Integrated Pest Management Methods for Control of Invasive Exotic Plant Species at Midewin National Tallgrass Prairie

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Prepared for the
Illinois Department of Natural Resources
by Ecological Services
Urbana, Illinois

1997

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Acknowledgments

This report was prepared under contract with the Illinois Department of Natural Resources. Francis Harty administered the contract. Lawrence Stritch and Eric Ulaszek of the U.S. Forest Service and William Glass of the Illinois Department of Natural Resources oversaw the effort.

The project was completed by Ecological Services (904 South Anderson Street, Urbana, Illinois 61801). Connie Carroll reviewed the literature regarding control methods and wrote the integrated pest management accounts. Lisa Bell and Beverly Miller assisted greatly by searching for literature and compiling information. Carol Bullard helped prepare documentation. John White wrote the introduction and edited the report.

Introduction

This report discusses methods for controlling 22 species of invasive exotic plants at Midewin National Tallgrass Prairie. These exotic plants are non-native species that are prone to invade and persist in natural plant communities or in areas that are being restored to native vegetation. These invasive exotic species are liable to alter the character of native vegetation or interfere with efforts to reestablish native plants.

Integrated Pest Management

Integrated pest management (IPM) emphasizes the control of unwanted species based on an understanding of the ecology of the species and the natural community in which it occurs. [1] Most definitions of IPM are tailored to agricultural or economic interests; a representative definition states that IPM is "the use of multiple tactics in a compatible manner to maintain pest populations at levels below those causing economic injury while protecting against hazards to humans, domestic animals, plants, and the environment." [2] A statement in *Introduction to Integrated Pest Management* is more germane to Midewin National Tallgrass Prairie:

> IPM uses a system approach to reduce pest damage to tolerable levels through a variety of techniques, including natural predators and parasites, genetically resistant hosts, environmental modifications and, when necessary, chemical pesticides. IPM strategies generally rely first upon biological defenses against pests before chemically altering the environment. [3]

Integrated pest management calls for a) an understanding of the biology of the pest species, particularly phases of its life cycle when it is most vulnerable to control measures, b) an emphasis on natural processes rather than artificial means of control, and c) use of a variety of control measures rather than relying on a single approach. IPM

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[1] For a discussion of integrated pest management in the context of natural ecosystems, see "IPM: A Review for Natural Area Managers" by J.E. Evans and M. Heitlinger (*Restoration & Management Notes* 2:18-22).

[2] Norris, R.F. 1982. Interactions between weeds and other pests in the agro-ecosystem. P. 343-406 *in*: J.L. Hatfield and I.J. Thomason (eds.). *Biometeorology in Integrated Pest Management*. Academic Press, New York.

[3] Flint, M.L., and R. van den Bosch. 1981. *Introduction to Integrated Pest Management*. Plenum Press, New York.

relies on a) early detection and control, b) continual monitoring to assess the effectiveness of control efforts, and c) flexibility in the choice of methods.

At Midewin National Tallgrass Prairie, many exotic weeds will be reduced when native vegetation is restored and natural ecological processes are re-introduced. These natural processes include competition from native vegetation, grazing by native herbivores, and prescribed burning. Control of many invasive species will result as habitats are restored. For example, garlic mustard grows in pastures beneath trees and in hedgerows; when the trees are removed, garlic mustard will be eradicated from these tracts.

The current infestation levels of many exotic plants at the National Tallgrass Prairie are regulated by farming. Agricultural practices suppress some weed species and foster others. When cultivation, haying, or livestock grazing are phased out on a particular tract, some weeds may decline while others may increase at least temporarily. For instance removal of cattle from a pasture may stimulate an increase in white sweet clover; but with management to restore a native grassland community, competition from grasses is likely to eventually crowd out the sweet clover in most situations.

IPM and the Infestation Severity Scale

The infestation severity scale is a ranking system developed to help set priorities for implementing IPM measures at Midewin National Tallgrass Prairie. The severity of an infestation is characterized by four factors:

(1) The *invasive nature* of the species: How bad is the weed?

(2) The *size* of the infestation: How big is this infestation?

(3) The *level* of the infestation: How bad is this infestation?

(4) The *sensitivity* of the habitat: How careful must the manager be when controlling this infestation?

These factors are discussed under the next four headings.

(1) *Invasive Nature* of the Species

Some species are by nature more invasive than others. All 22 species addressed in this report are quite invasive, but some are more pernicious than others. The invasiveness of a species depends on its biology and autecology; traits that come into play include the species' reproductive rate, competitive ability, and resistance to pests.

These invasive characteristics relate to the nature of a *species* as a whole, independent of the nature of any particular infestation. A weedy species' invasive character indicates the *potential* for problems: "How likely is this species to become a much bigger problem if it is not controlled soon?"

For the exotic weeds treated in this report, their invasive nature is denoted with a three-part scale:

A Extremely invasive
B Very invasive
C Invasive

See the companion report, *Invasive Exotic Plant Species at Midewin National Tallgrass Prairie: Survey Methods and Results* for ratings of the invasive nature of each of the 22 species treated by this project.

(2) *Size* of the Infestation

An infestation is measured in terms of its areal extent (acreage).

(3) *Level* of the Infestation

Among populations of a particular invasive exotic species, some infestations are more severe than others. The level of infestation for each species in each patch or infestation has been rated with a three-part relative scale:

1 Heavy
2 Medium
3 Light

A heavy infestation typically has robust individuals, is reproducing well, and is competing well with the surrounding vegetation. Such a population generally has a high density and coverage, or it exhibits the potential for a rapid increase in numbers. A medium infestation exhibits less severity in terms of its vigor. A light infestation may even be declining. Definitions for the three levels of infestation for each of the 22 exotic species are given in the accompanying volume, *Invasive Exotic Plant Species at Midewin National Tallgrass Prairie: Survey Methods and Results*.

(4) *Sensitivity* of the Habitat

Some weed infestations at the National Tallgrass Prairie are more serious than others because they are in or near sensitive habitats. These environments include a) native vegetation, b) wetlands, c) highly erodible soil, and d) other special features, determined on a case-by-case basis (such as the habitat of an endangered plant). If an infestation is in such a habitat, it is denoted as *sensitive*.

Controlling invasive weeds in sensitive habitats and on immediately adjacent land is a priority to a) protect the sensitive features, and b) deter further spread of weeds into an environment where control must be done with extra care (making some control measures difficult or impossible to apply).

Application of the Infestation Severity Scale

The infestation severity scale can be used to help set priorities for controlling infestations and to help select appropriate control methods.

Invasive nature of the species. Among other considerations, priority should be given to controlling the most invasive species (those rated A according to their invasive character).

Size of the infestation. The choice of control methods will be influenced by the extent of the area occupied by the weed. Some small patches and individual plants can be most expediently eliminated by hand-pulling. Extensive infestations may be practical to control by other means such as a program of prescribed burning.

Level of infestation. The vigor, density, and coverage of an invasive plant should be considered when selecting the kind of control method. A heavy infestation may require intensive control measures. For instance although honeysuckle may be partially controlled by burning, a dense stand of honeysuckle will not have enough fuel on the ground to carry a fire. In this case it may be necessary to cut the honeysuckle and open the ground to sunlight before the area can be burned. A light infestation may call for less drastic control measures.

Sensitivity of the habitat. The presence of sensitive features will affect the choice of control measures. For instance some herbicides are not licensed for use over open-water areas.

Species Accounts

The following pages review methods for controlling 22 kinds of exotic plants that are among the most serious invasive species at Midewin National Tallgrass Prairie. Each species is discussed under five main headings: *introduction*, *habitat*, *life history*, *control methods*, and *references cited*. Control methods are organized according to four categories: *mechanical*, *chemical*, *biological*, and *burning*. A fifth category—*combined methods*—appears in several of the treatments.

Information for control of problem species was taken from published accounts (articles, books, pamphlets, etc.). New methods for controlling problem species are continually being researched and tested. Many land managers work to develop environmentally safer methods for applying herbicides and other methods to control undesired species in natural areas. Land managers may have developed but not yet publicized successful control methods.

Much information concerning control of invasive exotic plants appears in the *Management Guidelines for Illinois Nature Preserves*. [4] The majority of these guidelines have been published in the *Natural Areas Journal* and have been reprinted by the Natural Areas Association. [5] A chapter summarizing these exotic vegetation guidelines appears in the recently released *Tallgrass Restoration Handbook*. [6]

The species accounts do not prescribe the single best set of methods for controlling each target species at Midewin National Tallgrass Prairie. The accounts review techniques that have been used successfully or unsuccessfully by land managers. The most appropriate approach for each species should be based on the current situation and on-site decisions, and should incorporate factors such as a) management and use objectives for each tract and for the site as a whole, b) the available time frame, and c) monetary considerations. The response of each species to ongoing control measures will help indicate the most appropriate course of action.

Each species should be correctly identified before any control measures are initiated.

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[4] Illinois Nature Preserves Commission. 1990. *Management Guidelines for Illinois Nature Preserves*. Springfield.

[5] Natural Areas Association. 1992. *Compendium on Exotic Species: Articles* 1-43. Mukwonago, Wisconsin.

[6] Solecki, M.K. 1997. Controlling invasive plants. P. 251-278 *in*: S. Packard and C.F. Mutel (eds.). *The Tallgrass Restoration Handbook.* Island Press, Washington, D.C.

INTEGRATED PEST MANAGEMENT FOR

GARLIC MUSTARD, *Alliaria petiolata* (M. Bieb.) Cavara & Grande

INTRODUCTION

The first North American record of garlic mustard (*Alliaria petiolata*) was in 1868 on Long Island, New York (Nuzzo 1993). Garlic mustard was first collected in Illinois in 1918 at Ravinia in Lake County (Nuzzo 1993). By 1991 it was documented in 44 Illinois counties. The greatest abundance occurs in the northern and central counties, with a few occurrences in southern Illinois (Nuzzo 1993). Data from Nuzzo (1993) indicate that the spread or detection of garlic mustard was still on the increase as of 1991. Garlic mustard aggressively invades natural areas and can dominate the ground layer. It often grows to the exclusion of other herbaceous species (Cavers et al. 1979; Nuzzo 1990; Nuzzo et al. 1991; Swink and Wilhelm 1994).

The mode of garlic mustard's entry into Illinois is unknown, but was most likely related to human activity. Garlic mustard was historically used as an herb and a medicinal plant in Europe (Grieve 1959), and it may have been brought into North America for these uses (Cavers et al. 1979).

HABITAT

Garlic mustard occurs in a variety of habitats in Illinois. It most often invades shaded, moist areas that have some level of disturbance, such as floodplain forests. It also occupies upland forests, savannas, shaded roadsides, and idle grounds (Nuzzo 1990, 1993; Nuzzo et al. 1991; Cavers et al. 1979). Garlic mustard can grow in dense shade (Nuzzo 1990; Nuzzo et al. 1991).

LIFE HISTORY

Garlic mustard is a member of the Brassicaceae (mustard family). It is a biennial, so it completes its life cycle in two growing seasons. Seeds germinate early in the growing season, beginning in late February or early March (Cavers et al. 1979; Baskin and Baskin 1992; Nuzzo 1994*a*). Germination in northern Illinois coincides with the emergence of spring beauty (*Claytonia virginica*) and false mermaid (*Floerkea proserpinacoides*) (Nuzzo 1994*a*). Cavers et al. observed that most seedlings in Canada emerge in late March, during a warm period and after a heavy rain. Flushes of emergence can occur after rainstorms in April, May, and June.

Seedlings develop basal rosettes in the first season (by June), overwinter, then send up a flowering stalk in the following May to June (Cavers et al. 1979; Nuzzo 1990, 1994*a*; Nuzzo et al. 1991). Plants usually produce one to two flowering stems, but as many as 10 to 12 stems may be produced (Nuzzo 1990, 1994*a*). Adults range in height from 2 to 48 inches (5 to 125 cm) (Nuzzo 1990). Each stalk produces numerous white, four-petalled flowers.

Garlic mustard reproduces readily and exclusively from seed (Cavers et al. 1979). The fruit of garlic mustard is a silique, which is a slender, linear capsule. Fruit production varies widely and can range from one or two siliques on smaller plants, up to 120 to 150 siliques on larger plants (Cavers et al. 1979). Each silique averages about 16 to 24 seeds (Lhotská 1975; Cavers et al. 1979). Nuzzo (1994*a*) found that plants produce an average of 360.5 seeds, but this can range from 194.3 to 608.2 depending on the habitat and growing conditions. Seed production is estimated to range from a minimum of 14 seeds on a plant with two siliques to a maximum of 7,900 seeds on a plant with 12 stems (Nuzzo 1994*a*). In dense patches of garlic mustard, Nuzzo (1994*a*) found that the number of seeds in the seedbank range from 3,607 to greater than 22,000 per m^2. In Illinois, garlic mustard seed capsules generally ripen and rupture in August (Nuzzo 1990).

Seeds require a cold stratification period to germinate (Lhotská 1975; Baskin and Baskin 1992). Cavers et al. (1979) noted that seeds often have a 20-month dormancy in Canada. Studies in Illinois and Kentucky indicate that seeds may stay dormant until the second season, but most have an 8-month dormancy and germinate during the first spring following dispersal (Baskin and Baskin 1992; Nuzzo et al. 1996). A small percentage of seed remains viable for up to 4 to 6 years (Nuzzo 1991; Baskin and Baskin 1992). The flowering plant dies after producing seeds.

Garlic mustard is often transported into natural areas along roads or trails by human activities (Nuzzo 1993). Cavers et al. (1979) reported that the seeds do not float well, but the distribution pattern of garlic mustard in Illinois indicates that waterways are a common dispersal corridor (Nuzzo 1993).

In natural areas in Illinois, garlic mustard is often found in clusters at the bases of trees. The mechanism of dispersal to these locations is unknown, but may be squirrels, racoons, opossums, or other animals. These animals have not been observed feeding on the plants, but Cavers et al. (1979) noted that seeds readily attach to moist surfaces.

CONTROL METHODS

Basal rosettes of garlic mustard can be easily mistaken for violets (*Viola* spp.), immature white avens (*Geum canadense*), or *Cardamine* spp. (Cavers et al. 1979; Nuzzo 1990). Distinguishing characteristics of garlic mustard include: 1) the leaves and stems exude a distinct garlic odor when crushed (this gradually diminishes by autumn), and 2) the roots of garlic mustard have a slender white taproot with a characteristic crook or "s" shape at the top of the root, just below the base of the stem (Nuzzo 1990, 1994*a*). Smelling the garlic odor is a reliable method of distinguishing garlic mustard until the odor disappears late in the growing season; after this time one may need to rely on the root characteristics. Proper identification should be made prior to attempting any control measures.

Areas where garlic mustard is not present or has been eliminated should be monitored at least annually for the presence of new plants. Detected individuals should be removed before they set seed.

Once garlic mustard has become established, management efforts should focus on controlling seed production and depleting the seed source. Seeds of garlic mustard will germinate up to 4 to 6 years following dispersal (Nuzzo 1991; Baskin and Baskin 1992). Continual control is required throughout this period to prevent adults from setting seed and replenishing the seedbank.

Recommended methods to control garlic mustard in natural areas include prescribed burning, cutting or pulling of flowering stems, and applying herbicides. Depending on the infestation level, one or more of these methods may be needed to provide adequate control.

Mechanical

Nuzzo (1991) found that cutting the flowering stems of garlic mustard significantly reduces survival, height of resprouted stems, and seed production. Flowering plants cut at ground level in late May experienced 99% mortality. Plants cut at 4 inches (10 cm) experienced 71% mortality. Surviving plants resprouted but produced significantly shorter stems, averaging about 11 inches (28 cm) with significantly fewer siliques. Seed production of individual plants was reduced by 93.7% to an average of 14.3 seeds per plant. Total seed production was reduced by 98%.

Hand-pulling of garlic mustard plants, including roots, is an effective means of control in areas of light infestation. If the stem of a plant breaks off or if roots remain, plants may resprout. Soil should be disturbed as little as possible and pressed firmly back into place after pulling the plant. Disturbance to the soil can make conditions favorable for garlic mustard germination (Nuzzo 1990; Nuzzo et al. 1991).

In dense populations where garlic mustard is basically a monoculture, The Nature Conservancy in Illinois found scything to be advantageous (Stephen Packard, pers. comm.). Large areas of the plants can be cut quickly without disturbing the soil. A "weed-whacker" or similar device may be used where conditions are suitable and surrounding native vegetation will not be affected (Nuzzo 1991).

Many exotic species produce viable seed even after their stems are cut. All garlic mustard stems should be removed from the site after cutting — unless future research indicates that this is not necessary.

Chemical

Where there is concern for surrounding vegetation, generally in protected areas—whether high quality or degraded — herbicides must be used cautiously. Herbicides should be applied when native, non-target vegetation is dormant to reduce inadvertent or unavoidable injury (Illinois Nature Preserves Commission 1990).

Nuzzo (1990, 1991, 1994*a*, 1994*b*) and Nuzzo et al. (1991) found that 1% to 3% solutions of Roundup (active ingredient: 41% glyphosate) applied to garlic mustard rosettes in late fall or early spring reduced adult cover by greater than 95%.

On buffer or severely disturbed areas, plants can be hand sprayed with 2,4-D amine. Application should be made according to the label instructions. To reduce drift, the amine formulation should be used rather than the ester formulation. The herbicide 2,4-D is selective for broadleaf plants and will not harm most grasses. Because of inconsistent results, Nuzzo (1994*a*) did not recommend 2,4-D to control garlic mustard.

