avoid getting knapweed sap into open cuts or abrasions (see NOTE OF CAUTION above the references).*****

IMPACTS (THREATS POSED BY THIS SPECIES)

Centaurea diffusa is a pioneer species that can quickly invade disturbed and undisturbed grassland, shrubland, and riparian communities. Once established, diffuse knapweed outcompetes and reduces the abundance of desirable native species (e.g. perennial grasses). *Centaurea diffusa* contains the allelopathic chemical cnicin, which can suppress the growth of other species and allow diffuse knapweed to grow in single-species stands (Watson and Renney 1974). The densities of these stands can range from 1-500 plants/m^2 (6)[1]. These stands can produce up to 40,000 seeds/m^2, which enables the infestation to proliferate rapidly (Watson and Renney 1974).

On rangeland, diffuse knapweed is generally unpalatable to livestock, and the spines of *C. diffusa* may cause injury to the mouth and digestive tract of grazing animals (Zimmerman 1997). Infestations can greatly reduce dryland forage production with estimated losses of up to 88% in some areas (Harris and Cranston 1979).

On agricultural land, the presence of diffuse knapweed can greatly reduce the value of hay and can decrease the value of the land. Other losses include soil erosion, and reductions in wildlife populations due to the decrease in forage production (Roche and Roche 1988).

Diffuse knapweed is a designated undesirable species in Colorado, a restricted noxious weed in Arizona, a candidate species for the New Mexico noxious weed list, and a designated weed species in Utah (Zimmerman 1997). It is listed as a noxious weed in British Columbia, Manitoba, and Ontario (Watson and Renney 1974).

GLOBAL RANGE

Centaurea diffusa is a native of Asia minor, the Balkans, and the southern portion of the former Soviet Union, especially the Ukraine and Crimea (Zimmerman 1997). Diffuse knapweed is also common in

[1] Internet references from unknown authors have been numbered and can be found under the heading INTERNET REFERENCES (UNKNOWN AUTHORS) at the end of this document.

Romania, the former Yugoslavia, northern Italy, Turkey, Greece, Bulgaria, Syria, and the eastern shore of the Mediterranean (Zimmerman 1997).

Diffuse knapweed was first collected in the U.S. in a Washington state alfalfa field in 1907 and is thought to have been introduced through impure Turkestan alfalfa or possibly hybrid alfalfa seed from Germany (Zimmerman 1997). Diffuse knapweed is now widespread throughout nineteen states, including all of the contiguous states west of the Rocky Mountains (Zimmerman 1997). Idaho, Montana, Oregon, and Washington report the worst infestations (Zimmerman 1997). In western Canada, levels of diffuse knapweed are increasing and roughly 7.5 million hectares appear to be susceptible to knapweed invasion (Harris and Cranston 1979).

HABITAT

Diffuse knapweed is found on plains, rangelands, and forested benchlands, particularly on rugged terrain that is not well suited for cultivation. In the United States, *Centaurea diffusa* is generally found on light, dry, porous soils (6). Diffuse knapweed has a northern limit of 53°N Latitude (Watson and Renney 1974), and has been observed at elevations up to 7,000 feet (Zimmerman 1997).

Diffuse knapweed can thrive in semi-arid and arid conditions which allows it to be a serious problem in the western United States and the arid southwestern interior of Canada, especially British Columbia (Zimmerman 1997). The density of a diffuse knapweed stand is often correlated with the level of soil disturbance. Additionally, diffuse knapweed prefers open habitats to shaded areas (Watson and Renney 1974). *Centaurea diffusa* is not common on cultivated lands or irrigated pasture because it cannot tolerate cultivation or excessive moisture (Watson and Renney 1974).

BIOLOGY-ECOLOGY

Diffuse knapweed plants first form low rosettes and may remain in this form for one to several years depending on environmental conditions. After they reach a threshold size they will bolt, flower, set seed, and die. Seeds germinate in the fall or early spring and moisture appears to be the most limiting factor (Watson and Renney 1974). Seedlings develop into rosettes and maximal root growth occurs during this juvenile period (Watson and Renney 1974). Like many other monocarpic species, diffuse knapweed rosettes may require a suite of chemical changes triggered by low temperatures (vernalization) before they can bolt (Thompson and Stout 1991). Diffuse knapweed rosettes do not respond to vernalization until they have reached a critical size or stage that marks the end of the juvenile period (Thompson and Stout 1991). The end of the juvenile period is better described in terms of developmental stage; typically leaf number, rather than chronological age because this stage may be reached more or less quickly depending on environmental conditions (Thompson and Stout 1991). Thompson and Stout (1991) derived a LN_{50} (leaf number at which 50% bolting is expected) using the lowest temperature and light intensity necessary, to obtain the most reliable estimate of the end of the juvenile period, ending at the formation of the thirteenth leaf. The mean lifespan of diffuse knapweed is two years (Watson and Renney 1974). The lifespan of an individual plant is dependent upon when the seed germinated and how quickly the plant completes its juvenile growth period. If dry conditions prevail after seedling emergence, many seedlings will perish (Watson and Renney 1974). However, mature plants are extremely drought resistant and thrive in arid and semi-arid habitats.