Nuzzo (1994*a*) mentioned that 2,4-D mixed with other chemicals may provide more effective results. A 1% solution of Mecamine (2,4-D plus dicamba) reduced garlic mustard cover (McClain pers. comm., in Nuzzo 1994*a*). Brown (pers. comm., in Cavers et al. 1979) reported kill of all flowering plants using Kilmore (2,4-D, MCPP, and dicamba) at 1.1 liter per ha.

Dunbar (pers. comm. 1990, in Nuzzo 1994*a*) found that Garlon 3A (active ingredient: 44.4% triclopyr) at 7 oz per 5 gal (a solution of just over 1%) applied in the spring killed 92% of the garlic mustard rosettes in a limited test.

In an area that was predominantly garlic mustard, Nuzzo (1994*b*) studied the effects of herbicides applied during the growing season. Basagran (bentazon) applied in early July at a rate of 0.5 lb per acre reduced garlic mustard cover by 94 to 96%. Nuzzo (1994*b*) stressed that further testing should conducted before applying herbicides to natural areas during the growing season.

Biological

No biological control agents are recognized for garlic mustard. Several pathogens have been tested, but none has yet been found to effectively control garlic mustard in the field.

A strain of turnip mosaic virus that infects garlic mustard plants in southern Canada (Stobbs and Van Schagen 1987) was studied for its potential to spread to commercial crops in the Brassicaceae. The strain that infects garlic mustard was found not to be a threat to *Brassica* crops. Stobbs and Van Schagen noted that siliques of infected garlic mustard plants are smaller, but the number of seeds per pod is not affected. Although seed size was reduced about 20%, germination was not affected. Seeds from infected plants did not carry the virus. These researchers did not discuss the potential of turnip mosaic virus as a biological control agent. But if seed production or germination is not affected, its usefulness as a biological control is most likely minimal.

In a search for a garlic mustard pathogen, Chen (1996) analyzed 82 fungal isolates from diseased garlic mustard plants in Illinois, including *Alternaria* spp., *Fusarium oxysporum*, *Fusarium solani*, *Phoma* spp., and *Sclerotinia sclertiorum*. These plant pathogens have been successful for biological control of other weeds (Chen 1996).

Greenhouse tests found that *Fusarium solani* isolates are very effective in killing garlic mustard plants. Seventy percent of the inoculated plants were killed as compared with no death in the control treatment. The fungus caused root rot and basal stem rot of the garlic mustard plants. Some plants showed severe symptoms in field tests, but no significant death rates were observed. Infection by the fungus did not kill the plants or stop seed production in the field. Pending further research, Chen summarized that "an effective and practical biological control for garlic mustard will not be available in the near future" and "no quick solutions are available for this invasive weed."

Burning

In fire-adapted communities, and where adequate fuel exists to carry fire, mid-intensity burns in the fall or early spring can reduce garlic mustard populations and prevent expansion (Nuzzo 1990, 1991; Nuzzo et al. 1991, 1996). Regular burns may also deter invasion of garlic mustard (Nuzzo 1991). A series of burns may be necessary. Fires need to be intense enough (mid-intensity) to burn the area thoroughly. Low intensity fires that leave areas unburned will not control garlic mustard effectively. Plants not burned should be removed by hand before flowering (Nuzzo 1990, 1991; Nuzzo et al. 1991).

The population of garlic mustard may increase during the first year or two following fires, especially low intensity burns (Nuzzo 1991), but continued treatment will eventually deplete the seed source and reduce the population (Nuzzo et al. 1996).

Nuzzo et al. (1996) noted that repeated burns successfully prevented the spread of garlic mustard, but did not eradicate it.

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INTEGRATED PEST MANAGEMENT FOR

PLUMELESS THISTLE, *Carduus acanthoides* L.

INTRODUCTION

Plumeless thistle (*Carduus acanthoides*) is native to Europe and Asia. It was first collected in the United States in 1879 in New Jersey (Desrochers et al. 1988). Swink and Wilhelm (1994) noted that its introduction into the northern Illinois area seems recent, and it may become a serious weed. *Carduus* thistles have become some of the most serious weeds of pastures in the United States (Kok 1976). Infestations of *Carduus* can reduce productivity of pastureland by suppressing growth of desirable vegetation and by preventing cattle from grazing (Desrochers et al. 1988). Heavy infestations are impenetrable to livestock grazing (Kok 1976). Plumeless thistle is dispersed by wind-borne seeds. As their distribution increases, the potential for spread of *Carduus* thistles into nearby natural areas or natural area restoration projects also increases.

HABITAT

Plumeless thistle adapts to a variety of soil conditions and habitats (McCarty et al. 1969). Batra (1978) noted that *Carduus* thistles are most abundant in the northeastern United States on fertile soils formed over limestone, but they occur on a variety of soils in the Midwestern and Rocky Mountain states. *Carduus* grows in moist, neutral, well drained soils over basalt or granite in Australia (Batra 1978). Plumeless thistle grows in well drained pastures, along roadsides and railroads, in idle lands, and often around gravel pits (Kok 1976; Desrochers et al. 1988), but it often infests poorly managed and overstocked pastures (Kok 1976).

Less is known about the habitat requirements or preferences of plumeless thistle than of its frequent associate, nodding thistle (*Carduus nutans*). Desrochers et al. (1988) noted that these two species are often present in the same areas and that conditions described for nodding thistle probably often apply as well for plumeless thistle. Moore and Mulligan (1956) observed that plumeless thistle occupies drier, better drained areas than does nodding thistle when they occur in the same pastures. Plumeless thistle and nodding thistle do not tolerate competition and are found mainly in open areas (Desrochers et al. 1988).

LIFE HISTORY

Plumeless thistle is an herbaceous biennial, winter annual, or annual that grows between 8 and 59 inches tall (20 to 150 cm) (Desrochers et al. 1988). It is a member of the Asteraceae (aster family). The stem is branched with many spiny wings extending to terminal flowering heads (solitary or clustered). Plants can produce several flowering heads, each of which produces many fruits (achenes) with a pappus. Flowering occurs from the end of May through the first of October in northern Illinois (Swink and Wilhelm 1994). The many heads of plumeless thistle enable it to flower continuously throughout the season (Desrochers et al. 1988). Feldman and Lewis (1990) observed that the total number of flowering heads per plant can range from 18 to 103. Each head is a composite of several flowers. Feldman and Lewis estimated that the total number of flowers ranges from 1,031 to 11,062 per plant.

Seed maturation and dispersal occurs shortly after flowering, usually within 1 to 3 weeks (Desrochers et al. 1988). The achenes are wind-dispersed to new areas. The seeds do not appear to require a dormancy period (McCarty et al. 1969; Feldman and Lewis 1990). Germination of a similar species, nodding thistle, occurs in the spring and fall, approximately 14 to 21 days after dispersal. Plumeless thistle usually functions as a biennial, but also acts as a winter annual or an annual. Plants overwinter as either seeds or rosettes (Desrochers et al. 1988). No vegetative reproduction has been reported in plumeless thistle (Desrochers et al. 1988). Hybrids between plumeless thistle and nodding thistle have been reported, but no hybrids between the two were recognized in Illinois by Mohlenbrock (1986) or Swink and Wilhelm (1994).

Feldman et al. (1994) observed that plumeless thistle seedlings in pastures survive better in areas with a rough soil surface and a litter layer. The litter layer seems to protect the seeds from desiccation and predation. Although seed output is very large, Feldman and Lewis (1990) found that the number of achenes in the seedbank is often very low because of high predation before and after dispersal. Seeds of nodding thistle generally fall within about 50 m of the parent plant (Smith and Kok 1984). After a laboratory study, Feldman and Lewis (1990) suggested that conditions are very similar with plumeless thistle and that long distance colonization is not very probable, although not impossible.

Control Methods

Mechanical

Desrochers et al. (1988) reported that nodding thistle do not produce viable seed when mowed within 2 days of anthesis. Plants produce significant quantities of viable seeds if mowed 6 and 11 days after anthesis. Plants that are mowed before anthesis resprout flowering stalks and produce viable seeds. Desrochers et al. found that more than one mowing per year is needed for effective control.

Chemical

McCarty et al. (1969) tested the effects of various herbicides at different rates on germination and growth of plumeless thistle seeds and seedlings. To reduce the germination of plumeless thistle by 50%, treatment requires 3 ppmw (parts per million by weight) of 2,4-D, 13 ppmw of dicamba, or 25 ppmw of picloram. All treatments severely reduce radical growth. These rates were tested in greenhouse experiments. McCarty et al. noted that these fairly high rates of herbicide need to be in direct contact with the achenes before the 50% reduction in germination was observed. As a result, they felt that relatively few achenes will be killed under field conditions even at the high herbicide rates that are needed for control. Herbicides with residual toxicity will kill seedlings after they emerge. McCarty et al. found that fall application of low rates of dicamba and picloram provided control of seedlings. The herbicide 2,4-D was not an effective control.

Desrochers et al. (1988) stated that both nodding thistle and plumeless thistle are most susceptible to hormone-like herbicides applied during periods of active growth of the seedlings or rosettes (during the spring or fall months). Desrochers et al. offered a brief review of studies that have tested herbicides on *Carduus*. Herbicides reported as controlling *Carduus* thistles are listed in the following table (see Desrochers et al. 1988:1063 for references):

Herbicide	**Rate of Application**	**Comments**
2,4-D	1 kg per ha	
2,4-D ester	4.48 kg per ha	
Dicamba	0.56 kg per ha	Reduced production of viable seed
Dicamba plus 2,4-D	0.56 kg per ha; 1.12 kg per ha	Reduced production of viable seed; provided excellent control
3,6-dichloropicolinic acid plus 2,4-D	Not given	Provided excellent control
Picloram plus 2,4-D	Not given	Provided excellent control
Dicamba plus IT 3456	Not given	Provided excellent control

Popay et al. (1989) found that the timing of application greatly influences the effectiveness of herbicides for controlling nodding thistle. They tested seasonal differences of various herbicides applied at different rates. The most effective include MCPA at 1.5 kg per ha, and MCPB ester at 1.0 kg per ha plus clopyralid at 0.03 kg. Most herbicides give results similar to the standard set by MCPA at 1.0 kg per ha, which ranges from 49 to 95 percent kill depending on conditions. Other tested herbicides include 2,4-D, MCPB, and MCPA plus MCPB.

Factors that Popay et al. found to affect percentage thistle kill include: date of seedling emergence, date of flowering stem elongation, possibly the size of the rosette, and the reduced effectiveness of herbicides in winter. The majority of seedlings emerge after fall rains in New Zealand. In one test location, applications of herbicide during the fall and early spring months were equally effective. In another location, only fall applications were effective. Environmental conditions differed between the two sites. One site had a milder climate, possibly encouraging earlier growth: these nodding thistle rosettes were generally larger in the spring and flowering stems elongated sooner. Nodding thistle plants are less susceptible to herbicides late in their growth. Popay et al. speculated that the larger size of the rosettes rendered them more resistant to the herbicides. Popay et al. encountered one test population of nodding thistle that had developed a resistance to MCPA and showed little effect from the herbicide.

Biological

Feldman et al. (1994) recommended that overgrazing be avoided. Overgrazing helps to create areas of generally low vegetation coverage and a discontinuous canopy, which provide niches for the invasion and regeneration of plumeless thistle.

Several organisms have been tested as potential biological agents for plumeless thistle and other thistles (see Desrochers et al. 1988 for a review).

A thistle-head weevil, *Rhinocyllus conicus*, was first imported from France in 1969 for biological control of plumeless thistle and musk thistle (*Carduus nutans*) (Kok 1976). Eggs of this weevil are laid on the bracts of the thistle head, and the larvae feed on the developing seeds within the receptacle. According to Kok and Mays (1991), *R. conicus* has been very successful in controlling musk thistle (*Carduus thoermeri*), but only partially successful on plumeless thistle because of poor synchronization with host flowering phenology. But this insect also has successfully targeted a rare native *Cirsium* species (Pemberton 1984).

Cassida rubiginosa is a leaf-feeding insect, native to Europe, that feeds on plumeless thistle. Pienkowski and Kok (1976) conducted preliminary research into the use of this insect as a biological control for the thistle. They found that *C. rubiginosa* has several parasites that decrease its probable effectiveness as a control for thistle. Further study will determine its potential.

Trichosirocalus horridus is a crown or rosette-feeding weevil that was introduced into the United States from Italy between 1970 and 1972 (Kok and Mays 1991). *T. horridus* is very successful in controlling plumeless thistle as well as musk thistle, but its impact on plumeless thistle may not be evident for several years. *T. horridus* shows a preference for musk thistle. This is especially noticeable where plumeless and musk thistles occur in the same area. Musk thistle will generally be the first of the two species to collapse. Population collapse of plumeless thistle can take much longer than that of musk thistle. Kok and Mays (1991) observed that collapse of plumeless thistle is apparent after 10 to 12 years, compared with about half of that time for musk thistle.

The length of time before impact to the host plant population is a limitation, but *T. horridus* has several advantages which enable it to effectively control plumeless thistle, including good synchrony with the host plant phenology, low mortality from predators or parasites, and the ability to maintain itself on low host densities. This means that the host plant (plumeless thistle) does not need to occur in large populations in order for *T. horridus* to maintain itself; the opposite occurs with *R. conicus*. *T. horridus* overwinters in several stages (adult, egg, and larva).

Although it may not be apparent within a few years after release, *T. horridus* will successfully control plumeless thistle in 7 to 13 years (Kok and Mays 1991). Studies such as this demonstrate the importance of establishing long-term monitoring programs. Additional research may find ways to enhance or shorten the impact time.

Burning

No information was located concerning the direct effects of burning on plumeless thistle. Desrochers et al. (1988) observed that increases in interspecific competition cause *Carduus* populations to decline. Prescribed burning generally enhances the health of many natural communities. In areas where native species occur, either vegetatively or in the seedbank, fire may improve the ability of local species to compete and possibly displace *Carduus*.

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INTEGRATED PEST MANAGEMENT FOR

SPOTTED KNAPWEED, *Centaurea maculosa* Lam.

INTRODUCTION

Spotted knapweed (*Centaurea maculosa*) is native to Europe. It is common throughout Europe and western Asia (Englert 1971, in Watson and Renney 1974). The first collection of spotted knapweed in North America was made in Canada at Victoria, British Columbia, in 1893 (Groh 1944, in Watson and Renney 1974). It was first collected in the United States in Montana in the 1920s. Contaminated agricultural seed most likely was the source of introduction (Lacey et al. 1992).

Spotted knapweed has become widely distributed across western Canada and the northern and northwestern United States, where it infests more than 7.25 million acres in eight states and the Canadian provinces of British Columbia and Alberta (U.S.D.A. 1994). It occurs in at least 34 states, with scattered populations in the north-central and northeastern United States. Swink and Wilhelm (1994) noted that spotted knapweed is increasing rapidly in the Chicago region; some pastures have become heavily infested.

HABITAT

Spotted knapweed colonizes a wide range of habitats, soils, and environmental conditions (Watson and Renney 1974; Lacey et al. 1992), but it does not grow well on sub-irrigated or wet meadow sites (Lacey et al. 1992). Knapweeds prefer open habitats and are not commonly found in shaded areas. They quickly invade disturbed sites and are common in habitats such as roadsides, railroad rights-of-way, trailsides, pastures, idle lands, railroad ballast, and overgrazed rangeland (Watson and Renney 1974; Fay et al. 1991; Swink and Wilhelm 1994). Once established in disturbed areas, knapweed may spread into adjacent natural areas. Tyser and Key (1988) found that spotted knapweed has invaded natural grasslands in Glacier National Park from adjacent roadside populations.

Human activities and soil disturbance have been integral in the establishment and spread of spotted knapweed (Watson and Renney 1974; Lacey et al. 1992). Its establishment in an area is often enhanced more by soil disturbance than by soil properties (Lacey et al. 1992). Disturbances include those caused by human activities (i.e. roadside construction and maintenance, vehicle traffic, etc.) and those caused by animals (i.e. burrowing and foraging) (Tyser and Key 1988; Lacey et al. 1992).

LIFE HISTORY

Spotted knapweed is a herbaceous plant of the Asteraceae (aster family). Researchers have often referred to it as a biennial, short-lived perennial, or perennial. Boggs and

Story (1987) found that the plants can be aged by counting annual rings in the taproots. According to their findings, spotted knapweed plants can live for at least 9 years. Plants tend to senesce and develop root rot after about 7 years, making it more difficult to determine the age of a plant. Based on the results of their study, Boggs and Story (1987) reported that spotted knapweed is most appropriately referred to as a perennial.

Spotted knapweed reproduces mainly by seed, but can also reproduce vegetatively from lateral shoots that develop from the roots. The shoots grow horizontally underground for about 3 cm before forming a rosette. These rosettes mature during the following season but do not detach from the parent rootstock (Watson and Renney 1974).

Knapweeds overwinter as rosettes or as seeds. Most seeds germinate in the spring, but they can germinate in the fall when conditions are favorable. Seedlings develop into rosettes and maximum root growth occurs at this stage. The rosettes generally produce one to six stems, and older plants commonly produce 15 or more. Stems are erect and branching and grow between 30 and 100 cm tall (Watson and Renney 1974). Plants that have overwintered as rosettes usually bolt in the spring, but Tyser (in Tyser and Key 1988) observed that spotted knapweed may persist in the rosette stage for 4 or more years before developing a floral stalk.

Flower buds form in June in British Columbia (Watson and Renney 1974). Blooming occurs from the first of July through early October in northern Illinois (Swink and Wilhelm 1994). Flowers are insect pollinated. They are usually purple, and the heads are surrounded by bracts with black tips. The flower heads are mainly terminal and produced in numerous corymbs or corymbose panicles. An average of about 16 flowering heads are produced on each plant (Watson and Renney 1974).

Each plant can produce an average of about 1,000 seeds in Montana (Chicoine and Fay 1984; Lacey et al. 1992). Seed production is very high. Annual production in a mature stand can average between 30,000 to 43,000 seeds per 0.5 m^2 (Watson and Renney 1974; Chicoine and Fay 1984). Mortality of seedlings is also high, however, and seedling density generally averages between 500 to 1,000 per 0.5 m^2. Mature seeds (achenes) are formed by mid-August. Seeds are shed immediately and if there is adequate moisture, seeds can germinate and form rosettes by the fall. Seeds can remain viable in the soil for at least 5 to 8 years (Davis and Fay 1989, in Lindquist et al. 1991; Davis et al. 1993).

Seeds of spotted knapweed plants are expelled up to a meter when stems are moved; spotted knapweed plants do not break off at the ground as do some other knapweeds. Water and wind provide some dispersal (Lacey et al. 1992).

Seeds can become attached to passing animals or objects and be carried long distances from the parent plants (Watson and Renney 1974). People and motor vehicles are the main cause of spread for spotted knapweed in Montana (Lacey et al. 1992).

Spotted knapweed plants release an allelopathic chemical (cnicin) into the soil, which may suppress seed germination and root growth of grasses and trees (Watson and Renney 1974; Lacey et al. 1992).

CONTROL METHODS

Spotted knapweed has been a significant pest in western rangelands of Canada and the United States for several decades. Numerous methods have been tested and employed to control its invasion and spread.

The main concern in the West is preserving, reclaiming, and improving the yield of grazing lands for livestock. Knapweed infestations are often very large, and control methods must accommodate these situations. Methods to best control knapweeds have long been studied in the western states, and the studies and references are seemingly endless. Several information sources are available if further reading is desired.

Spotted knapweed at Midewin National Tallgrass Prairie occurs in scattered patches, some of which cover a few acres. Many of the control methods presented here have been developed for large knapweed populations in western rangelands. Modifications of these treatments may be necessary to accommodate the present condition of spotted knapweed infestations at Midewin National Tallgrass Prairie.

As with many invasive exotic species, the key to stopping the spread of spotted knapweed is early detection and treatment. Because of the longevity of spotted knapweed seeds in the soil, control programs must continue annually for several years (Lacey et al. 1992).

Mechanical

Diligent hand-pulling can control very small infestations of knapweed. Large numbers of seedlings germinate each year from seed, so areas must be monitored and plants must be pulled annually until the seedbank is exhausted (Lacey et al. 1992). Roots must be pulled to prevent resprouting. Plants should be bagged and removed from the site to prevent dispersal or maturation of seeds; or the seeds should be disposed of by deep burial or by burning in a very hot fire (Lacey et al. 1992).

Mowing can reduce the number of seed-producing plants (Watson and Renney 1974), but it will not prevent seed production (Lacey et al. 1992). Watson and Renney (1974) found that mowing at the flowering stage and mowing twice (once during the bud stage and again during the flowering stage) significantly reduces the number of seed-producing plants, which in turn significantly reduces germination. They concluded that mowing is most effective when conducted at the flowering stage.

Tyser and Key (1988) observed that unmowed roadside knapweed plants are noticeably larger and produce more seed heads per stem than mowed plants. Mowed plants produce more stems, and this offsets the fewer flowering heads per stem. As a result, the overall seed production remains about the same.

Spotted knapweed does not persist under cultivation (Müller-Schärer and Schroeder 1993).

Lacey et al. (1992) found that human-related activities and disturbances, especially the driving of vehicles through knapweed-populated areas, significantly influence the spread and establishment of spotted knapweed. Controlling or minimizing public access to knapweed-infested areas will reduce the rate of spread (Tyser and Key 1988; Lacey et al. 1992).

Chemical

Picloram (trade name Tordon), clopyralid (trade name Stinger), 2,4-D, and dicamba (trade name Banvel) are the main herbicides used to control spotted knapweed on rangelands.

Picloram has a long persistence in soil, which discourages re-infestation and germination; therefore picloram is considered the most effective herbicide for long-term control of spotted knapweed (Fay et al. 1991).

Picloram provided effective long-term control of spotted knapweed when applied at 0.25 lb active ingredient per acre (0.28 kg per ha) (Maddox 1979; Lacey et al. 1992). Number of years of control include: 2 to 5 years (Lacey et al. 1992), 5 years (Belles et al. 1980 and Fay et al. 1989, in Fay et al. 1991), and 7 years (Fay et al. 1991). Lacey et al. (1992) observed 100% control of spotted knapweed when picloram was applied in June in Montana. Fay et al. (1991) observed 100% control of mature plants for 3 years, then 85% control 7 years after application of picloram. They found that rates between 0.14 to 0.28 kg per ha achieve significantly similar results. Fay et al. (1991) found that a rate of 0.07 kg per ha is also effective over the 7-year period, but provided a lower percentage of control.

Soil properties and seasonal rainfall affect the longevity of picloram. The period of control is shorter in gravel soils and areas of higher precipitation (Lacey et al. 1992). Fay et al. 1991) reported that knapweed seedlings begin to re-establish when picloram levels in the soil drop below 0.012 parts per million. Similarly, Fay et al. (1991) observed that re-invasion of seedlings occurs between 2 and 4 years after application.

Knapweed plants can be controlled in the rosette stage by spraying them with 0.25 lb per acre of clopyralid, 2 lb per acre of 2,4-D, or 1 lb per acre of dicamba (Lacey et al. 1992).

Control is often inconsistent with 2,4-D and dicamba. 2,4-D products must be applied annually until the seedbank is exhausted to achieve long-term control (Fay et al. 1991; Lacey et al. 1992). Clopyralid and dicamba may need to be applied every second, third, or fourth year depending on conditions (Fay et al. 1991; Lacey et al. 1992). Dicamba may be more effective initially than 2,4-D, but the effectiveness decreases in subsequent years (Fay et al. 1991).

2,4-D has been most effective against spotted knapweed when applied at the vegetative rosette stage in late spring (Bucher 1984, in Story et al. 1988). Annual applications at 1.1 and 2.2 kg active ingredient per ha (1 and 2 lb per acre) prevented seed production (Belles et al. 1978 and Wattenbarger et al. 1980, in Fay et al. 1991).

Clopyralid applied at rates greater than 0.07 kg per ha significantly reduced spotted knapweed density one year following treatment; rates of 0.28 kg per ha provided 100% control one year after treatment (Lacey et al. 1989). Seedlings re-established by the second year after application of the herbicide, making re-application necessary (Fay et al. 1991).

Picloram and clopyralid both provided significant control of knapweed density at 0.28 kg per ha without detrimental effects to native forbs in Montana. Neither herbicide at that rate significantly reduced native forb diversity, and they had minimal impact on native forb density (Lacey et al. 1989). Clopyralid is more selective than picloram and has a shorter residual life in the soil, making it more suitable for use in environmentally sensitive areas (Fay et al. 1991).

Lacey et al. (1992) found that all four of these herbicides are most effective if applied when the plants are developing flowering stalks (late May to early June in Montana). Other researchers found 2,4-D to be most effective when applied during the rosette stage (Story et al. 1988). Herbicide effectiveness declines rapidly after flowering (Lacey et al. 1992).

Roundup (active ingredient: 41% glyphosate) is labeled to for use on two other *Centaurea* species, Russian knapweed and yellow star-thistle (*Centaurea repens* and *C. solstitalis*). To control Russian knapweed, the manufacturer recommends applying 4 qt per acre of Roundup when plants are actively growing and are in the late-bud to flowering stage. Yellow star-thistle can be controlled by applying a 2% solution of Roundup as a spot treatment or by using a broadcast treatment of 2 qt per acre in 10 to 40 gal per acre of water carrier. Best results are obtained if Roundup is applied when most plants are actively growing, including the rosette, bolting, or early flowering stage.

As summarized by Müller-Schärer and Schroeder (1993), aerial treatments of knapweed are justified when used to increase yield on good quality rangelands, but treatments of large areas with a persistent, broad-spectrum herbicide is often uneconomical (Maddox 1979) and is highly undesirable ecologically. Spot application of herbicides to spotted knapweed plants is feasible in small, local infestations, but is too costly in large populations.

As an alternative to herbicides, Upadhyaya (1986) proposed the use of gibberellic acid (a growth regulator) to induce bolting in spotted knapweed. He speculated that induced bolting may assist control methods in a variety of ways, i.e. induced bolting at an earlier age in the spring may reduce seed production, or induced bolting in the fall could increase winter kill. Induced bolting could possibly increase a population's susceptibility to mowing or herbicides. Much research needs to be conducted to determine whether the use of gibberellic acid will be advantageous.

Biological

Watson and Renney (1974) reported that spotted knapweed rosettes are not grazed by cattle, but flower heads are eaten in overgrazed areas. Lacey et al. (1992) found that livestock often graze the basal leaves of the rosettes, but the plants seem to tolerate grazing with little damage. As a result, they felt that grazing by livestock would not provide adequate control of spotted knapweed. Overgrazing can reduce plant competition against knapweed and provide favorable conditions for its establishment and spread.

Maxwell et al. (1992) found knapweed more abundant on grazed versus non-grazed areas. After spraying study plots with herbicide (picloram), Maxwell et al. found that knapweed re-established more rapidly on the grazed than on the ungrazed plots. They speculated that the effects of grazing on knapweed density and establishment may be influenced by the season of grazing.

Twelve insects that are natural enemies of knapweeds in their native ranges have been cleared by the U.S.D.A. for release in the United States as biological control agents. Two seedhead-feeding flies (*Urophora affinis* and *U. quadrifasciata*) have become the most widely distributed of all the knapweed biocontrol agents (U.S.D.A. 1994). *U. affinis* was the first biological control agent introduced into North America for spotted knapweed control. It was first released in Canada in 1970 and in the United States in Montana in 1973 (Lacey et al. 1992; Müller-Schärer and Schroeder 1993). The second seedhead-feeding fly (*U. quadrifasciata*) was introduced in Montana in 1980 (Lacey et al. 1992). The combined effects of the two flies reduced seed production by 80 to 95% but did not affect knapweed density (Müller-Schärer and Schroeder 1993). Four root-feeding insects were released in Montana after 1982. Of these four, a root-feeding moth (*Agapeta zoegana*) has become the best established.

Burning

Prescribed burning has not proven to be an effective means of control for spotted knapweed (Xanthopoulos 1988; Lacey et al. 1992). In dense patches of knapweed, coverage of fine grass fuels is often not adequate to carry fire through the entire population, leaving unburned patches of knapweed to mature and set seed (Xanthopoulos 1988; Lacey et al. 1992). Burning does not affect the rosettes, and fires usually are not hot enough to eliminate all viable seed in the soil or to prevent crowns from resprouting (Lacey et al. 1992). Burning may provide some aid by removing litter and stimulating knapweed growth so that herbicides are more effective.

Many researchers (e.g. Watson and Renney 1974; Lacey et al. 1992) have remarked that increases in interspecific competition (especially by grasses) may help to control the spread of spotted knapweed. Prescribed burning generally enhances the health of many natural communities. In areas where native species occur, either vegetatively or in the seedbank, fire may improve the ability of local species to compete against and prevent invasion or reduce the spread of spotted knapweed.

Maxwell et al. (1992) tried seeding knapweed areas with crested wheat grass (*Agropyron cristatum*) or Russian wild rye (*Psathyrostachys junceus*). In addition, Maxwell et al. sprayed some of the seeded areas with picloram. They found that picloram was the most effective treatment to reduce knapweed cover, which in turn increased the desirable forage cover. Maxwell et al. found no real advantage in seeding the areas.

Combined Methods

Most researchers concur that control of spotted knapweed requires a combination of methods over several years. Large populations of spotted knapweed can be controlled by implementing an intensive management program that includes cultivation, irrigation, and either annual crops or a seeded perennial forage. Small patches can be eliminated with a persistent herbicide or cultural control program (Lacey et al. 1992).

Classic biological control and herbicide application have been believed to be mutually exclusive (Müller-Schärer and Schroeder 1993). But recent research found that carefully timed applications of some herbicides are compatible with the use of biological control agents. 2,4-D applied at the rate of 2 lb active ingredient per acre (Story et al. 1988) or 1.1 or 2.2 kg per ha (1 or 2 lb per acre) (McCaffrey and Callihan 1988) is compatible with the two seedhead-feeding flies (*Urophora affinis* and *U. quadrifasciata*) when applied during the spring rosette stage of spotted knapweed. Picloram applied at rates of 0.3 or 0.6 kg per ha in the spring (May 12) is also compatible (McCaffrey and Callihan 1988).

Mowing, on the other hand, is most effective during the flowering period. This timing is not compatible with the two flies because it causes extensive mortality of the insects (Story et al. 1988).

The two seedhead flies by themselves are not expected to control spotted knapweed densities in the East, because they have not done so in western North America (Wheeler and Stoops 1996). But their combined efforts are expected to reduce seed production.

Successful biological control can also reduce the rate or amount of herbicide needed (Müller-Schärer and Schroeder 1993).

As many researchers concur, a multi-pronged strategy will be the only solution for knapweed control (Müller-Schärer and Schroeder 1993). This will include a combination of herbicides, effective biological control agents, and increased public awareness and responsibility (Müller-Schärer and Schroeder 1993). Spotted knapweed cannot be controlled in a single treatment or in a single year (Lacey et al. 1992).

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INTEGRATED PEST MANAGEMENT FOR

CANADA THISTLE, *Cirsium arvense* (L.) Scop.

INTRODUCTION

Despite its name, Canada thistle (*Cirsium arvense*) is not endemic to Canada. It probably was first introduced into Canada in the 1600s (Moore 1975). It was introduced separately into the United States in Vermont and New York (Hansen 1918; Moore 1975; Donald 1990), probably in contaminated farm seeds (Hansen 1918). Canada thistle had become so common by 1795 that Vermont enacted a law to stop its spread (Hansen 1918; Moore 1975). New York had a similar law by 1831. Its center of origin is unknown, but Canada thistle is endemic in Europe, western Asia, and northern Africa (Donald 1990), and possibly native to southeastern Europe and the eastern Mediterranean region (Moore 1975).

Canada thistle is distributed world-wide. It is reportedly viewed as a weed in 36 countries, 22 of which consider it a serious weed (Donald 1990). Canada thistle is common in the United States north of the 35th parallel. It is classified as a noxious weed in at least 35 states (Dewey 1991), including Illinois.

HABITAT

Canada thistle is adapted to a wide range of soils – from clay or muck soils to sand, gravel, or limestone soils (Detmers 1927; Hodgson 1968; Moore 1975; Donald 1990). It is acclimated to temperate regions that have moderate summer temperatures and moderate rainfall (Donald 1990). In the United States, the most severe infestations occur in the northern half of the country. High temperatures limit its southern spread in North America. In Illinois it is common in the northern half of the state, but much less common in the southern half (Hutchison 1990).

Canada thistle thrives in disturbed areas such as overgrazed pastures, old fields, waste places, roadsides, and railway embankments (Hutchison 1990, 1992; Moore 1975). Good light intensity is required (Moore 1975) and it does not fare well in shaded areas. Canada thistle appears to need some type of disturbance to establish and usually is not a problem in areas with healthy, well established communities such as undisturbed prairies, good to excellent pastures, or woodlands (Hutchison 1990, 1992; Evans 1984). When invasion does occur, Canada thistle is capable of crowding out native grasses and forbs (Hutchison 1990, 1992; Solecki 1997). It is detrimental to natural areas, particularly non-forested communities, where it can alter the natural structure and species composition (Hutchison 1990, 1992). Areas that are susceptible to invasion include prairies, barrens, savannas, and glades that have been disturbed or are undergoing manipulative restoration management. Canada thistle can spread from disturbed sites into adjacent sedge meadows and wet prairies (Hutchison 1990, 1992).

LIFE HISTORY

Canada thistle is a dioecious, weedy perennial that characteristically grows in patches and has an extensive root system (Johnson 1912; Donald 1990; Hutchison 1990, 1992). Introduction of this thistle into a new area occurs mainly by wind-borne seeds or by run-off in ditches, down hillsides, or along streams (Johnson 1912; Cox 1913; Hutchison 1990, 1992). Once it has become established, Canada thistle spreads mainly vegetatively by its root system rather than by seed.

Seeds are known to remain viable in the soil for up to 21 years in some cases (Moore 1975), but most seeds germinate within the first year. Some seeds germinate immediately and produce rosettes before winter; these plants flower during the first spring (Evans 1984). Other seeds germinate in the following spring. Basal leaves usually are produced during the first year; flowering stems appear in the next year (Hutchison 1990, 1992). Within 3 weeks of germination, the roots of Canada thistle seedlings begin to form buds. To prevent the seedlings from becoming perennial, they must be tilled or killed before 3 weeks of age (Haderlie et al. 1991).

According to Haderlie et al. (1991) the roots of Canada thistle are often incorrectly referred to as rhizomes. Rhizomes are underground stems with nodes and internodes; buds on rhizomes develop at the nodes. Canada thistle root tissue is simply a root and does not have nodes or internodes; root buds can develop at any location along the root or at any time of the year when conditions are favorable (Haderlie et al. 1991). McAllister and Haderlie (1985, in Haderlie et al. 1991) found that root bud development is greatest in the fall when the soil is still warm and ambient temperatures are dropping. The photoperiod during that time is 13 hours. Root buds arise from the roots to form new adventitious shoots (Donald 1990). Aerial shoots are sent up at about 2 to 6-inch intervals (Hutchison 1990, 1992). In Illinois emergence occurs in May and vertical growth begins in mid-to-late June (Hutchison 1990, 1992).