Diffuse knapweed plants that complete their juvenile growth by the fall, and overwinter as rosettes, bolt in early May (Watson and Renney 1974). Plants that have not finished the juvenile stage by the end of fall remain as rosettes through the second year and bolt during the third year. The rosettes usually produce one stem each, rarely two (Watson and Renney 1974).

Flower buds are formed in early June and flowering occurs in July and August (Watson and Renney 1974). Diffuse knapweed is insect pollinated (entomophilous) and, unlike most *Centaurea* species, it is generally regarded as self-compatible (Zimmerman 1997, Watson and Renney 1974). However, Harrod and Taylor (1995) reported that diffuse knapweed was self-sterile (obligately xenogamous) and that the few seeds that were produced autogamously could have resulted from wind blown pollen. Honeybees (*Apis mellifera*), bumble bees (*Bombus bifarius*), and a species of digger bees (*Anthophora* sp.) were the most important flower visitors and none discriminated between flower colors (Harrod and Taylor 1995).

Mature seeds are formed by mid-August (Watson and Renney 1974). A single diffuse knapweed plant can produce up to 18,000 seeds (Harris and Cranston 1979) and a stand of diffuse knapweed can produce up to 40,000 seeds per square meter (Watson and Renney 1974). In one study, open-pollinated, purple-flowered plants set significantly more seed than white-flowered plants (Harrod and Taylor 1995). Schirman (1981) determined that diffuse knapweed seed production was 1,000 fold that necessary to maintain observed levels of infestation. Laboratory germination tests showed up to and sometimes greater than 95% seed viability (Zimmerman 1997, Schirman 1981). These two observations indicate that an extreme reduction of seed production would be needed to control diffuse knapweed.

Diffuse knapweed seeds demonstrate polymorphic germination behavior, which distributes seed germination over time (Nolan and Upadhyaya 1988). Two types of dormant seeds, light-sensitive (50-60% of total), and light insensitive (35-45% of total), and one non-dormant type of seed, (5% of total), were found in diffuse knapweed seed samples (Nolan and Upadhyaya 1988). If moisture is available, the non-dormant seed will germinate in the autumn immediately after dispersal. The two dormant types of seeds do not germinate until spring. Polymorphic seed germination hampers control efforts as diffuse knapweed is able to reinfest pulled or treated sites from dormant seed reserves in the soil.

Seed dispersal for diffuse knapweed is mainly by wind (Watson and Renney 1974). The seeds often remain in the urn-shaped heads even after they mature and break away from the receptacle. Some of heads that are held horizontally open and release seeds in the fall as the plant dries out (Watson and Renney 1974). When the heads sway and whip about in the wind, the seeds fall from the small openings at the top of the heads and are distributed around the parent plant (Watson and Renney 1974). However, most of the heads remain closed until the plant dries up, breaks off at ground level and effectively becomes a tumble-weed, allowing seeds to be individually dispersed over long distances (Zimmerman 1997).

Centaurea diffusa contains an allelopathic chemical, cnicin that prevents other species from establishing allowing formation of pure diffuse knapweed stands (Fletcher and Renney 1963). Cnicin inhibits root growth of other plants, and destroys their ability to compete for limited soil moisture and nutrients. The highest concentrations of cnicin are found in the leaves of diffuse knapweed and the compound may makes its way into the soil by way of leaching or decomposition of leaves or both (Fletcher and Renney 1963). The extent to which the cnicin and plant materials are toxic to their own seeds was not determined as difficulties were encountered in attempting to germinate knapweed seeds (Fletcher and Renney 1963). However, field observations indicate diffuse knapweed seedlings readily develop in close proximity to mature plants (Fletcher and Renney 1963).

RECOVERY POTENTIAL

The recovery potential of areas cleared of diffuse knapweed has not been fully determined. Residual allelopathic chemicals present in the soil may hinder the resurgence of native and non-native annual grasses and forbs, and of native perennial forbs. Also, dormant diffuse knapweed seeds may germinate and reinfest an area that has recently been cleared. Since natural recovery might be slow to develop, replanting with native species, or non-native suppresser species may enhance the recovery of desirable vegetation.

RESEARCH NEEDS

Research is needed to study the field effectiveness of cumulative stress or multiple control procedures, (e.g. several biocontrol species combined with herbicide application) in the field. Certain auxin-type herbicides, like 2,4-D, have been shown to stimulate the effects of some biocontrol insects, by increasing plant protein synthesis, and hence, the availability of nitrogen to the insects (Muller-Scharer and Shroeder 1993). Additional research is needed to determine the most effective combinations of biological control agents and herbicides.

Additional research is needed to determine the recovery potential of areas that have been cleared of diffuse knapweed. Particularly, how quickly will natural communities recover and what can be done to enhance the recovery of natural areas?

MANAGEMENT PROGRAMS

Diffuse knapweed programs on the Tom McCall and Clear Lake Ridge Preserves in Oregon as well as control programs in Washington state indicate that monitoring should be conducted two to three times a year (Dunwiddie 1998, Youtie 1997). Spring and summer searches should be timed to occur after diffuse knapweed has bolted and possibly flowered (to help identification) but before they set seed. Any mature plants should be destroyed immediately. During the autumn search, particular attention should be paid to diffuse knapweed rosettes because they can indicate how dense and widespread the infestation will be the following year. Measures should be taken to document the location and densities of any diffuse knapweed stands or individual plants in order record the rate of spread of the infestation and to know where to look for emerging seedlings and rosettes the following year.

MANAGEMENT PROCEDURES

***** As a precaution, anyone working with diffuse knapweed or other knapweed species should wear protective gloves and avoid getting knapweed sap into open cuts or abrasions (see NOTE OF CAUTION above the references).*****

A successful management program should set a goal of < 5% knapweed cover. This is the assumed density of the weed in its native range (Muller-Scharer and Shroeder 1993). Lasting control will require a combination of proper land management, biological control, physical control, chemical control, and suppression by desirable vegetation. This "cumulative stress" method will keep the plant constantly under stress, reducing its ability to flourish and spread. Also, a cumulative stress approach provides a level of redundancy in case one type of control treatment is missed or ineffective.

An effective management program needs to first control existing infestations, and then develop a land management plan to deter re-infestation. Since diffuse knapweed reproduces entirely by seed, the key to controlling existing infestations is to eliminate new seed production and deplete the existing seed bank. Since diffuse knapweed tends to grow in dense patches, it is relatively easy to locate and conduct spot treatments. If adequate labor is available, and the infested area is relatively small, hand pulling before seed set may be an effective method of control. Tordon (picloram) is the most widely recommended herbicide for treatment of diffuse knapweed (Harris and Cranston 1979, Watson and Renney 1974). 2,4-D, dicamba, and glyphosate are also considered effective (Muller-Scharer and Shroeder 1993, Watson and Renney 1974). Effective, long-term control will be extremely difficult without development of effective biocontrols for diffuse knapweed (Harris and Cranston 1979).

Once the existing infestation has been controlled, steps should be taken to deter any new infestations of diffuse knapweed. Walk through hand pulling or spot herbicide treatment programs should be conducted three times annually for several years to eliminate any seedlings that germinate from seeds that break out of dormancy. In the fall, the number of rosettes can indicate the quantity of diffuse knapweed plants that will bolt the following spring and help determine what type of management effort will be required.

Certain species can act as vegetative suppressants to diffuse knapweed. Two species studied as suppressants are crested wheatgrass (*Agropryon cristatum*) and Russian wild-rye (*Elymus junceus*) (Berube and Myers 1982). Crested wheatgrass showed high rates of suppression while Russian wild-rye showed only moderate rates of suppression (Berube and Myers 1982). Suppression was due to the lack of soil moisture available to diffuse knapweed seedlings. Any suppresser species must grow early in the spring and withdraw moisture from the soil before diffuse knapweed seeds can germinate. However, the effects of introducing one exotic plant to suppress another should be evaluated before it is used as a method of control.

Additionally, since diffuse knapweed has the ability to travel and spread seeds over relatively long distances as a tumble weed, an effort should be made to analyze prevailing winds and infestations on neighboring lands to identify any populations that may pose a threat.

Finally, public awareness should be included in any management program. Diffuse knapweed does not respect boundaries and maintaining a high level of public awareness is important for successful control (Muller-Scharer and Shroeder 1993).

BIOLOGICAL CONTROL

Currently, there is no single biological control agent that effectively controls diffuse knapweed populations. The biological control of weeds is based on the premise that insect feeding kills and/or stresses plants, or reduces seed production, and eventually causes a reduction in weed density (Berube and Myers 1982). Biological controls, which lower the competitive ability of weeds, could also enhance the effectiveness of other control methods. Biological agents rarely completely eliminate the target pest from an area. Complete elimination of the pest would be self-defeating to long-term control as it would lead to the starvation of the agent and leave the area wide open to re-invasion.

The USDA Animal and Plant Health Inspection Service (APHIS) lists twelve biological control agents that are known to attack diffuse knapweed (1). At this time, nine have been established in the United States (Rees *ET al*. 1996). Although many of these agents sharply reduce seed production or inhibit root and shoot growth, none of them has been shown to significantly reduce diffuse knapweed densities.

Currently, there is debate concerning the effectiveness seed-feeding agents versus root-feeding agents (Muller-Scharer and Shroeder 1993). Historically, seed production has been used as a measure to monitor the impact of biocontrol agents. However, reductions in seed output will only lead to reduced densities if seedling recruitment is seed-limited (Muller-Scharer and Shroeder 1993). Diffuse knapweed seed production was determined to be 1,000 fold that necessary to maintain equilibrium levels of infestation (Schirman 1981). Hence, even a 95% reduction in seed production may not reduce plant density or cover. A release of three seed-feeding agents in British Columbia supports this hypothesis. Although these insects brought about a drastic decline of seed production, there was no change in plant density (Muller *et al*. 1988). This suggests that agents that feed on the roots of diffuse knapweed may play a greater role in reducing stand densities.