Vertical roots penetrate to the water table (Hayden 1934). The main root system commonly grows at a depth of 2 to 3 m (Moore 1975), but has been observed at depths of 5.5 to 6.75 m (Malvez 1931 and Rogers 1928, in Moore 1975).

Canada thistle is a long-day plant that requires at least 14 hours of daylight to flower (Haderlie et al. 1991). Numerous small, compact rose-purple or white flowers appear on upper stems from late May to early October in Illinois (Hutchison 1990; Swink and Wilhelm 1994). Pollination is mainly by honeybees (Moore 1975).

Canada thistle is most suited to the northern temperate zone because its growth is inhibited by high temperatures (Haderlie et al. 1991).

As the density of Canada thistle increases in an area, plant species diversity usually decreases (Stachon and Zimdahl 1980; Hutchison 1990, 1992). Stachon and Zimdahl (1980) found apparent allelopathic activity in Canada thistle, but they advised that more research is needed to provide sufficient evidence.

CONTROL METHODS

Canada thistle is a very persistent plant. Many researchers emphasize that there is no one single method or "best" set of methods to control Canada thistle. Management must often be sustained over several years. As stated by Johnson (1912), ". . . the success of the method used is very largely dependent upon the intelligence, thoroughness and persistence with which it is carried out."

Mechanical

Canada thistle has been a pernicious weed for centuries, and many methods have been used to eradicate it. Before the development of herbicides, land managers had to rely on a combination of mechanical control methods, many of which are still reliable. Many of the manual methods were developed for use in agricultural fields and are moderately to severely disruptive to soil conditions.

A commonly recommended treatment for large patches of Canada thistle has been the bare fallow or summer fallow method, which involves plowing an area without planting a crop (Johnson 1912; Cox 1913; Hansen 1918; Donald 1990). It is usually recommended to shallowly plow a thistle patch just before blooming. The plow should be shallow enough to avoid the horizontal root system; disturbing the root system during the growing season only serves to spread the plant. For the remainder of the growing season, the area should be cultivated with a disk harrow or with sweeps often enough to keep the thistle shorter than 3 inches. Keeping down the top growth is essential and serves to exhaust the root resources (Johnson 1912; Cox 1913; Hansen 1918). This practice should be continued until fall. At that time the area should be plowed deeply to expose as many rootstocks as possible to be killed by winter frosts (Johnson 1912; Hansen 1918).

Hutchison (1990, 1992) recommended that severely disturbed sites with heavy infestations be plowed and sowed to a cover crop if practical and desirable. In the following spring, the cover crop can be plowed, and the area can be planted in the desired native species. Planting of a cover crop is highly recommended; otherwise tillage may provide ideal conditions for re-invasion by thistle or introduction of other exotics (Hutchison 1990, 1992).

Another point to keep in mind, as mentioned by Darwent et al. (1994), is that frequent cultivation in summer fallow can increase soil erosion. Johnson (1912) and Donald (1990) warned that disking should be done cautiously; if done improperly, disking can drag root segments to other parts of a field where they can resprout.

On large disturbed or buffer sites (old fields, ditch banks, roadsides) with heavy infestations, Canada thistle should be mowed when in full bloom or just as blooming starts, and as close to the ground as possible. If the flower heads have begun to mature, they should be removed to prevent scattering of seeds on the site or to adjacent areas. Repeated mowing for several years may be needed to achieve control (Cox 1912; Hutchison 1990, 1992). As with plowing, continued cutting of the thistle will eventually exhaust its root resources (Cox 1913). Seely (1952) learned that tilling at 21 or 28-day intervals eradicated *Cirsium arvense* within one growing season.

For small patches of Canada thistle, repeated or frequent pulling, hand cutting, or hoeing will eventually starve underground stems (Johnson 1912; Hutchison 1990, 1992). Cutting or pulling should be done at least three times each season, in June, August, and September (Hutchison 1990, 1992; Solecki 1997). This treatment is feasible for light and moderate infestations but may be impractically time-consuming in heavy infestations.

Many researchers point out that Canada thistle is most vulnerable to cutting during the bud stage, just prior to flowering. During this time the root's carbohydrate levels are lowest.

Because Canada thistle does not effectively invade undisturbed communities, management practices that maintain and encourage the development of healthy stands of other species will help prevent establishment of Canada thistle or will help shade and weaken existing plants (Evans 1984; Hutchison 1990, 1992).

Chemical

Salt was the old favorite for killing weeds. Several early handbooks suggest applying a handful of salt to each cut stem. Crude carbolic acid, hot brine, sulfuric acid, kerosene, caustic soda, and arsenite of soda were also offered to help control Canada thistle (Johnson 1912; Cox 1913; Hansen 1918). Costs and toxicity most likely prevented frequent use.

Control of Canada thistle must focus on preventing seed production and controlling or killing the root (Haderlie et al. 1991). As with cutting or mowing, many researchers agree that chemical control can be maximized if applied to Canada thistle when the root resources are at their lowest, during bud stage (Johnson 1912; Hansen 1918; Amor and Harris 1977; Hutchison 1990, 1992; Haderlie et al. 1991). However, Haderlie et al. (1991) pointed out that translocation of herbicide to the roots is higher during the fall than in any other time of the year — when good growing conditions exist; therefore, herbicide application in the fall is ideal if the plant has young leaves and there is adequate soil moisture for growth.

Many studies have evaluated the effectiveness of various herbicides in controlling Canada thistle. Donald (1990) and Evans (1984) offered excellent literature reviews on some of the studies concerning herbicidal and other methods of control for Canada thistle. The majority of research concerns controlling Canada thistle in crop fields, which involves the application of herbicides on a large scale. In this situation there is little worry about surrounding vegetation, but residual effects on crop yield are of great concern. Some studies offer information on control of the thistle in pastures, and recent studies have addressed its control in no-till croplands. Comparatively few studies have focused on Canada thistle in natural areas. The majority of information presented in this section concerns management of Canada thistle in natural areas, grasslands, or pastures.

Spot application of 2,4-D (amine formulation) according to label instructions can control this plant (Hutchison 1990, 1992). Individual plants should be treated with a wick applicator, hand sprayer, or gloved hand (Hutchison 1990, 1992; Solecki 1997). This can be done relatively safely just before flowering (Solecki 1997). 2,4-D amine is selective for broadleaf plants. The amine formulation reduces drift (Hutchison 1990, 1992).

On disturbed sites, a foliar application of a 1 to 2% solution of Roundup (active ingredient: 41% glyphosate) can be applied in spring when plants are 6 to 10 inches tall (15 to 25 cm) (Hutchison 1990, 1992; Solecki 1997). Individual plants should be spot-treated with a wick applicator.

Roundup is a non-selective herbicide; precautions should be taken to avoid contacting non-target plants. To avoid injury to native vegetation, Roundup should not be used on high quality natural areas during the growing season (Amor and Harris 1977; Hutchison 1990, 1992).

Amor and Harris (1977) found Tordon 50-D (picloram), MCPB, and 2,4-DB to be the most effective in reducing thistle density. They reported that MCPB was the main herbicide used for control of Canada thistle in Dutch clover (*Trifolium repens*) pastures at that time (1977), but 2,4-D showed similar efficacy and was more cost efficient. Therefore they recommended that 2,4-D should receive greater consideration for use. When boom-sprayed, glyphosate reduced Canada thistle better than MCPB, but it also killed the tops of surrounding vegetation. Lee (1973, in Amor and Harris 1977) found that the effectiveness of glyphosate varies with the growth stage of the thistle. He also found that glyphosate is most effective when Canada thistle is at full flower stage.

The most common methods of controlling Canada thistle in pastures in Victoria, Australia, are to mow the infestations once or twice per year or to spray with MCPB (Amor and Harris 1977).

Glenn and Heimer (1994) tested the effectiveness of several herbicides on Canada thistle in no-till corn. They found that 2240 g per ha glyphosate plus 560 g per ha 2,4-D was the most effective treatment at planting time. Post-emergence treatments of clopyralid at 210 or 280 g per ha alone or 106 or 210 g per ha with 560 g per ha 2,4-D, and primisulfuron or nicosulfuron tank-mixed with 2,4-D or dicamba all provided effective control.

Haggar et al. (1986) researched chemical control of Canada thistle in grasslands of England and Wales. They obtained better results by using mixtures of herbicides (bentazone, clopyralid, and triclopyr). They emphasized that repeat spraying is necessary to kill the root system.

Biological

Grazing is not considered an effective control mechanism because the prickles on the stem and leaves discourage livestock (Hutchison 1990, 1992; Solecki 1997). Trumble and Kok (1982) found that rotational grazing or removal of grazing reduced the spread of Canada thistle, but continuous grazing allowed the thistle to spread rapidly. According to Detmers (1927), young thistle shoots are sometimes grazed by animals.

Because of its worldwide distribution as a noxious weed, much effort has been spent seeking a biological agent for Canada thistle. The following discussion about natural enemies of Canada thistle is mainly summarized from Moore (1975) and Rees (1991). Moore (1975) named several species which cause damage to Canada thistle—but most of these species do not cause enough damage to control thistle, or they require more study.

Vanessa cardui

The painted lady butterfly (*Vanessa cardui*) is native to the southernmost United States, including Arizona and New Mexico (Rees 1991). The larvae of this butterfly defoliate the thistle (Moore 1975). The painted lady is normally kept in very low numbers by a virus, but it periodically shows large, short-term population increases (Rees 1991). Stands of thistle with large populations of the butterfly larvae can be eliminated, but generally this insect occurs in numbers too low to be an effective method of biocontrol (Moore 1975; Rees 1991).

Ceutorhynchus litura

Ceutorhynchus litura is a weevil that was first released near Belleville, Ontario, in 1965, 1966, and 1967 (Moore 1975; Rees 1991). Adults overwinter and emerge just before the rosette stage of Canada thistle (Rees 1991). The adults eat young thistle shoots and rosette leaves, but do not cause serious damage. Eggs are laid in the main vein of leaves in the rosette stage. Larvae mine from the veins and migrate into the stem, then down to the root collar (Moore 1975; Rees 1991).

Studies conducted at Bozeman, Montana, established the following information: 1) *C. litura* spread up to 9 km in 10 years; 2) *C. litura* increased to infest more than 80% of Canada thistle stems in a 10-year period; 3) the infestation level of Canada thistle stems was not influenced by the presence or absence of surrounding vegetation; 4) many secondary organisms (mites, spiders, springtails, nematodes, and fungi) occur in *C. litura* mines; 5) the underground parts of shoots attacked by *C. litura* generally do not survive the winter; 6) underground parts of some unattacked plants also die in winter if they are connected by lateral roots to attacked plants; and 7) if a plant has at least one shoot attacked by *C. litura*, it produces less than two shoots during the following year (Rees 1991). Rees concluded that *C. litura* is an effective biocontrol agent. He noted that thistle stands were often able to maintain themselves by recruitment from plants that were not attacked, but if *C. litura* is supplemented by another biocontrol agent, the recruitment level will most likely be depressed below the replacement level.

Urophora cardui

Urophora cardui is a gall-producing fly whose native range includes Sweden, the Mediterranean, France, and Crimea (Peschken et al. 1982). Females deposit eggs at the growing tips of terminal or side shoots (Peschken et al. 1982). The larvae burrow into the stem and induce the plant to create large galls (Rees 1991). Larvae overwinter and pupate in the galls; the adults emerge in the following spring. There is one generation per year (Peschken et al. 1982; Rees 1991). Galls that develop near the terminal meristem can prevent the plants from flowering (Rees 1991). Peschken et al. (1982) found that the *U. cardui* galls caused only minor stress to the host plant, although past laboratory studies had indicated a significant reduction in Canada thistle vigor. *U. cardui* suffered a high mortality rate in this study. Peschken et al. recommended further investigation into the causes of the insect's mortality.

Rhinocyllus conicus

Rhinocyllus conicus attacks the seed heads of Canada thistle. Since the main propagation strategy of Canada thistle is to spread by its roots, *R. conicus* is likely to have a limited impact on plant populations (Rees 1991).

Cassida rubiginosa

This defoliating beetle appears to have been accidentally introduced into North America (Rees 1991). As a result, no host specificity studies or testing has been conducted. In a study by Forsyth and Watson (1984), *C. rubiginosa* did not produce sufficient defoliation to cause significant damage to Canada thistle plants. Ang et al. (1994) received favorable results by combining the biological control of *C. rubiginosa* with the planting of desirable vegetation that could compete against Canada thistle (in this case, crown vetch and tall fescue). *C. rubiginosa* already occurs in the eastern and central United States, but Rees (1991) recommended that further studies into host specificity be conducted prior to releasing this insect into other areas.

Puccinia punctiformis

Forsyth and Watson (1984) found that *P. punctiformis* significantly stressed Canada thistle and that systemically infected shoots rarely survive the season. Unfortunately the natural field level of this fungus is very low and rarely eliminates Canada thistle populations. Further research may determine whether this agent can become an effective means of control.

Burning

Hutchison (1990, 1992) found prescribed fire to be an effective and preferred treatment for controlling Canada thistle. Late spring burns, between May and June (in Illinois), are most detrimental and should be used whenever possible. Burns should not be conducted early in the spring, because early spring fires can increase sprouting and reproduction of this species. During the first 3 years of control efforts, burns should be conducted annually (Hutchison 1990, 1992).

Olson (1975, in Evans 1984) noted that May burns in North Dakota produced short-term increases in Canada thistle compared to a control plot, but thistle abundance declined below that of the control plot within two growing seasons. Immediate reductions in the thistle population followed June burns.

Walkup (1991) provided the following summary of fire effects on *Cirsium arvense* (see her report for references):

> Fire top-kills Canada thistle. . . . After top-kill, plants resume growth from perennating buds located on their roots. Total herbage production was unaffected following winter and spring prescribed fires in Oregon. Although there were fewer mature plants, the high density of new vegetative shoots compensated for the loss in herbage production. Patches of Canada thistle were reduced in Minnesota after 4 years of consecutive spring burning of low to moderate intensity. Density and aboveground biomass were unchanged after a spring fire (May, before growth began), and increased after both summer (August, peak of growth) and fall (October, winter dormancy) fires in Manitoba. The increase on fall fire was lower than on the summer fire.
>
> . . . Prescribed spring burning may be a useful means of slowing the spread of Canada thistle. Spring fires would reduce the number of mature plants. They

would also reduce the number of functional flower heads, resulting in lower seed production and a slow-down in the spread of new plants. Dormant-season fire is also beneficial to many native grass species, which would make stands more productive. Increased grass production would interfere with Canada thistle growth and reproduction, and possibly decrease its spread.

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INTEGRATED PEST MANAGEMENT FOR

CROWNVETCH, *Coronilla varia* L.

INTRODUCTION

Crownvetch (*Coronilla varia*) is a perennial legume that was introduced into North America probably some time in the 1800s. It is indigenous to Europe, southwestern Asia, and northern Africa (Gleason 1968). Crownvetch has been planted extensively in the United States for erosion control on highway embankments, pond slopes, mine spoils, and other highly disturbed, easily erodible grounds (Hoebeke et al. 1993; Swink and Wilhelm 1994). It is also used as a cover crop in no-till farming and as a forage crop (Hoebeke et al. 1993).

Crownvetch has been introduced or has become naturalized in much of the northern two-thirds of the United States (Phillips Petroleum Company 1963). It has been recorded in more than half of the counties in Illinois (Heim 1990). Crownvetch has spread from plantings and is quite a weed in some areas (Heim 1990; Swink and Wilhelm 1994). It has become a serious invader in some prairies and dune areas (Heim 1990). Crownvetch forms large monocultures that can completely shade out the ground below them. Eventually this shading results in reduced vegetation cover and increased erosion problems (Swink and Wilhelm 1994).

HABITAT

Crownvetch grows best in full sunlight and occurs in a wide variety of soils. Crownvetch grows well in almost any well drained soil, but in fertile soils, it can grow rampantly and be difficult to eradicate (Voigt et al. 1983). It can be found along roadsides and railroads, and in open fields (Heim 1990). It is planted on sites where erosion is a concern, especially highly disturbed areas with steep slopes.

LIFE HISTORY

Crownvetch is a perennial herbaceous legume that develops a heavy, multi-branched creeping root system. It reproduces readily by seed and spreads vegetatively by fleshy rhizomes. These rhizomes may extend 10 ft or more. New plants arise from nodes on the rhizomes, and a single plant may produce enough sprouts to cover 75 to 100 square ft in 4 years, under ideal conditions (Phillips Petroleum Company 1963).

Crownvetch flowers from the latter half of May through late September in northern Illinois (Swink and Wilhelm 1994). Seeds are produced in long finger-like, compartmentalized seed pods that ripen in late summer.

CONTROL METHODS

Little research has been done concerning the control or eradication of crownvetch. Most interest has been toward helping crownvetch become established, and improving its management and productivity.

Mechanical

Heim (1990) recommended late spring mowing of crownvetch in areas where this activity is feasible. Mowing must be conducted for several successive years to provide adequate control.