The following biological control information is abstracted from *Biological Control of Weeds in the West* (Rees *et al.,* 1996) unless otherwise noted.

Agents that reduce seed production

Urophora affinis (banded gall fly)

Urophora affinis is a seed head feeding fly native to Europe and western Asia, and is now established California, Idaho, Montana, Oregon, Utah, and Washington. Adults are 4 mm (0.16 in) long, black, and have faint horizontal bands on the wings. Eggs are deposited during summer in the immature knapweed seed-heads, inducing the plants to form galls. Larvae feed on the nutritive cell lining of the gall chamber. Pupation occurs within the gall during late May. Adults are active during June and July when flower buds are forming. This species is widely distributed through knapweed-infested areas of the northwestern United States and can reduce seed production by up to 95% (Rees *et al*. 1996).

Urophora quadrifasciata (UV knapweed seed head fly)

Urophora quadrifasciata is a seed-head-feeding fly native to Eurasia and is currently established in Idaho, Montana, Oregon, Utah, and Washington. Adults are 4 mm (0.16 in) long, black, and have distinctive dark bands forming a “UV” pattern on each wing. Eggs are deposited during the summer in the bracts of developing flower buds. Larvae feed and develop in the maturing seed heads. Pupation occurs within papery galls formed by the plants. First- generation adults can be found from spring until early summer, while second-generation adults live from late summer until fall. This species can reduce knapweed seed production by up to 95% (Rees *et al*. 1996).

Bangasternus fausti (broad-nosed seed-head weevil)
Bangasternus fausti is a seed-head-feeding weevil native to northern Greece that is now established in Montana, Oregon, and Utah. Adults weevils are grayish-black, 3.5 to 4.0 mm (0.14 to 0.16 in) long. They deposit eggs on the seed head bracts or the ends of stems and leaflets from May to mid-August. The new larvae mine directly into the young seed-heads and feed within them, or they enter the stems and then tunnel into the buds. The larvae pupate within cells in the damaged seed-heads. Adults overwinter in the seed heads and are active from May until late July. Larvae consume up to 95% of the seeds in a head (Rees *et al*. 1996).

Chaetorellia acrolophi (knapweed peacock fly)
Chaetorellia acrolophi is a seed-head-feeding fly native to Switzerland, northeastern France, eastern Austria, Hungary, and Romania and is now established in Montana and Oregon. Adult flies are orange-yellow with some spotting on the thorax and abdomen, 4 to 5 mm (0.16-0.2 in) long, and have clear wings with brown bands. They deposit eggs underneath the bracts of unopened buds. The larvae of this species go through three stages. The first-instar larvae burrow horizontally through the bracts into the center of the bud. They feed on immature florets and move downward to the seeds. The second- and third-instar larvae feed on the developing seeds, florets, and partly on the receptacles. The pupae lie vertically between the florets, and adults are present from mid-May until mid-November depending on climatic conditions.

Larinus minutus (lesser knapweed flower weevil)
Larinus minutus is a seed eating weevil native to Greece, and now established Montana, Oregon, and Washington. Adult weevils are 4 to 5 mm (0.16 to 0.2 in) long, black, and have a large snout. They deposit eggs in the unopened seed-heads between the pappus hairs from June to September. The larvae feed on pappus hairs and move downward to the seeds. Each larva constructs a cocoon and pupates within it. Adults are active in the field from May until August and will feed on leaves and flowers prior to laying eggs. Adults generally live up to fourteen weeks.

Agents that reduce plant biomass/productivity

Agapeta zoegana (sulfur knapweed moth, yellow-winged knapweed root moth)
Agapeta zoegana is considered a promising control agent for diffuse knapweed (Muller-Scharer and Shroeder 1993). It is established in British Columbia, Montana, Oregon, and Washington, with high rates of rosette attack at a few sites and first signs of reduction in knapweed densities (Muller-Scharer and Shroeder 1993). Adults are about 11 mm (0.44 in) long and have bright yellow wings with brown markings. Eggs are laid on the surface of stems and leaves of the host plant, generally in crevices. Upon hatching, the larvae migrate immediately to the crown area and mine into the root. Pupation and the overwintering generation occur within the damaged roots. Adults emerge the next summer between mid-June and mid-August. Females mate within 24 hours of emergence and lay eggs one day later. Adults live up to 11 days. Feeding by the young larvae often kills small plants and prevents many of the larger plants from flowering.