Little information is available concerning the effectiveness of mowing for controlling crownvetch. In a study to determine the best cutting times and frequencies for forage production, Brann and Jung (1974) found that cutting crownvetch in late May to early June provided succulent regrowth during late July in West Virginia. They found that cutting crownvetch at ground level doubled the number of stems as compared with other cutting heights (7.5 cm and 15 cm). They concluded that two cuttings per year resulted in equal or superior yield than three cuttings. Cutting at 15 cm resulted in higher carbohydrate reserve levels in the roots, probably because of the greater leaf area remaining and the reduced need to rely on root reserves for continued growth. Other than that, Brann and Jung found no consistent differences between cutting at 15 cm and at 7.5 cm.

Adequate control of crownvetch will most likely require a combination of mowing with other control mechanisms such as herbicides.

Chemical

Foliar applications of herbicides control crownvetch. The majority of these methods are not recommended for high quality natural areas or where surrounding vegetation is to be protected.

A foliar application of the herbicide 2,4-D amine can be used in the early spring when crownvetch is growing actively (Heim 1990). The herbicide should be applied with a hand sprayer at the recommended application rates on the label instructions. The amine formulation should be used rather than the ester formulation to avoid vapor drift. A 1% solution of Mecamine (2,4-D plus dicamba) is also effective as a foliar treatment (Heim 1990). Similarly, a 1 to 2% solution of Roundup (active ingredient: 41% glyphosate) is also effective as an early spring foliar application. Spring application may require repeated treatments in the following fall or spring to combat regeneration from seeds or roots (Heim 1990). Garlon 4 can be applied to mature plants (Solecki 1997).

A spring or fall burn conducted in the target area will remove accumulated litter and increase completeness of foliar coverage with the herbicide.

In the process of trying to learn what methods encourage the growth of crownvetch, we also learn what can hinder or control its growth. The following paragraphs describe two such studies. Some of their "negative" effects may provide information useful toward controlling crownvetch. Further investigation may indicate that these or similar treatments could be acceptable to control crownvetch in some situations. They are not recommended for use in high quality natural areas, or where surrounding vegetation might be affected, or where herbicide residuals in the soil might be a concern.

Crownvetch is sometimes used as a cover crop in no-till farm crops. Herbicides are used to suppress crownvetch early in the season to improve the productivity of the planted crops, yet allow the vetch to recover later in the season and provide protection as a groundcover. Cardina and Hartwig (1980) found that treatments with Atrazine plus Simazine plus dicamba (3,6-dichloro-o-anisic acid) work too well and suppressed crownvetch too severely to allow recovery.

Linscott et al. (1970) conducted a study to determine the best herbicides to control weeds in crownvetch. They found that crownvetch plants are severely reduced with EPTC at 4 lb per acre plus dinoseb at 1 lb per acre. Simazine and Bromacil both provided excellent weed control and severely retarded the growth of crownvetch. Linscott et al. found 2,4-DB to be the most damaging to crownvetch. More than 85% of the vetch plants sprayed were killed with a 2,4-DB solution at 1.5 lb per acre.

Biological

No published information was found concerning biological control agents for crown-vetch. Hoebeke et al. (1993) discussed a new pest of crownvetch. *Coleophora colutella*, a lepidopteran, is a European species that has been introduced into North America presumably in contaminated plant material. As of 1993, crownvetch is the only known host of *C. colutella* in North America. Larvae of *C. colutella* feed on the leaves of crownvetch, forming large white blotch mines (Hoebeke et al. 1993).

In a nursery field in Rhodesdale, Maryland, 60% mortality of crownvetch plants was caused by the organism *Pythium myriotylum*. Symptoms of the diseased plants included wilting, yellowing, defoliation of maturing plants, and rot of the root cortex. *P. myriotylum* caused substantial losses to the crownvetch crop over several growing seasons in the Rhodesdale fields (Dutky and Lumsden 1986).

Future research could determine whether these organisms will provide a reasonable biological control for crownvetch. Because crownvetch is a desirable plant in some situations, it may be difficult to develop a biological control that can be applied in areas where it is undesirable without affecting planted populations nearby.

Burning

In fire-adapted communities, prescribed burning in the late spring can control crownvetch seedlings, but mature plants are only top-killed and will resprout (Solecki 1997). Burning most likely needs to be combined with another control method, such a herbiciding, to adequately control seedlings and mature plants.

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INTEGRATED PEST MANAGEMENT FOR

CUT-LEAVED TEASEL, *Dipsacus laciniatus* L.

COMMON TEASEL, *Dipsacus sylvestris* Huds.

INTRODUCTION

Cut-leaved teasel (*Dipsacus laciniatus*) and common teasel (*D. sylvestris*) are non-native, invasive species that can become problems in natural areas (Glass 1990; Solecki 1993). The genus *Dipsacus* is native to Eurasia and northern and eastern Africa (Salamun and Cochrane 1974). *Dipsacus laciniatus* is considered native to southern Europe, south-western Russia, and Persia (Salamun and Cochrane 1974). Teasel was introduced into North America probably in the 1800s for ornamental purposes or accidentally in the form of toys, decorations, etc. (Werner 1975*a*). Another species, *D. fullonum*, was introduced and cultivated until 1950 for its head which was used to "tease" or raise the nap of wool (Mullins 1951; Werner 1975*a*).

Teasel has spread rapidly in the Midwest in the last 10 to 30 years (Glass 1990; Solecki 1993). Roadsides and cemeteries act as refuges from which teasel can invade nearby ecological communities. Natural areas in Illinois infested with large teasel populations often are adjacent to or near cemeteries or roads that harbor teasel populations (Solecki 1993). Natural communities in Illinois that have been invaded by teasel include high quality prairies, savannas, seeps, and sedge meadows (Glass 1990; Solecki 1993). If left untreated, both species of teasel can quickly form large, dense colonies that nearly exclude other species (Werner 1977; Glass 1990; Solecki 1993; Huenneke and Thomson 1995).

Solecki (1993) and Glass (1997) have found *D. laciniatus* to be much more robust and aggressive than *D. sylvestris* in Illinois natural areas. Until recent years, occurrences of *D. laciniatus* have been less prevalent than *D. sylvestris* (Gleason 1968; Salamun and Cochrane 1974; Werner 1975*a*), but *D. laciniatus* seems to be increasing rapidly in Illinois. Jones and Fuller (1955) reported *D. laciniatus* only from Cook County; by 1978 Mohlenbrock and Ladd reported it in 25 counties statewide. Swink and Wilhelm (1994) commented on the plant's increase from Jones and Fuller's reference to Cook County (1955) to its current presence in 14 counties in the Chicago area.

HABITAT

Optimal conditions for teasel are mesic habitats (Glass 1990; Solecki 1993), but occasionally it will be found in dry areas (Solecki 1993). Werner (1975*a*) found *D. sylvestris* on a variety of sites from sandy soil with abundant moisture, to heavy clay soil in poorly drained areas such as ditches or low spots. *Dipsacus laciniatus* has a narrower habitat range than that of *D. sylvestris*, and it prefers somewhat moister habitats (Werner 1975*a*). Teasel is found mainly in fallow cropland or hay fields, pastures, roadsides, open areas along ditches and creeks, and waste ground or other disturbed areas (Gleason 1968; Werner 1975*a*; Lorenzi and Jeffery 1987; Solecki 1993). Both species usually grow in open sunlight with leaf surfaces above dead plant litter or other vegetation (Werner 1975*a*; Glass 1990; Solecki 1993).

LIFE HISTORY

In northern Illinois *Dipsacus sylvestris* blooms from about June 22 through September 26, and *D. laciniatus* blooms from about July 4 through September 30 (Swink and Wilhelm 1994). Seeds mature and are dispersed in the fall, generally from September to November (Werner 1975*a*).

Werner (1975*a*) noted that *D. sylvestris* seeds germinate in early April to early June in Canada; a few germinate in early September. No cold treatment is needed to initiate germination. Seedlings develop rosettes and grow until late autumn.

According to Werner (1975*c*) *D. fullonum* rosettes must attain a minimum diameter of about 30 cm to produce a flowering stem. The amount of energy reserves (or size of the rosette)—rather than the age of the plant—is the deciding factor. A plant may stay in the vegetative rosette state for several growing seasons until it reaches this minimum size, although plants often are large enough by the second growing season. Because of this latter tendency, *Dipsacus* is often inaccurately classified as a biennial (Werner 1975*c*), but it is more appropriately considered a monocarpic perennial (Glass 1990; Solecki 1993).

Flowering stems generally begin growing out of the rosette base in May and reach full height by early July. Flowers are produced continually from July to early September (Werner 1975*a*). Phenology may vary somewhat depending on locale. No vegetative reproduction has been observed in *Dipsacus* (Werner 1975*a*).

Werner (1975*a*) calculated that a single teasel plant has a potential to produce approximately 3,333 seeds. Each inflorescence may average approximately 850 seeds; the number of seeds produced is directly related to the size of the flower head. Ninety-nine percent of the seeds are deposited within 1.5 m of the parent. Seeds can float in water for up to 16 days, making water a likely long distance dispersal mechanism (Werner 1975*a*).

The seeds tend to have a very high germination rate, 28 to 86% in field studies (Werner 1975*b*) and 95 to 99.6% in laboratory studies (Werner 1975*b*; Solecki 1989). Germination rates in the field are inversely correlated to the amount of litter cover

(Werner 1975*a*, 1975*b*, 1977). The growth form of teasel provides an advantage in its own colonization efforts. Teasel seeds require open spots at ground level for germination (Werner 1977). When a teasel rosette dies after producing a flowering stalk, an opening is created in the ground cover which is quickly colonized by teasel seedlings during the following spring. When conditions are favorable, teasel plants will largely exclude other species and often create near-monocultures locally (Werner 1977; Glass 1990; Solecki 1993; Huenneke and Thompson 1995).

Teasel has other attributes that aid its colonization. *D. sylvestris* has a large, well developed taproot that can exceed 75 cm in length. Both species are heavily armed with barbs and spines which protect the plants from grazing. In addition, as with many non-native species, both *D. sylvestris* and *D. laciniatus* are photosynthetically active for longer periods than most native species. Both species become green earlier in the spring and stay green longer in the autumn, giving them a growing advantage over many native species.

CONTROL METHODS

Mechanical

Manual methods that were employed for controlling teasel prior to the development of herbicides are still reliable today. Cutting or mowing the flowering stems of teasel provides one method of control if done before the flowering heads mature (Blatchley 1912; Long and Percival 1910; Georgia 1914; Werner 1975*a*; Glass 1990; Solecki 1993). According to Glass (1990) and Solecki (1993), flowering stems should be cut after flowering has started, but toward the latter period of development, usually late July or early August. Flowering stems should not be cut prior to flowering or early in flowering development because plants will usually produce a new flowering stalk. Cut stems should be monitored for re-flowering and cut again if necessary. All flowering heads should be removed from the site because the seeds continue to mature and can germinate even though the stalks have been cut. Several years of continued control probably will be necessary to deplete the seed bank (Glass 1990; Solecki 1993).

Rosettes can be destroyed from the roots in the fall or early spring with a spade, dandelion digger, or plow (Georgia 1914; Lorenzi and Jeffery 1987; Glass 1990). As much of the root as possible must be removed to prevent resprouting (Glass 1990).

Early detection is often the best protection against many exotic invasives. Sites should be monitored regularly for the presence of teasel.

Chemical

Herbicides are an effective means of control where other treatments are not feasible or other treatments alone are not effective. Glass (1990) and Solecki (1993) found a combination of cutting and herbiciding to be an effective control. In addition to cutting the flowering stems, rosettes are sprayed with a 1.5 to 2% solution of glyphosate (trade name Roundup) during early spring. Glyphosate is a nonselective herbicide, so caution must be taken to avoid contact with nontarget plants (Glass 1991).

The herbicides 2,4-D amine and tryclopyr amine (trade name Garlon 3A) are selective to broadleaf plants and will not harm most grasses. Tryclopyr and 2,4-D should be applied by hand sprayer at the application rate recommended on the label for spot-spraying weeds.

In natural areas, all of these herbicides are best applied during early spring or late fall when most surrounding, native vegetation is dormant (Glass 1990, 1991). Herbicides should be applied uniformly and should wet the entire leaf. Use of amine formulations rather than ester formulations reduces vapor drift (Glass 1990, 1991).

Werner (1975*a*) noted that the Ontario Herbicide Committee recommended repeated application of the herbicides 2,4-D, 2,4,5-T, or Silvex to control teasel.

Biological

No published information was found concerning biological agents used to control *Dipsacus*. Werner (1975*a*) noted that *D. sylvestris* plants are highly reduced in size in areas where cattle graze, possibly because of trampling of the rosettes. At Midewin National Tallgrass Prairie, grazing appears to maintain *D. sylvestris* in a dwarfed rosette stage, although populations can still be very dense.

Dipsacus seems to be relatively free from parasites and fungal infections (Werner 1975*a*), but Werner (1977) observed a stem-boring lepidopteran (*Papaipema cataphracta*) that occasionally infests some of the more shaded plants. This *Papaipema* feeds on the stem pith — which subsequently weakens the stem, hinders flower development, and therefore reduces the number of seeds produced (Werner 1975*a*, 1977).

Burning

Solecki (1993) found that burning does not control *D. laciniatus*. Dense colonies of the green rosettes do not burn well, and fire does not carry well through teasel-infested areas (Glass 1990; Solecki 1993). Even though isolated rosettes suffer fire damage in many instances, the core of the rosette remains undamaged, which allows the plant to recover

(Solecki 1993). Werner (1975*a*) noted that a new shoot may arise from the rootstock when the above-ground portion of a teasel rosette is clipped down to crown level. Plants with rosettes 10 cm in diameter grow new leaves more than half of the time (Werner 1975*a*). Late spring burns may help control teasel before it becomes dense, but prescribed burns probably will work best in combination with other control methods (Glass 1990).

Combined Methods

Glass (1997) recommended conducting a prescribed burn in the spring or fall (provided that enough fuel exists to carry the fire), then treating the rosettes with herbicide in early May (in northern Illinois). Re-treatments may be necessary to control missed or later-developing plants. Areas should be rechecked during flowering time to discover missed or new plants. All flowering heads should be cut and removed from the site. If the population does not occur in a sensitive natural area, plants can be herbicided again at this time; otherwise unnecessary damage may occur to non-target species. Areas should be rechecked regularly, and new sprouts or flowering heads should be removed as necessary.

Glass (1997) found that this combination of burning, cutting, and herbiciding works effectively to control teasel. Land managers emphasize that control of teasel with any method requires long-term monitoring and continued treatment until the seedbank is depleted.

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INTEGRATED PEST MANAGEMENT FOR

AUTUMN OLIVE, *Elaeagnus umbellata* Thunb.

INTRODUCTION

Autumn olive (*Elaeagnus umbellata*) is indigenous to China, Korea, and Japan (Olson 1974). It was introduced into North America for cultivation in 1830 (Rehder 1940). Autumn olive has been planted in the eastern and central United States for many purposes: ornamental shrubbery, wildlife cover and food, revegetation of strip mines, and shelterbelts. It has spread quickly from these plantings to invade roadsides, unmowed meadows, degraded open woods, and other agricultural land (Kuhns 1987; Swink and Wilhelm 1994). Sternberg (1982) warned that autumn olive has the potential of becoming one of the most troublesome adventive shrubs in the eastern and central United States.

Autumn olive was first planted in east-central Illinois in the 1970s, and by 1981 it had become naturalized in a variety of habitats (Ebinger and Lehnen 1981). It is a capable competitor against native species and has encroached into several natural areas in Illinois (Nestleroad et al. 1987; Szafoni 1990, 1991). It seems to be most problematic near plantings, from which it invades nearby areas (Ebinger and Lehnen 1981; Nestleroad et al. 1987; Eckardt 1995).

HABITAT

Autumn olive grows well in a variety of soils (Holtz 1981, in Eckardt 1995; Nestleroad et al. 1987). Because of its ability to fix nitrogen, autumn olive can grow in very poor soils (Fowler and Fowler 1987). Mature shrubs tolerate light shade, but produce more fruit in full sunlight (Holtz 1981, in Eckardt 1995). Autumn olive occurs in disturbed areas, fallow or successional fields, pastures, and roadsides (Kuhns 1987; Szafoni 1990, 1991). It has invaded several types of natural areas, including prairies, open woodlands, and forest edges (Szafoni 1990, 1991).

Nestleroad et al. (1987) observed that autumn olive does not spread into areas of dense woods or areas with dense grass cover that are mowed regularly. It does not appear to adapt to very wet areas (Szafoni 1990, 1991).

LIFE HISTORY

Autumn olive is a fast growing, non-leguminous, nitrogen-fixing shrub or small tree that grows to heights between 3 and 12 ft at maturity (Olson 1974). It is one of the earliest shrubs to break dormancy in the spring. Autumn olive usually starts leafing out about mid-March in southern Illinois and advances north with the season about 100 miles per week (Sternberg 1982). Flowering occurs from early May to June (Olson 1974; Swink and Wilhelm 1994). The fruit is small and drupe-like, containing a dry, indehiscent achene surrounded by a fleshy perianth (Olson 1974). Fruits ripen in August to October and generally are dispersed from September to November (Olson 1974). Seeds require cold stratification to germinate; the optimum time period is 16 weeks (Olson 1974; Fowler and Fowler 1987).

The seeds are consumed and dispersed primarily by birds (Olson 1974; Nestleroad et al. 1987), but as Fowler et al. (1982) found, foxes consume enough seeds to be considered an important dispersal mechanism. Other mammals have been documented feeding on autumn olive fruit and most likely also contribute to the dispersal of this shrub (Nestleroad et al. 1987).

Olson (1974) mentioned that autumn olive attains a minimum age of 6 years before producing fruit, but Nestleroad et al. (1987) and Sternberg (1982) found that reproduction occurs at 3 to 4 or 3 to 5 years, respectively, in Illinois. An individual plant can produce 2 to 8 lb of seeds per year (Sternberg 1982). The number of seeds per lb can range from 20,000 to 54,000 (Sternberg 1982).

Autumn olive has many characteristics that contribute to its invasive success, including its rapid growth, adventive nature, high fruit production, dispersal of seeds by birds and mammals, and ability to grow in a wide variety of habitats—aided by its nitrogen-fixing capabilities.

Control Methods

Mechanical

Young seedlings and sprouts can be hand-pulled in early spring. This should be done when soil is moist enough to allow removal of the roots. Autumn olive leafs out earlier in the spring than many native shrubs, which aids in its detection (Szafoni 1990, 1991).

Cutting autumn olive without herbicide treatment will not provide effective control. Shrubs resprout vigorously, and each regrowth results in a thicker stem and more branches (Sternberg 1982; Szafoni 1990, 1991).

Chemical

Herbicide is needed in combination with cutting to efficiently control autumn olive and prevent the shrubs from resprouting. A 10 to 20% solution of Roundup (active ingredient: 41% glyphosate) should be applied to the cut stump (Nyboer pers. comm. and

Kurz pers. comm., in Eckardt 1995). Herbicide can be applied with a hand-held sprayer or wiped on the stump with a sponge applicator. The Roundup label calls for a 50 to 100% solution for stump treatments, but lower concentrations have proven effective on several shrub species (Kline 1981; Nyboer 1992; Glass 1994). Herbicide should be applied immediately after cutting for the best results. According to the herbicide label, best results are obtained if Roundup is applied during active growth and full leaf expansion. It is particularly effective when applied late in the growing season (July through September) when the plants are actively translocating resources to the root system (Szafoni 1990, 1991; Eckardt 1995). In natural areas and where protection of neighboring plants is of concern, herbicides should be applied during early spring or in the fall when most native vegetation is dormant and the potential for injury is reduced.

Most of the following herbicide applications are best used on buffer or severely disturbed areas and are not recommended for high quality natural areas or where surrounding vegetation is to be protected.

Kuhns (1987) tested the effectiveness of various rates of several herbicides on autumn olive. Foliar applications in late June of dicamba (trade name Banvel) at 2 qt per 100 gal per acre plus a surfactant provided 90% total kill of the shrubs. Foliar applications of 2,4-D/2,4-DP, triclopyr, and 2,4-D/triclopyr did not provide total control, but complete coverage of foliage was not possible and stems that were not herbicided continued to grow throughout the season.

Dicamba and 2,4-D are herbicides selective for broadleaf plants. Applicators should take care to avoid contact with non-target broadleaf vegetation. These herbicides should be applied during the growing season, and 100% of the foliage should be covered to receive the best results (Szafoni 1990, 1991).

Kuhns found that triclopyr (trade name Garlon) alone or in combination with 2,4-D as a basal application provides excellent control of autumn olive at low concentrations. Basal bark treatments were applied on March 15. Basal bark treatments (covering 12 inches of the stem) of full strength triclopyr provided almost immediate 100% kill by March 29. Thin-line basal bark treatments of full strength triclopyr provided 99% and 95% kill of the shrubs by July 11. Basal bark treatments with half-strength triclopyr also provided complete kill by March 29, as did a thin-line application of 2,4-D/triclopyr at full strength. Dilutions were made with diesel fuel.

Effects of basal bark treatments were tested down to rates of 1% solutions of triclopyr and 2,4-D/triclopyr. Kuhns found that the lower concentrations works effectively (provided total kill), but take longer.

Diesel fuel can damage surrounding vegetation and should not be used in high quality natural areas. Several other oil diluents can be used with Garlon 4. Garlon 4 should not be used if rain is in the forecast for the following 1 to 4 days (Szafoni 1990, 1991).

Glyphosate (trade name Roundup) was not tested by Kuhns. According to Eckardt (1995), Roundup (active ingredient: 41% glyphosate) is an effective foliar spray at a 1 to 2% solution. This treatment is not recommended in natural areas or where surrounding vegetation is to be protected because Roundup is a non-selective herbicide that can cause unnecessary damage to surrounding vegetation (Szafoni 1990, 1991).

Biological

No published information was found concerning biological agents used to control autumn olive.

Burning

Prescribed burning is not recommended as an effective control mechanism for autumn olive. Burning, like cutting, results in numerous resprouts from the damaged stems (Kuhns 1987).

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INTEGRATED PEST MANAGEMENT FOR

LEAFY SPURGE, *Euphorbia esula* L.

INTRODUCTION

Leafy spurge (*Euphorbia esula*) is native to Europe. Selleck et al. (1962) used several references to ascertain the extensive global range of leafy spurge. It is reported as occurring worldwide except in Australia and polar regions. Leafy spurge extends across northern and southern Europe, with its distribution center in the Caucasus. It was first collected at Newbury, Massachusetts, in 1827 (Bakke 1936) and is thought to have arrived in Minnesota in 1890 with oats from Russia (Kommedahl and Johnson 1969). It has become naturalized in much of the northern United States.

Leafy spurge has been a weed control problem in North Dakota for more than 50 years (Messersmith and Lym 1990). It spreads rapidly and is considered a dangerous weed to become established anywhere (Steyermark 1981). Swink and Wilhelm (1994) mentioned that it is becoming a serious pest in northwestern Illinois but is still uncommon in the Chicago region. Leafy spurge is not yet a serious problem in the remainder of Illinois, but, as many researchers indicate, early detection and treatment are imperative for its prevention.

A latex is present in the entire plant in all stages from early emergence until late maturity (Selleck et al. 1962). The latex can cause scours and weakness in cattle, often resulting in death (Muenscher 1939). In badly infested fields, horses have been reported to have suffered blistering of the skin and loss of hair from their fetlocks where they come in contact with the milky sap (Muenscher 1939; Steyermark 1981).

HABITAT

Leafy spurge invades many types of habitats, including pastures, roadsides, idle lands and fields, railroad rights-of-way, and open-grown woods (Selleck et al. 1962; Best et al. 1980; Cole 1990, 1991; Swink and Wilhelm 1994). It adapts to a wide variety of habitats, soils, and conditions that are unfavorable to the growth of most plants. It can even survive long prolonged flooding (4.5 months in potted plants) if the shoots can grow above the water surface (Selleck et al. 1962).

Infestations are most common in abandoned or disturbed lands, cultivated fields, and overgrazed pastures (Selleck et al. 1962). Natural communities that are susceptible to leafy spurge invasion include open areas such as disturbed or undisturbed dry to mesic prairies, and possibly savannas (Cole 1990, 1991).

LIFE HISTORY

Leafy spurge is a perennial herbaceous plant of the Euphorbiaceae (spurge family) that reproduces vigorously from seeds and rhizomes. The plants develop a deep, woody root system that makes eradication difficult. The stems of leafy spurge range from 8 to 36 inches high and often branch below the soil surface to produce erect clumps. Stems are pale green in summer, but become red in the fall (Selleck et al. 1962).

The root system consists of long and short horizontal and vertical roots. The vertical roots usually average 2.4 m deep and can reach depths of 9 m (Bakke 1936). Vegetative reproduction from adventitious buds along the horizontal roots is the main mechanism of spreading once plants are established. Shoots die back at the end of the growing season, leaving a vertical underground stem (Best et al. 1980).

As stated by Selleck et al. (1962), "leafy spurge displays a remarkable capacity for vegetative reproduction." Selleck et al. found that the periphery of leafy spurge patches could grow outward an average of 1.64 to 2.09 ft (0.5 to 0.6 m) per year depending on conditions and habitats. Patches in ungrazed native grasslands displayed the largest average spread in Saskatchewan.

Shoots and seedlings emerge in the early spring, usually when temperatures fluctuate around freezing (Cole 1990, 1991; Swink and Wilhelm 1994). Seedlings are often deep red or purplish during this time (Cole 1990, 1991). Selleck et al. (1962) found that the shoots from perennial roots generally emerge earlier than seedlings in the spring.

Flowering occurs from the middle of May until early October in northern Illinois (Swink and Wilhelm 1994). The flower cluster (cyathium) usually consists of about 15 to 20 single, stalked, staminate flowers, and a single pistillate flower. The whole cluster is enclosed by two yellowish-green involucral bracts 1 to 1.3 cm long, which may give the impression of a larger flower. The inflorescence becomes more yellow with maturity (Selleck et al. 1962).

Seeds mature within about 30 days after the appearance of female flowers. Seed development continues throughout the season until about 30 days beyond the appearance of the last female flower (Selleck et al. 1962). As a result, flowering and seed production are continuous from about May through November in northern Illinois. The mature seed capsules rupture and expel the seeds up to 15 ft (4.6 m) from the parent plant (Bakke 1936). Flowering shoots produce an average of 10 to 50 capsules, and each capsule can average between 196 and 252 seeds, depending on conditions (Selleck et al. 1962). Animals (including birds and insects) and water are also agents of dispersal (Selleck et al. 1962).

Most seeds germinate in the spring. The majority of the seeds (99%) germinate within 2 years after dispersal, under favorable conditions (Selleck et al. 1962). Selleck et al. reported that seeds retain 10% or more germination until the eighth year, and some viability remains after 13 years under laboratory conditions. Martin (1994) recorded a re-appearance of a patch of leafy spurge 7 years after eradication, with no individuals emerging in the interim. As a result Martin suggested that patches be monitored for at least 10 years.

Leafy spurge seedlings develop an extensive root system in a short time. Within 7 to 10 days after seedlings emerge, vegetative buds have developed on the hypocotyl. These buds can produce shoots if the seedling is cut 1 inch below the soil surface (Selleck et al. 1962). In favorable conditions, horizontal roots can develop by the middle of the first growing season. Competition from surrounding vegetation can severely restrict the growth of seedlings (Best et al. 1980). In areas of high competition such as most grasslands, horizontal roots may not develop until the second or third season (Raju et al. 1963). In an area free from competition, leafy spurge seedlings can flower and produce seed within the first year (Morrow 1979), but under most conditions plants set seed in their second year (Selleck et al. 1962).

Light is a limiting factor for germination, shoot survival, and flowering (Selleck et al. 1962; Best et al. 1980).

CONTROL METHODS

Leafy spurge has been a significant pest for several years, especially in the northwestern United States. Several methods have been tested and employed to control its invasion and spread, ranging from mowing, to application of herbicides, to grazing by goats and sheep. The main concern in the West is the preservation and reclamation of grazing lands for livestock. Infestations are often very large, and control methods must accommodate these situations. Methods to best control leafy spurge have long been studied in the western states and the references are seemingly endless. Several information sources are available if further reading is desired. The *Leafy Spurge Newsletter* is dedicated to the management and control of leafy spurge. Many of the references cited here were received from "Purge Spurge: Leafy Spurge Database" version 3.0, which is available on CD-ROM through the U.S. Department of Agriculture.

Leafy spurge at Midewin National Tallgrass Prairie was found in one patch of relatively few individuals. The majority of control methods presented here focus on those suited to the present condition of the spurge infestation on at Midewin National Tallgrass Prairie, with suggestions for options if the species becomes a large-scale problem.

As the majority of managers and researchers emphasize, an invasion of leafy spurge should be controlled immediately — as soon as the first few individuals appear. The sooner it is treated, in its first year if possible, the better the chance of control (Cole 1990, 1991; Lym 1994).

Martin (1994) discussed several important factors to consider when trying to control leafy spurge and other exotic invasives, including: 1) working with neighbors to control invasive species on surrounding properties (this is especially important with such persistent species as leafy spurge and spotted knapweed that can pose severe, long-term problems if undetected), and 2) continued extensive searches to map new or undocumented populations of the species. Finding new patches that originate from seed sources can be very difficult.

Martin (1994) cautioned that areas should be monitored for at least 10 years even if a patch is considered eradicated, because seeds can remain viable in the soil for several years.

Mechanical

Leafy spurge is very resilient and can recover from severe disturbance. Selleck et al. (1962) reported that the removal of the surface 1 ft of roots and rhizomes does not significantly affect the plant's density or vigor. Removal of 2 ft of underground roots and rhizomes results in decreased top-growth densities, but the plants sometimes recover even after removal of the upper 3 ft of underground parts.

According to Cole (1990, 1991), hand-pulling, digging, and tilling are not effective unless complete eradication of the root system can be achieved. These methods can result in fragmented root segments which sprout and spread the population. Mowing or cutting is not completely effective because the roots remain undamaged. Mowing can stimulate the growth and development of lateral branches, which can increase the number of inflorescences.

Plumb (1986) found that repeated topping of leafy spurge can temporarily reduce stem density, but he felt that the tenacity of the root system and resprouts would render this treatment ineffective over the long term.

Messersmith and Lym (1990) concurred that mowing and burning have been ineffective in reducing leafy spurge, but these treatments may provide uniform regrowth that increases the effectiveness of herbicides.

Selleck et al. (1962) reported that repeated hoeing of small patches every time growth appears is an effective method of eradication. They observed that root resources are exhausted within about 3 years if vegetation is not permitted to grow higher than about 2 inches throughout the growing season. This method is often impractical with large infestations, but may help eradicate small patches.

Chemical

As mentioned by Lym (1994), almost every herbicide on the market has been tested on leafy spurge since the development of 2,4-D in the 1940s. Herbiciding is the most common means to control leafy spurge on rangelands. Many researchers comment that herbicides limit leafy spurge by reducing stem density and decreasing the spread of the patches, but they do not necessarily eradicate large populations. Persistent herbicide treatments can eventually eradicate small populations, but large patches require continuing control (Lym 1994).

Herbicides most commonly used on rangelands to control leafy spurge include 2,4-D, dicamba, glyphosate, and picloram. Picloram, dicamba, and 2,4-D are selective for broadleaf plants. Glyphosate is non-selective and controls both grasses and broadleaf plants (Lym 1994).

Picloram plus 2,4-D at a rate of 0.28 kg plus 1.1 kg ae (acid equivalent) per ha is the most widely used treatment for both leafy spurge control and improved forage production (Lym and Messersmith 1990). Biesboer et al. (1994) found that picloram applied in the fall at a rate of 0.5 and 1.0 lb ai (active ingredient) per acre is very effective at targeting leafy spurge crown buds; this treatment significantly reduces above-ground cover for two years. Martin (1994) had success treating patches of leafy spurge with picloram (Tordon) at 2 lb per acre using pump sprays, backpack sprayers, or small booms on an ATV four-wheeler. Martin recommended that patches be rechecked for new shoots within 2 weeks to a month.

Glyphosate applied with 2,4-D in early summer provides better control than glyphosate applied alone, and injury to grass is minimal (Lym 1994). Glyphosate at 0.38 lb per acre applied with 2,4-D at 0.34 lb per acre or with dicamba at 0.172 lb per acre has provided an average of 60 to 70% leafy spurge control with 30 to 40% grass injury 9 months after treatment (August and September) in western states (Lym et al. 1991).

Low rates of glyphosate do not provide control for long. In Minnesota Biesboer et al. (1994) found that fall applications (October) of glyphosate at 1.0 lb ai per acre reduces leafy spurge coverage initially, but results in a significant increase in the above-ground cover by the following summer.

Messersmith and Lym (1990) reported that leafy spurge is most susceptible to 2,4-D, dicamba, and picloram during flowering development, which is from mid to late June in Illinois. Glyphosate appears to be most effective about the time of seed dispersal (late July to early August in North Dakota). The second most effective time to apply these herbicides is when leafy spurge undergoes its fall regrowth, in early to mid-September in Illinois, but before a killing frost.

Lym (1994) noted that most herbicides that effectively control leafy spurge must be applied at relatively high rates and have long residual life in the soil; therefore they often cannot be applied to environmentally sensitive areas. Glyphosate plus 2,4-D is an exception, but severe grass damage will result if this treatment is applied to the same area in two consecutive years (Lym 1994). Picloram (trade name Tordon) has not been approved for use on high quality natural areas in Illinois (Cole 1990, 1991).

On natural areas, a 2% solution of 2,4-D can be applied as a foliar spray twice a year to control top-growth of leafy spurge (Cole 1990, 1991). Cole recommended applying the first treatment during mid to late June, when plants are flowering in Illinois. The second treatment should be applied during early to mid-September during fall regrowth.

A 5% solution of Roundup (active ingredient: 41% glyphosate) applied as a foliar spray will provide 80 to 90% control of leafy spurge (Cole 1990, 1991). Roundup should be applied between mid-August and mid-September. A follow-up treatment with a 2% solution of 2,4-D amine should be applied between mid-June and mid-July of the following year to control seedlings (Cole 1990, 1991).

In an initial study, Glass (1992) received excellent control of leafy spurge with a 3% solution of fosamine (trade name Krenite), plus 28.35 g (1 oz) of X-77 surfactant and 28.35 g (1 oz) of blue tracer dye per 7.6 liters (2 gal) of fosamine solution. Fosamine appeared to completely eliminate leafy spurge shoots without damage to surrounding vegetation. Fosamine is selective to several woody species and a few non-woody plants. Further study and observation will determine whether cumulative effects of the herbicide will result in damage to the surrounding non-target vegetation.

Biological

Research to find biological control agents for leafy spurge has been under way for several years. Seven insects have been released in North Dakota to control leafy spurge. Four root-feeding beetles (*Aphthona cyparissiae*, *A. flava*, *A. czwalinae*, *A. nigriscutis*) have had the most effect on leafy spurge (Messersmith and Lym 1990; Lym 1994).