Sphenoptera jugoslavica (bronze knapweed root-borer)
Sphenoptera jugoslavica is a root-mining moth native to Greece, now established in California, Idaho, Montana, Oregon, and Washington. Adults are 8 to 10 mm (0.3 to 0.4 in) long, somewhat flattened, metallic dark reddish-brown. Eggs are deposited between appressed petioles of diffuse knapweed rosette leaves in July and August. Larvae enter the petiole and mine down to the taproot where they overwinter. They pupate within the upper part of the root for 15-21 days beginning sometime between mid-May and early June, depending on the climate. Adults normally emerge in July and feed externally on the leaves of diffuse knapweed. Feeding by the larvae depletes root carbohydrate reserves and stops rosette growth.

Pterolonche inspersa (grey-winged root moth)

Pterolonche inspersa is a root-mining moth native to Austria, Greece, and Hungary, and is now established in Montana. Adults are 8.2 mm (0.33 in) long, with a 1.9 to 2.5 cm (0.76 to 1.0 in) wingspan, white to dusky brownish-grey. Eggs are deposited in the summer on the lower leaf surface. Larvae feed down the root and spin webs to cover the area where they are feeding. Pupation occurs from early to mid-July. Adults emerge in late July.

Cyphocleonus achates (knapweed root weevil)
Cyphocleonus achates is a root weevil native to Austria, Greece, Hungary, and Romania, and now established in Colorado, Montana, Oregon, and Washington. Adult weevils are 14 to 15 mm (0.56 to 0.6 in) long. They females deposit eggs in notches they excavate on the root crowns, just below the soil surface. Immediately after hatching the larvae mine towards the cortex of the root. There are four larval instars. The second-instar larvae overwinter and the third- and fourth-instar larvae cause gall-like enlargements in the roots. Feeding by the older larvae can cause considerable damage to the root systems. The pupal period lasts about two weeks and occurs within the galled root. Adults generally live eight to fifteen weeks.

Contacts for more information on the biocontrol agents described above:

- Eric M. Coombs: Oregon Department of Agriculture, 635 Capitol St. NE, Salem, OR 97310; telephone: (503) 986-4624; e-mail: ecoombs@oda.state.or.us

- Gary L. Piper: Department of Entomology, Washington State University, Pullman, WA 99164-6382; telephone: (509) 335-5504; e-mail: glpiper@wsu.edu

Pathogens
Two fungi that attack diffuse knapweed are being studied but are not yet cleared as biocontrol agents or for movement across state lines.. *Puccinia jaceae* attacks the leaves of diffuse knapweed, while *Sclerotinia sclerotiorium* attacks the root crowns.

Obtaining federal permits for field releases
To introduce one of the biological agents described above into your state, you must first obtain a permit from the USDA-APHIS-PPQ. To obtain a permit you must complete a form PPQ-526, "Application and Permit to Move Live Plant Pests or Noxious Weeds", and send the application to the Department of Agriculture in the state that the release is to be made. The form must be signed and sent for processing to the USDA-APHIS-PPQ office, Biological Assessment and Taxonomic Support (BATS), 4700 River Road, Unit 113, Riverdale, MD 20737. When this is signed by PPQ, a copy will be returned to the applicant as an approval record.

To find the phone number and address of the APHIS-PPQ State Plant Health Office in your state check on-line at: (http://www.aphis.usda.gov/oa/ppqoffice.html). For more information about the permit process, to download forms, check the status of your permit, or to search the Code of Federal Regulations, you can browse the APHIS-PPQ home page at: (http://www.aphis.usda.gov/ppq/bats/permits/). Finally, an expedite list of all insects, mites, and nematodes that require APHIS permits can be found on-line at: (http://www.aphis.usda.gov/ppq/bats/weedagen.htm).

Obtaining permission to release biological control agents on TNC land
TNC policy prohibits intentional releases of non-indigenous biological control agents on conservation lands that they own and/or manage. However, exceptions allowing releases on individual preserves may be approved by the Director of the Conservation Science Division. This policy is designed to ensure non-indigenous biocontrol agents are used only when the potential benefits clearly outweigh the risks that they may attack and damage non-target native species populations.

A formal proposal must be submitted first to the Weed Specialist (John Randall) who will evaluate it and make a recommendation to the Director of Conservation Science. The proposal must address questions about the benefits and risks of the release, including how the agent was tested for host-specificity, whether it has been shown to reduce populations of the target pest in the field, and how impacts of the proposed release will be monitored. Contact TNC's Weed Program (530.754.8890 or jarandall@ucdavis.edu) for details on the scope of the proposal and assistance in preparing it.

BURNING

Burning has been shown to be an effective control of diffuse knapweed with strong grass regrowth occurring on burned sites (Zimmerman 1997, Watson and Renney 1974). Within two years of burning, most diffuse knapweed rosettes were eliminated (Zimmerman 1997).

A low-severity fire may only top-kill diffuse knapweed, but a severe fire will probably kill the plant (12). Dry soil conditions associated with burns may discourage diffuse knapweed re-infestation as moisture is the limiting factor for diffuse knapweed seed germination (12). Re-seeding desirable species may be necessary following burns to deter re-infestation by diffuse knapweed or other exotic species.