Other agents have also been studied for leafy spurge biocontrol, such as *Alternaria tenuissima* f. sp. *euphorbiae*, *Melamspora* spp., and *Uromyces striatus*, but none has effectively reduced spurge populations (Messersmith and Lym 1990). Yang and Jong (1995) found that *Myrothecium verrucaria* could severely damage leafy spurge top-growth, but was ineffective in killing plants with root buds; therefore they concluded that this organism has little potential as a biological control pathogen for leafy spurge.

Grazing by goats and sheep has been used on rangelands in western states to control large populations of leafy spurge. Grazing can reduce stem density and prevent flowering and seed production. Sedivec and Maine (1993) recommended a stocking rate of at least 6.7

Angora goats per acre per month or 1.5 goats per acre for 4.5 months. This method is not likely to be practical on small patches of leafy spurge or in sensitive natural areas.

Cattle and horses normally do not eat leafy spurge unless no other forage is available (Montgomery et al. 1956, in Best et al. 1980); therefore they would not provide an effective biological control. Overgrazing, on the other hand, bares the soil and provides areas suitable for leafy spurge invasion and establishment (Selleck et al. 1962). Messersmith and Lym (1990) noted that "as a somewhat 'tongue-in-cheek' benefit, sometimes leafy spurge competition is less detrimental to the survival of native plant species than overgrazing by cattle."

Burning

Used alone, prescribed burning is not considered an effective method to control leafy spurge. Burning in the spring (late April to mid-May) stimulates leafy spurge stem production (Cole 1990, 1991; Masters 1994; Wolters et al. 1994), but can effectively reduce survival of seedlings (Wolters et al. 1994).

Burning can aid management by increasing the visibility of the plants and eliminating interference from litter, which may increase the effectiveness of herbicide applications (Martin 1994). The growth stimulation that results from burning may increase the plant's susceptibility to herbicides (Cole 1990, 1991; Masters 1994).

Several researchers have observed that increases in interspecific competition decreases coverage of leafy spurge (Selleck et al. 1962; Best et al. 1980; Biesboer et al. 1994). Prescribed burning generally enhances the health of many natural communities. In areas where native species occur, either vegetatively or in the seedbank, fire may improve the ability of local species to compete against leafy spurge and reduce its coverage.

Combined Methods

As mentioned by many researchers and emphasized by Lym (1994), no single treatment will eradicate leafy spurge, especially large populations.

Combined treatments of prescribed burning and herbicides may be more effective than either method alone. Burning can stimulate growth, supplying more surface area for herbicide application and increasing the plant's vulnerability to the treatment (Cole 1990, 1991; Martin 1994). Cole suggested spraying plants with 2,4-D during the fall, about September, and burning the following spring, about April. This treatment should be followed by another spraying of 2,4-D in June and a burn in October. This process may need to be repeated several times.

Wolters et al. (1994) recommended that the best all-around treatment for reducing both the germination and stem density of leafy spurge would be a fall application of picloram plus 2,4-D followed by prescribed burning in the spring. Wolters et al. found that burning in the spring, with or without herbicide application, provides the most effective treatment to reduce leafy spurge germination; herbicides with or without burning provide the best treatment for reducing leafy spurge stems.

Selleck et al. (1962) recommended using a vigorous, competitive grass, such as crested wheat grass (*Agropyron cristatum*), to increase competition against leafy spurge and reduce its vegetative spread. The herbicide 2,4-D should then be applied to these stands at a rate of 2 lb per acre as spurge regrowth occurs throughout the season (as many as 5 times annually). This combination can reduce the density of leafy spurge vegetative growth by 95 to 98% and, if continued for 2 to 3 years, results in eradication.

Biesboer et al. (1994) found that plantings of little bluestem (*Schizachyrium scoparium*) as a monoculture or in combination with side-oats grama (*Bouteloua curtipendula*) and buffalo grass (*Buchloë dactyloides*) significantly reduce coverage of leafy spurge. Glyphosate applied to the site at 1.4 lb ai (active ingredient) per acre followed by disking provides a very effective site preparation prior to seeding the grasses. This reduces the cover of leafy spurge enough to allow establishment of the grasses.

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INTEGRATED PEST MANAGEMENT FOR

BUSH HONEYSUCKLES

Lonicera maackii (Rupr.) Maxim., *L. tatarica* L., *L.* x *bella* Zabel, and *L.* x *muendeniensis* Rehder

INTRODUCTION

Several bush honeysuckle species have been introduced into the United States. Many were planted throughout the northern United States (especially the eastern states) and in southeastern Canada for wildlife habitat and ornamental purposes (Jackson 1974; Brinkman 1974). They have since escaped cultivation and have aggressively invaded many grasslands, woodlands, and disturbed areas (Pringle 1973; Clark 1984; Nyboer 1990, 1992; Williams et al. 1992; Woods 1993; Swink and Wilhelm 1994; Luken and Thieret 1996).

Four bush honeysuckles that have become invasive problems in Illinois include *Lonicera tatarica*, *L.* x *bella*, *L.* x *muendeniensis*, and *L. maackii*. *Lonicera tatarica* originated in Turkey and southern Russia and was introduced into the United States in 1752 (Brinkman 1974). *Lonicera* x *bella* is a hybrid between *L. tatarica* and *L. morrowii*. *Lonicera* x *muendeniensis* is a hybrid that originated from the seed of *L.* x *bella* in a botanical garden at Münden, Germany (Swink and Wilhelm 1994). *Lonicera maackii* is a native of Manchuria, China, Japan, eastern Siberia, and Korea (Brinkman 1974; Clark 1984) and was introduced into the United States about 1855 to 1896 (Brinkman 1974; Luken and Thieret 1996). *Lonicera maackii* is of the most recent concern; as stated by Swink and Wilhelm (1994), "It would be difficult to exaggerate the weedy potential of this shrub."

Bush honeysuckles produce abundant fruit which is readily dispersed by birds. This enables plants to spread extensively from locations where they are planted (Clark 1984). Those concerned with the impact of these species on native woodlands most likely agree with Clark (1984) when he stated, "for the sake of the future ecological integrity of native woodlands, it [Amur honeysuckle] should not be planted in most areas."

HABITAT

Native habitats of *L. maackii* and *L. tatarica* include floodplains, forests, open woodlands, and marshes (Woods 1993; Converse 1995; Luken and Thieret 1996). In the United States, most bush honeysuckle species are very hardy plants that have adapted to a wide variety of soils, moisture regimes, temperature ranges, and habitats (Pringle 1973; Jackson 1974; Clark 1984; Nyboer 1990, 1992). They tend to be moderately shade tolerant to moderately shade intolerant (Clark 1984; Nyboer 1990, 1992; Luken 1993; Converse 1995; Luken and Thieret 1996). As a result, they have successfully invaded several types of habitats in the eastern United States and southeastern Canada, including disturbed areas and waste grounds, forest edges, forest clearings, pastures, and fencerows (Pringle 1973; Swink and Wilhelm 1994; Luken and Thieret 1996).

Most natural communities are susceptible to invasion by one or more bush honeysuckle species. Communities affected in Illinois include lake and stream banks, marshes, fens, sedge meadows, wet and dry prairies, savannas, and floodplain and upland forests (Nyboer 1990). Once established on a site, honeysuckle can persist indefinitely unless removed.

Bush honeysuckles can quickly colonize woodlands, where they often form an almost impenetrable understory that shades out or prevents growth of native shrubs, tree seedlings, and herbaceous species (Clark 1984; Nyboer 1992; Woods 1993). The soil beneath honeysuckle shrubs is often bare (Converse 1995).

LIFE HISTORY

Bush honeysuckles are upright, multi-stemmed, deciduous shrubs that can grow to heights of 3.5 to 6 m (Luken and Thieret 1996). In northern Illinois, *L. maackii* and *L.* x *bella* begin blooming in early May and continue until about June 10; *L. tatarica* and *L.* x *muendeniensis* bloom from early May to late May (Swink and Wilhelm 1994).

Most bush honeysuckles produce abundant fruits which are readily consumed and dispersed by birds (Pringle 1973; Jackson 1974; Brinkman 1974; Ingold and Craycraft 1983; Clark 1984; Luken and Thieret 1996). Often plants can be found growing under tall shrubs or trees that have been used as perches (Nyboer 1990). Bush honeysuckles are long-lived plants that generally begin producing fruit between 3 and 5 years of age (Jackson 1974; Luken and Thieret 1996). Each berry contains few to many seeds, depending on the species (Brinkman 1974). Fruit ripen in mid-to-late summer and persist until early fall (Jackson 1974; Clark 1984). Pre-germination requirements vary, but the seeds of most species appear to require some type of cold stratification (Brinkman 1974; Nyboer 1990, 1992).

A major factor limiting the growth and spread of bush honeysuckle is low light levels during the seedling stage (Luken 1993; Luken and Goessling 1995; Luken and Thieret 1996).

Open-grown honeysuckle shrubs resprout readily from the base when cut, but forest-grown shrubs show less tolerance of this stress (Luken and Mattimiro 1991).

Bush honeysuckle breaks dormancy much earlier in the spring than many other species, and it holds its leaves much later in the fall, until November in Illinois (Nyboer 1990, 1992; Woods 1993; Luken and Thieret 1996). This characteristic combined with the plant's high reproductive rate and environmental adaptability give bush honeysuckle several advantages for colonizing natural communities.

Control Methods

Mechanical

Methods to control bush honeysuckle manually include grubbing the roots, pulling seedlings and small individuals, and cutting stems (Nyboer 1990, 1992; Converse 1995). Seedlings are most easily pulled when the soil is moist. Because of their early leaf expansion, honeysuckle seedlings are more noticeable early in the season while most native plants are dormant. Care must be taken to remove as much of the root as possible to help prevent resprouting (Nyboer 1990, 1992). Mature plants can be grubbed; but as with seedlings, all of the large roots should be removed. Grubbing or hand pulling of plants can significantly disturb the soil, which can aid re-invasion or resprouting by honeysuckle or invasion by other undesirable species. These methods should be avoided in sensitive natural areas or other localities where invasion of exotics is a concern (Nyboer 1990, 1992; Converse 1995). Stems of mature plants can be cut at the base; this also results in resprouting, but may temporarily reduce seed sources (Kline pers. comm. 1983, in Converse 1995).

Luken and Goessling (1995) found that the density of native tree seedlings increased after a single cutting to remove honeysuckle from a forest understory. They also found that honeysuckle seedlings increased twofold. Converse (1995) also warned of this possibility. Sites should be regularly monitored to check for re-invasion and resprouting, and seedlings should be pulled as necessary.

Adequate manual control of bush honeysuckle will most likely require some appropriate combination of several of the above methods.

Chemical

Herbicide is often needed in combination with other methods to efficiently control species that resprout after cutting. To prevent resprouting of bush honeysuckle, a 20% solution of Roundup (active ingredient: 41% glyphosate) can be applied to the cut stump (Nyboer 1990, 1992). Herbicide can be either applied with a hand-held sprayer or wiped on the stump with a sponge applicator. The Roundup label calls for a 50 to 100% solution for stump treatments, but a 20% solution has been proven to be effective (Kline 1981; Nyboer 1990, 1992; Conover and Geiger 1993). Herbicide should be applied immediately after cutting for the best results. According to the herbicide label, best results are obtained if Roundup is applied during active growth and full leaf expansion. But on natural areas and where protection of neighboring plants is of concern, herbicide should be applied during early spring or in the fall when most native vegetation is dormant and potential for injury is reduced. Rodeo is another glyphosate product that can be applied in wetlands and over open water. Roundup is only approved for use in non-wetlands. The Rodeo label calls for a 50 to 100% solution for cut stumps; effectiveness of lower concentrations has not documented for this product (Nyboer 1990, 1992).

A foliar spray of 1 to 1.5% Roundup can be used on seedlings and mature plants, but this method should be reserved for areas where concern for surrounding vegetation is not as crucial as on high quality natural areas (i.e., severely disturbed sites, buffer zones, or patches where honeysuckle is basically a monoculture and native vegetation does not occur) (Nyboer 1990, 1992; Conover and Geiger 1993). This method may be necessary on disturbed or buffer sites that lack enough fuel to carry a fire (Nyboer 1990, 1992). Conover and Geiger (1993) found that the most effective time to apply the herbicide is when the leaves are fully expanded, but still light green and not yet leathery. In the Dayton, Ohio area, a month-long window for application starts about mid-May (Conover and Geiger 1993). In northern Illinois, Nyboer (1990, 1992) recommended applying herbicide to mature shrubs just after blooming in June. Application should occur from late June to just prior to leaf-color changes in the fall. Conover and Geiger (1993) noted that the spray must reach most of the leaves on all the major branches. If a section of a bush is left unsprayed, the stem and roots of that segment will survive.

In wet areas, a foliar spray of 1% Rodeo will control seedlings, and a 1.5% spray will control mature plants (Nyboer 1990, 1992). Timing of application is similar to that of Roundup.

In less dense patches or where surrounding vegetation is of concern, Conover and Geiger (1993) had some success applying foliar spray in the fall when adjacent native vegetation was dormant. They found 80% mortality on honeysuckle shrubs in the shaded woodland interior, but less for shrubs growing in higher light conditions. Conover and Geiger (1993) and Luken and Goessling (1995) found that native herbaceous and woody plants characteristic of oak-hickory and mesic woodlands appear after honeysuckle is eliminated. Honeysuckle seedlings also emerge, but Conover and Geiger (1993) found them easy to control with late fall herbiciding.

Kline (pers. comm. 1983, in Converse 1995) mentioned that 2,4-DP and 2,4-D in a 1:8 mixture with diesel fuel provided about 86% control when applied to the base of uncut plants in various habitats. Diesel fuel generally has undesired effects on surrounding vegetation; therefore this solution is not recommended where surrounding vegetation is to be protected.

Nyboer (1990, 1992) noted that Krenite controls bush honeysuckle when applied according to label instructions.

Biological

No biological control agents are acknowledged in the literature for bush honeysuckles, but a recently introduced aphid (*Hyadaphis tataricae*) is rapidly becoming a pest on ornamental honeysuckles in the north-central United States (Voegtlin 1982). *H. tataricae* was first found in North America in Quebec Province about 1976 (Boisvert et al. 1981). It was first observed in the United States in 1979, in the northeast corner of Lake County, Illinois (Voegtlin 1981). It has since spread very rapidly into Ohio, Wisconsin, Michigan, Minnesota, Iowa, and Nebraska (Mahr and Dittl 1986, Coffelt and Jones 1989). The spread seems to often be aligned with major highway systems and may have resulted from movement and transfer of infested honeysuckle stock that often landscape these systems (Voegtlin 1982).

H. tataricae feeds on the new, succulent growth at the terminal portions of the stems (Mahr and Dittl 1986, Coffelt and Jones 1989). This results in stunted leaves which fold upward along the midvein to enclose the aphids. Terminal shoots are killed, but secondary buds develop and produce very obvious, unsightly "witches' brooms" (a cluster of dead twigs) (Voegtlin 1982; Mahr and Dittl 1986; Coffelt and Jones 1989). In northern Illinois and southern Wisconsin, naturalized honeysuckles have been severely damaged by this aphid (Voegtlin 1983). The damage appears to be progressive, and the number of witches' brooms increases with the age of the infestation (Voegtlin 1982). As observed by Voegtlin (1982) in northern Illinois, "virtually every growing tip on the plant is attacked during the third year and the witches' brooms change the color and shape of the plants making them nearly unrecognizable as honeysuckle."

H. tataricae eggs hatch early in the spring, and populations can be found until late fall (Voegtlin 1982). Voegtlin noted that records are not as numerous in the southern parts of Illinois and other states, suggesting that *H. tataricae* may be limited by hot weather. Honeysuckles of the *Lonicera tatarica* complex are the main hosts for this aphid. The origin of *H. tataricae* is unknown, but it is most likely native to the same area as its host plant, northern and western Asia (Turkey and south Russia) (Voegtlin 1982).

Grigorov (1965, in Voegtlin 1982) reported that plants in eastern Europe show increasing damage with several successive years of infestation, which results in severe stunting and eventual death. North American observations have not yet confirmed this effect (Voegtlin 1983); damage seems to be largely aesthetic thus far, but may hinder flowering and fruiting. *H. tataricae* appears to have natural predators in this country, including syrphid larvae and ladybug beetles, which may limit its populations. Further research is needed to determine whether *H. tataricae* would be a reasonable or dependable biological control for bush honeysuckles.

Browsing is not generally viewed as an effective long-term control method for honeysuckle. As noted by Jackson (1974), "Tatarian honeysuckle withstands moderate browsing by deer and cattle, and regrowth is rapid." However, honeysuckle was eliminated at a Long Island site after 3 years of heavy browsing where deer populations were high (Renkavinsky pers. comm., in Jackson 1974).

Burning

Prescribed burning will kill seedlings and can top-kill mature honeysuckle plants (Nyboer 1990, 1992). Bush honeysuckles resprout vigorously; therefore repeat burnings are necessary for adequate control. Annual or biennial burns for 5 years or more may be needed (Nyboer 1990, 1992).

A combination of methods including, burning, cutting, and herbiciding may provide the most effective control for bush honeysuckles.

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INTEGRATED PEST MANAGEMENT FOR

PURPLE LOOSESTRIFE, *Lythrum salicaria* L.

INTRODUCTION

Purple loosestrife (*Lythrum salicaria*) is native to Eurasia and occurs widely from Great Britain to central Russia (Thompson et al. 1987; Mal et al. 1992). Extensive reviews of its distribution are given in Stuckey (1980) and Thompson et al. (1987).