CHEMICAL

Several herbicides are relatively effective at controlling diffuse knapweed. Tordon (picloram) is the most widely recommended (Harris and Cranston 1979, Watson and Renney 1974). Other effective herbicides include dicamba, 2,4-D, and glyphosate (Beck 1997, Youtie 1997, Watson and Renney 1974). To save money and reduce grass injury resulting from higher use rates of a single herbicide, several of these herbicides can be combined (Beck 1997). Tank-mixes of picloram and dicamba (0.25 to 0.5 lb./acre + 0.125 to 0.25 lb./acre), picloram plus 2,4-D (0.188 lb./acre + 1.0 lb./acre), and dicamba plus 2,4-D (0.5 lb./acre + 1.0 lb./acre) all control diffuse knapweed (Beck 1997). A backpack sprayer or a wick is highly recommended in small areas to minimize damage to non-target plants. Herbicides should be applied before the mature plants set seed to maximize effectiveness.

Picloram

Trade name(s): Tordon

Picloram applied at a rate of 0.5 to 1.0 qt/acre (0.25 to 0.5 lb./acre) is currently recommended for the control of diffuse knapweed (Owsley 1998, Beck 1997). On semi-arid rangeland sites in the interior of British Columbia, picloram provided selective control of diffuse knapweed for 3 to 4 years (Watson and Renney 1974). However, a waiting period of 6 to 12 months before reseeding is recommended because picloram is detrimental to root growth in grass seedlings (Harris and Cranston 1979).

Picloram is an auxin-type herbicide that induces effects similar to an overdose of the plant hormone auxin. It can be used for control of a variety of broad-leaved plants. Like other auxin-type herbicides, picloram is an organic acid that takes on a negative charge after ionization of acids and salts. Esters are hydrolyzed to acids or salts in both plants and soils (Ross and Childs 1998)

Picloram does not bind to soil and may leach into groundwater. The half-life of picloram in soil ranges from 55 (warm/wet climates) to100 (cool /dry climates) days (2). The half-life of picloram in water is 2.3-41.3 days (2). Picloram is not expected to bioconcentrate in aquatic organisms.

In humans, the EPA has found that acute exposures to picloram could cause weakness, diarrhea, weight loss, and central nervous system damage. Long-term exposure above safe drinking water levels has the potential to cause liver damage(2).

Although picloram is effective against diffuse knapweed, it is a relatively non-selective compound and has been observed to have a residual effect on other perennial broad-leaved plants. If used, it should be applied carefully to minimize damage to non-target plants.

Dicamba

Trade name(s): Banvel, Clarity, Vanquish, and Veteran

Dicamba at rates of 0.5 to 1.0 lb./acre (0.5 to 1.0 qt/acre) provided effective control of diffuse knapweed (Beck 1997). Dicamba can also be mixed with 2,4-D for spot treatments of diffuse knapweed (Beck 1997, Youtie 1997). Dicamba is used to control annual and perennial broad-leaved plants in grain crops, grasslands, pastures, and rangeland (4). However, dicamba should not be used alone when diversity is the goal, as it has a tendency to eliminate all broadleaved species leaving only grasses (Owsley 1998).

Dicamba does not bind to soil and may leach into groundwater. It has a typical half-life of 1-4 weeks in soil (4). Dicamba does not bioconcentrate in aquatic organisms, and is broken down mainly by microbial degradation in aquatic systems.

When used according to instructions, dicamba poses little threat to wildlife. Dicamba is considered only slightly toxic to birds, and is of low toxicity to fish and aquatic organisms. Dicamba is not toxic to bees.

In humans, acute exposure to dicamba is moderately toxic by ingestion and slightly toxic by inhalation and dermal exposure. Symptoms of poisoning with dicamba include loss of appetite, vomiting, muscle weakness, slowed heart rate, shortness of breath, central nervous system effects, and exhaustion following repeated muscle spasms (4).

Like picloram, dicamba is an auxin-type herbicide. It is a relatively non-selective compound and has a residual effect on other broad-leaved plants.

2,4-D
Trade name(s): Weedtrine-II, Aqua-Kleen, Barrage, Plantgard, Lawn-Keep, Planotox, Malerbane, and many others

Several tests indicated 2,4-D at 1.0 and 1.5 kg/ha completely controlled stands of diffuse knapweed (Watson and Renney 1974). However, that control proved to be temporary and did not prevent heavy seedling establishment the following year (Watson and Renney 1974). When a combination of 2,4-D and dicamba was used on the Clear Lake Ridge Preserve in northeastern Oregon, it reduced the infestation enough so that hand pulling two to three times a year was adequate to control the spread of diffuse knapweed on the preserve (Youtie 1997).

Like picloram and dicamba, 2,4-D is an auxin-type herbicide that can be used to control many types of broad-leaved plants (3). It does not kill grasses. 2,4-D can be taken up by plant leaves, stems, and roots. It is used in cultivated agriculture, pastures, rangeland, forest management, gardens, and for control of aquatic vegetation (3). 2,4-D kills many species of broad-leaved plants, and the effects that it will have on non-target species should be evaluated before it is used.

2,4-D does not bind well to soil particles and is listed as a chemical that will likely leach from soil. The half-life of 2,4-D in the soil ranges from 7-16 days (3). In aquatic environments, microorganisms readily degrade 2,4-D. The half-life of 2,4-D in water can range from one to several weeks depending on the temperature and oxygen concentration in the water (3).

2,4-D is slightly toxic to wildfowl, and some formulations are highly toxic to fish (3).
Additionally, moderate doses severely impaired the brood production of honeybees (3). In humans, symptoms of 2-4, D poisoning can be fatigue, weakness, and nausea.

Glyphosate
Trade name(s): Roundup Ultra, Rodeo, Accord

Glyphosate was wiped on diffuse knapweed plants near a creek on the Clear Lake Ridge Preserve in northeastern Oregon with successful results (Youtie 1997). However, glyphosate will only provide control during the year of application, and will not kill seeds or inhibit germination the following season.

Glyphosate inhibits production of the aromatic amino acids tryptophan, tyrosine, and phenylalanine in plants. It is a non-selective compound and kills both broad-leaved plants and grasses. Thus, glyphosate will kill or damage non-target plants. To minimize damage to non-target plants glyphosate can be applied directly to the leaves of diffuse knapweed and other targeted plants with a hand-held sprayer or wick applicator. Glyphosate is rapidly inactivated upon contact with soil or muddy water because it binds tightly to clay particles (Ross and Childs 1998). Therefore it must be applied to living leaves or stems.

Glyphosate biodegrades in soil and has a half-life of about 60 days. The half-life in water is a few days, and it is not expected to bioconcentrate in aquatic organisms (5).

In humans, acute exposure to glyphosate can cause lung congestion and an increased breathing rate. Long-term exposure to glyphosate above safe levels has the potential to cause kidney and reproductive system damage (5).

Additional information on chemical control

More information on chemical control of diffuse knapweed can be obtained from the Weed Management Library at 1-800-554-WEED, or from your State Weed Specialist.

Arizona: Everett Hall: Arizona Department of Agriculture, Plant Services, 1688 West Adams, Phoenix, AZ 85007; telephone: (602) 542-3309; e-mail: adaphyx18@getnet.com

California: Joseph DiTomaso: University of California Davis, 210 Roberts Hall, University of California, Davis, CA 95616-8746; telephone: (916) 754-8715; e-mail: ditomaso@vegmail.ucavis.edu

Colorado: Dr. George Beck (weed control specialist): Colorado State University, C 120 Plant Sciences Building, Fort Collins, CO 80523-6021; telephone: (970) 491-7568; e-mail: gbeck@lamar.colostate.edu

Idaho: Dr. Robert Callihan: University of Idaho, AS 317 General Services, Moscow, ID 83844-2339; telephone: (208) 885-6617; e-mail: bccallihan@uidaho.edu

Montana: Harrold Stepper (weed control specialist): Montana Department of Agriculture, P.O. Box 200201, Helena, MT 59620; telephone: (406) 444-5400

New Mexico: Dr. Richard Lee (weed control specialist): New Mexico State University, Extension Plant Services, Box 30003, Department 3AE, Las Cruces, NM 88003; telephone: (505) 646-2888; general e-mail: crops@nmsu.edu

Oregon: Tim Butler: Oregon Department of Agriculture, Noxious Weed Control Program, 635 Capitol St. NE, Salem, OR 97310-0110; telephone: (503) 986-4625; e-mail: tbutler@oda.state.or.us

Utah: Dr. Steve Dewey (Extension weed specialist): Utah State University; Plants, Soils, and Biometeorology Department; Logan, UT 84322-4820; telephone: (801) 750-2256; e-mail: steved@ext.usu.edu

Washington: Greg Haubrich (state weed specialist): Washington Department of Agriculture, 2015 South 1st St., Yakima, WA 98903; telephone: (509) 576-3039; e-mail: ghaubrich@agr.wa.gov

Wyoming: Dr. Tom Whitson (weed science specialist): University of Wyoming, Department of Plant Science, P.O. Box 3354, Laramie, WY 82071-3354; telephone: (307) 766-3113; e-mail: twhitson@uwyo.edu

CUTTING

Cutting, or removing the above ground portion of the plant, before seed set may be an effective way to reduce seed production, but it will not eliminate diffuse knapweed infestations. Cut plants can sometimes survive and bolt again (C. Owsley personal communication) or may produce flowers and set seeds at the cut height (Jepson 1995). In addition, the seeds may remain dormant for several years. Cutting the rosettes is very difficult because they are close to the soil surface. Volunteers at the Tom McCall preserve in northern Oregon had to dig rosettes by hand in order to remove them (Youtie 1997). However, a long-term program in which only bolted plants are cut for several consecutive years can sharply reduce numbers and cover of diffuse knapweed.

GRAZING, DREDGING, AND DRAINING

Grazing is not an effective control method for diffuse knapweed. Diffuse knapweed is generally unpalatable to livestock, and the spines around the flowerheads may injure the mouths and digestive tracts of grazing animals (Zimmerman 1997). Additionally, the ground disturbance created by grazing creates ideal habitat for knapweed infestation. Effective grazing management is necessary to reduce knapweed in pastures and rangelands.

We found no reports indicating dredging or draining have been tested, or would be effective control measures for diffuse knapweed.

MANIPULATION OF WATER LEVEL AND SALINITY

Diffuse knapweed does not tolerate flooding or irrigation (Zimmerman 1997, Harris and Cranston 1974). Therefore, periodic flooding may reduce knapweed infestations on cultivated land.

Manipulation of salinity levels has some affect on diffuse knapweed. A study conducted by Kiemnec and Larson (1991) concluded knapweed root growth was reduced by an initial increase in salinity (4 dS m^{-1}), but not by higher salt concentrations.

MOWING, DISKING, AND PULLING

***** As a precaution, anyone working with diffuse knapweed or other knapweed species should wear protective gloves and avoid getting knapweed sap into open cuts or abrasions (see NOTE OF CAUTION above the references).*****

Zimmerman (1997) reported that mowing actually increased populations of diffuse knapweed. Mowing can severely damage or disturb surrounding vegetation and may make the area more susceptible to knapweed infestations.

Deep plowing may be an effective measure of control on agricultural lands as diffuse knapweed seeds do not germinate below 3 cm of soil (Zimmerman 1997, Watson and Renney 1974). However, shallow plowing actually increased the amounts of diffuse knapweed in test plots (Zimmerman 1997, Watson and Renney 1974).

Hand pulling diffuse knapweed plants before they set seed each year may provide effective control. For example, diffuse knapweed densities were reduced by 97% on TNC's Tom McCall preserve in northern Oregon by volunteers who hand pulled the mature plants and dug up rosettes every year for five years (Youtie 1997). Hand-pulling can also be used to maintain or further reduce low knapweed densities brought about by herbicide treatments as was done at TNC's Clear Lake Ridge Preserve in northeastern Oregon(Youtie 1997).

Hand pulling should be conducted three times annually (spring, summer, and late summer) to capture as many plants as possible. Pulling should be conducted before seed set, and if seeds have formed in the flower heads, the plants should be bagged to keep the seeds from spreading.

Although hand pulling has been effective in some areas, it failed to provide adequate control in others. A hand-pulling experiment on City of Boulder (CO) Open Space land failed to provide control. Five meter by twenty-five meter test plots that were hand pulled twice annually for three years had knapweed densities nearly equal to those in adjacent plots where the knapweed was not pulled (A. Carpenter, personal observation). Although some of the reinfestation was a product of the existing seed stock in the soil, seeds spread from plants in neighboring unmanipulated plots seemed to play an important role in the reinfestation of diffuse knapweed. This suggests that clearing small areas within a larger area populated by knapweed may not provide adequate control.

Hand pulling programs should be repeated annually for as long as diffuse knapweed is a problem in the surrounding area. Seeds in the soil may remain dormant for several years and an area can become quickly reinfested. Also, the “tumble weed” nature of diffuse knapweed allows it to distribute seed over a large area. A few rogue knapweed plants can quickly destroy years of hard work if left undetected. However, hand pulling can lead to significant reductions in knapweed populations and the labor required to maintain control should decrease over the years.

NOTE OF CAUTION:
As a precaution, anyone working with diffuse knapweed or other knapweed species should wear protective gloves and avoid getting knapweed sap into open cuts or abrasions. Workers should wash their hands and exposed skin with soap and water following contact with this plant. An e-mail message widely broadcast to land managers around the nation in September 1997 (Niefoff 1997, detailed below) indicated several knapweed species may contain a cancer causing compound. It is difficult to determine the veracity of this report and an extensive search for mention of this compound or any cancer-causing properties of knapweeds in the medical and other scientific literature failed to turn up anything.

Jerry Niefoff (1997) of the Idaho Panhandle National Forest sent a broadcast e-mail message reporting that he had gotten knapweed sap rubbed directly into a abrasions on his right pinkie and ring finger while pulling the plants and later developed a lump in his pinkie. The lump persisted and grew and so he had it removed by a surgeon who said it was a “very aggressive benign tumor”. Niefoff reported that a month or two later the tumor re-appeared and he had it removed again. After the second surgery, the tumor started to spread towards the hand, so the surgeon removed Niefoff’s right pinkie. Shortly after the removal of his little finger, a tumor developed in his ring finger so he visited the cancer Center at the University of Washington. Several surgeries failed to eliminate the tumor so his right ring finger was eventually removed too. Niefoff reports that the tumors were all in the tendon sheaths of his fingers could not be treated with chemotherapy or radiation, only physical removal. He reported that two and a half years after the removal of his ring finger the tumor no other problems had appeared in his other fingers or hand. Niefoff reported that a doctor at the University of Washington told him a compound that is cancer causing had been isolated from Russian knapweed and probably occurs in spotted and diffuse knapweed also.

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