The species may have been introduced into North America in the 1800s in the solid ballast or discarded animal bedding and fodder from ships that navigated the Erie and St. Lawrence canal systems, and the Great Lakes (Stuckey 1980; Thompson et al. 1987; Mills et al. 1994). By the mid-1800s it was already so common in the Northeast that Torrey and Gray (1838–40) considered it "probably native."

Purple loosestrife readily invades wetlands and quickly forms a monoculture that crowds out native species (Mal et al. 1992). As stated by Stuckey (1980), "*L. salicaria* has the ability to move rapidly, become firmly established, and eliminate other species in both natural and artificial wetlands." Many stands in the northeastern United States have been self-replacing without loss of vigor for more than 20 years (Thompson et al. 1987).

The greatest abundance of purple loosestrife occurs in the northeastern and north-central United States; there are scattered populations in the West and South (Stuckey 1980; Mal et al. 1992). Ornamental plantings of purple loosestrife and its use as a honey plant have aided its distribution (Pellett 1977; Stuckey 1980; Thompson et al. 1987).

Purple loosestrife was observed in Illinois in the early 1900s and reportedly was cultivated in St. Louis around 1910 (Stuckey 1980). The plant appears to have begun to spread in Illinois in the 1950s (Stuckey 1980). Swink and Wilhelm (1994) noted the rapid increase of purple loosestrife in the Chicago region, particularly where industrial or highway runoff enters wetlands.

Purple loosestrife has been declared a noxious weed in many states in the United States and provinces in Canada (Mal et al. 1992). It is listed in the Exotic Species Act of Illinois.

HABITAT

Purple loosestrife grows in a wide variety of disturbed and natural freshwater habitats, including roadside ditches, streambanks, river mudbars, marshes, bogs, sedge meadows, wet prairies, fens, lake edges, and floodplains (Heidorn 1990; Heidorn and Anderson

1991; Mal et al. 1992; Swink and Wilhelm 1994). It grows best in habitats that are temporarily covered by water in the spring and are moist but not wet during the growing season (Mal et al. 1992). It grows in both calcareous and slightly acid soils (Perring and Walters 1964, in Mal et al. 1992) and is found in many different soil types or textures including sand, clay, gravel, organic soils, and crushed rock ballast (Mal et al. 1992).

LIFE HISTORY

Purple loosestrife is a herbaceous perennial in the Lythraceae (loosestrife family). Plants develop a strong, perennial taproot within the first year. Several stems arise annually from each rootstock (Mal et al. 1992). Stems become woody with age and can grow up to 8 ft tall (Skinner et al. 1994). Purple loosestrife reproduces by seed or vegetatively from adventitious shoots or roots on fragmented or buried stems (Thompson et al. 1987). Researchers have referred to the plant's rhizomatous or "creeping" root system, but after excavation and study of purple loosestrife crowns, Thompson et al. (1987) found no evidence of spread by rhizomes.

Seeds germinate in late spring or early summer in Canada, and flowering begins about 8 to 10 weeks afterward (Mal et al. 1992). Purple loosestrife blooms from early June through the first of October in northern Illinois (Swink and Wilhelm 1994). Flowers are produced in a spike-like inflorescence with numerous blooms. The flowers are bisexual and insect pollinated. The lower blooms of the inflorescence develop and mature first; flowering proceeds up the spike with the blooms at the top maturing late in the season. Seed set begins in mid-July in Minnesota and progresses as flowers develop through the season. Each plant can produce as many as 30 to 50 flowering stems (Skinner et al. 1994). An average of 1,000 seed capsules are produced per stem, and an average of 90 seeds are produced per capsule. The mean number of seeds produced per plant is estimated at 2,700,000 (Thompson et al. 1987).

Most seeds are dispersed within 10 m of the parent plant (Thompson et al. 1987). Water is the main dispersal mechanism for longer distances, but seeds are occasionally spread by wind, or by adhering to wet or muddy surfaces of clothing, fur, feathers, vehicles, etc. (Thompson et al. 1987). Germination is generally very high. Malecki (1990, in Mal et al. 1992) reported 100% germination from fresh seeds and 80% after 2 to 3 years of submergence. In infested sites, seedling density can range from 10,000 to 20,000 per m^2 (Mal et al. 1992).

CONTROL METHODS

Purple loosestrife has been found in only a few isolated patches in and near Midewin National Tallgrass Prairie. Most researchers emphasize the importance of controlling purple loosestrife as soon as possible. Depending on the management plan at Midewin

National Tallgrass Prairie, development or enhancement of wetlands could create habitat for the establishment of purple loosestrife. Current efforts should focus on removal of the existing plants to prevent dispersal to other parts of the Prairie.

An article by Skinner et al. (1994) contains a summary table with recommended control methods for purple loosestrife based on site characteristics and infestation size. Some of the treatments include combined methods such as herbicides and biological control for large infestations.

Mechanical

Many researchers and land managers have reported that hand-pulling is the most successful method to remove purple loosestrife in small or new infestations (Evans 1983; Mal et al. 1992; Skinner et al. 1994; Solecki 1997). Hand-pulling works better on younger plants (up to about 2 years). Older plants should be dug out; roots can be worked loose using a hand cultivator (Heidorn 1990; Heidorn and Anderson 1991). Plants should be pulled before flowering, then bagged and removed from the area to prevent flower or seed development. Roots need to be removed to prevent resprouting. Sites should be monitored, and follow-up treatments should be applied as necessary for at least 3 years (Solecki 1997).

Flooding at various water levels and for different durations has produced inconsistent results for controlling purple loosestrife. Mal et al. (1992) reported that a few researchers observed that stem density is reduced by flooding treatments. Thompson et al. (1987) and Skinner et al. (1994) reported that most researchers have observed no major reduction in purple loosestrife cover after flooding. Balogh (1986, in Skinner et al. 1994) found that 8 weeks of flooding controlled loosestrife seedlings 100%. Balogh concluded that duration of flooding is more important than depth as a factor in seedling mortality. Mal et al. (1992) concluded that flooding could provide effective control and could possibly eradicate infestations under some circumstances because purple loosestrife cannot tolerate long periods of inundation. If this method of control is attempted, care must be taken to protect or consider native or desired vegetation that might also be harmed by prolonged flooding.

Mowing alone does not appear to be an effective means of controlling purple loosestrife (Heidorn 1990; Heidorn and Anderson 1991). Plants generally resprout after cutting or mowing, although seed production can be reduced. Mowing can fragment roots and stems that subsequently resprout and disperse the population (Heidorn 1990; Heidorn and Anderson 1991; Malecki and Rawinski 1985). On the other hand, Gabor and Murkin (1990, in Mal et al. 1992) found that clipping plants at 21 days of age helps control seedling establishment and vegetative reproduction. But clipping at 42 days of age results in an increase in above-ground first-year stems.

Chemical

Several herbicides have been used on purple loosestrife with varying results. Glyphosate has provided the most consistent results. Up to 95% control can be achieved with great regularity, as cited from several researchers by Skinner et al. (1994). Malecki and Rawinski (1985) found that timing of glyphosate application is very critical – more important than application rate. Glyphosate applied at a rate of 1.7 kg per ha during late flowering (mid-August in central New York) produced 100% control of shoots. Seedling emergence during the following spring was also affected. Plots sprayed in June (during vegetative growth) were re-infested with seedlings. Plots sprayed in July and August were free of loosestrife seedlings.

Heidorn (1990), Heidorn and Anderson (1991), and Solecki (1997) recommended applying a 1.5% solution of Rodeo (active ingredient: 53.8% glyphosate) as a spot treatment immediately after flowering has begun, with re-treatments as necessary every 2 to 3 weeks to kill plants that were missed during earlier applications. Treatments should be repeated annually until control is achieved.

Glyphosate is most effective if applied in the beginning stages of flowering. If application of glyphosate is not possible during this time, the period between flowering and the first frost is also effective (Solecki 1997). Glyphosate is non-selective and controls both broadleaf plants and grasses. Spot treatments of glyphosate, especially in sensitive natural areas, allow for less exposure of the herbicide to non-target plants (Heidorn 1990; Heidorn and Anderson 1991; Solecki 1997).

The herbicide 2,4-D has been the second most common herbicide used on purple loosestrife (Skinner et al. 1994). Applications of the herbicide alone and or in combination with dicamba have produced mixed results (Thompson et al. 1987), but dicamba is often used because of its selectivity for broadleaf plants and its lower cost. Skinner et al. (1994) and Welling and Becker (1993) found 2,4-D products (labeled for aquatic habitats) to be most effective on first-year seedlings.

Studies were conducted in Minnesota in 1988 and 1989 to compare the effectiveness of Rodeo, Garlon 3A (active ingredient: 44.4% triclopyr), and 2,4-D products for controlling purple loosestrife. Herbicides were applied with high-powered hand sprayers, backpack sprayers, and low-volume broadcast techniques at various rates. Rodeo was found to be the most effective of the three. Rodeo provided 70 to 90% control when applied at rates of 0.5 and 1% solutions plus 0.1% Cidekick II (surfactant) in water. Spot treatments using a 1% solution of Rodeo plus a 0.25% surfactant solution (Cidekick II or Valent X-77) provided the most effective control of purple loosestrife plants (Skinner et al. 1994).

Results with 2,4-D and Weedestroy AM 40 (a 2,4-D product) were variable and unpredictable. 2,4-D eliminated a year's production of seed but did not kill the plants completely; therefore the plants could resprout the following year (Skinner et al. 1994).

Garlon 3A has not been labeled for aquatic use and was tested with an experimental use permit from the U.S. Environmental Protection Agency. Garlon 3A provided better control that 2,4-D products. Best results were received when a 1% solution of Garlon 3A containing 0.25% X-77 surfactant was applied to purple loosestrife plants until they were wet. Low-volume applications of Garlon 3A were effective at a rate of 6 lb per acre, but rates of 1.5 and 3.0 lb per acre were ineffective (Skinner et al. 1994). Skinner et al. (1994) commented that once Garlon 3A becomes labeled for aquatic use, it will be the herbicide of choice because of its selectivity for broadleaf plants and its lower cost.

Until it is approved for use over open water, a foliar application of Garlon 3A or Roundup (active ingredient: 41% glyphosate) can be sprayed according to the label instructions in areas where no surface water occurs. Roundup is also not approved for use over open water. Applications should occur before plants set seed. Follow-up treatments may be necessary within a few weeks to kill any missed plants (Heidorn 1990; Heidorn and Anderson 1991; Solecki 1997).

For large populations, Garlon 3A or Roundup (where no water is present), or Rodeo (where water is present) can be applied using a vehicle-mounted sprayer. One should begin treatments at the periphery of the area and work toward the center in successive years. This procedure allows native vegetation to begin re-establishing at the edges and spread inward (Heidorn 1990; Heidorn and Anderson 1991; Solecki 1997).

Purple loosestrife plants set seed from the middle to late flowering period; therefore, where possible, seed heads should be cut, bagged, and removed from the site before herbicide application to prevent seed development (Heidorn 1990; Heidorn and Anderson 1991).

Biological

Japanese millet (*Echinochloa frumentacea*) and reed canary grass (*Phalaris arundinacea*) have shown potential as replacement control species for purple loosestrife (Thompson et al. 1987; Mal et al. 1992; Skinner et al. 1994). These species are able to out-compete purple loosestrife, and are planted with the objective of establishing a dominant species that is less objectionable than purple loosestrife. This technique is not likely to be wise or feasible in a natural wetland community. If this method is used, one should first consider the desirability of the new dominant and the potential effects on the community.

Because of purple loosestrife's continued spread in spite of the many control efforts, many researchers believe that the achievement of long-term control for large, established stands will require biological control.

In 1992 the U.S. Department of Agriculture approved the release of three insects as biological control agents for purple loosestrife in the United States (Malecki et al. 1993; Skinner et al. 1994). The insects include a root-boring weevil (*Hylobius transverso-vittatus*) and two leaf-eating beetles (*Galerucella calmariensis* and *G. pusilla*).

In 1994 the Illinois Department of Natural Resources purchased 7,000 leaf-eating beetles (*G. calmariensis* and *G. pusilla*) and released them in seven sites in northern Illinois. In 1995 a partnership was developed between biologists from the Department of Natural Resources and county land managers to further the progress of the biological control program. Another 3,000 adult leaf-eating beetles were released in June 1995, as well as several hundred eggs of the root-feeding weevil (*Hylobius transversovittatus*) (Voegtlin and Wiedenmann 1996).

Monitoring of the sites indicated that the released insects survived the northern Illinois winters and were able to establish productive populations (Wiedenmann 1997).

The Illinois Natural History Survey began rearing populations of the beetles to facilitate large releases of the beetles economically. In 1996 at total of 167,000 beetles were released in 33 sites, with a minimum of 1,000 beetles at each site (Wiedenmann 1997). Further monitoring and study will determine the effectiveness of these insects as a control for purple loosestrife.

Nyvall (1995) has begun research to develop a mycoherbicide as a biological control for purple loosestrife. Many potentially useful pathogenic fungi have been isolated from purple loosestrife plants, but much more research is needed before results are conclusive.

As mentioned by Wiedenmann (1997), biological control is a very long process and will take many species and many years to achieve desired results.

Burning

Most researchers concur that prescribed burning is not an effective method of control for purple loosestrife. Burning fails to kill the rootstock, and plants usually resprout afterward (Thompson et al. 1987; Mal et al. 1992; Skinner et al. 1994).

Combined Methods

Malecki and Rawinski (1985) found that cutting alone does not provide reliable control of purple loosestrife, but cutting provides control of loosestrife for several years when combined with subsequent flooding.

Malecki and Blossey (1994) suggested that an effective, long-lasting, cost-effective, and environmentally sound weed control program will consist of successful biological control agents, other sound control methods, and improved land management practices.

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INTEGRATED PEST MANAGEMENT FOR

OSAGE ORANGE, *Maclura pomifera* (Raf.) Schneid.

INTRODUCTION

Osage orange was introduced into Illinois in the mid-1800s as a hedge plant for agricultural fields and pastures. John Wright, editor of the *Prairie Farmer*, first promoted this species as a candidate for hedges in 1841. After years of researching the utility of Osage orange for this purpose, Professor Jonathan Baldwin Turner of Illinois College in Jacksonville issued his first circular in 1847 offering plants for sale. Its popularity grew so quickly that as stated by Mary Louise Rice, "After 1848 the enthusiasm for Osage hedging blazed across the prairie like wildfire" (Rice 1937). It was planted for hedges, windbreaks, and other purposes in almost all of the lower 48 States (Burton and Barnett 1995) and has now become naturalized in many states (Bonner and Ferguson 1974).

HABITAT

Accounts vary as to the native range of Osage orange, but authors have most considered it to be indigenous to the drainages of the Arkansas and Red Rivers in eastern Texas, and southern Arkansas and southeastern Oklahoma (Bonner and Ferguson 1974; Grimm 1962; Burton and Barnett 1995), and possibly Louisiana (Steyermark 1981). It prefers rich bottomlands similar to its native locale, but flourishes in a wide range of habitats. In its current range it is characteristically found in hedgerows or pastures, but natural regeneration often occurs in habitats such as disturbed forests, overgrazed grasslands, abandoned farmsteads, ravines, floodplains, and riverbanks (Nyboer and Ebinger 1978; Glass 1992; Burton and Barnett 1995).

LIFE HISTORY

Osage orange is a small tree whose height at maturity averages 30 to 60 ft. It can grow up to 70 ft in fertile soils (Vines 1960; Bonner and Ferguson 1974). It is a multi-trunked tree that develops a large bole and thick bark. Young trees and branchlets, especially those grown in full sunlight, are very well armed with sharp, stout thorns.

Osage orange is dioecious, bearing male and female flowers on separate trees. The small, green, inconspicuous flowers bloom from May to June in Illinois (Mohlenbrock 1986). The fruit is a large, globose, aggregate fruit, composed of one-seeded drupelets. Fruits ripen in September to October and can average approximately 300 seeds each (calculated from data in Bonner and Ferguson 1974). Each tree can bear several fruits.

Trees usually bear fruit by age 10. Osage orange propagates easily from seed and may spread to cover large areas. Plants resprout vigorously after cutting.

A few animals use the fruit and may aid in its dispersal. The seeds are eaten by quail, squirrels, opossums, and other animals (Martin et al. 1951; Steyermark 1981). Cattle have been observed feeding on the fruits at Midewin National Tallgrass Prairie.

CONTROL METHODS

Mechanical

Cutting offers one solution for control of Osage orange. Cutting during the summer months usually provides the best results by affecting the plant when energy reserves in the roots are low. Two cuttings per year are more effective than one. Repeated cuttings may be necessary for complete control because of the plant's ability to resprout vigorously from cut stumps (Glass 1992).

With the advent of barbed wire around 1880, most hedges became neglected and overgrown. After its development in the 1950s, the bulldozer became many farmers' tool of choice for removal of undesired Osage orange hedges and trees (Burton and Barnett 1995). Osage orange trees readily resprout from cuttings; as Symons and Peairs stated as early as 1909, "It is a waste of time to cut down the hedge without grubbing up the roots."

The results of girdling Osage orange are not well documented. Glass (1992) suggested that girdling may be successful on smaller trees but more difficult on larger trees that have thick bark. If girdling is attempted, the phloem should be removed without damaging the xylem. Two parallel cuts 7 to 10 cm apart should be made, cutting through the bark slightly deeper than the cambium. Girdles should be rechecked every several weeks to make sure bark does not grow over the cut area (Glass 1992).

Because of the strong tendency of Osage orange to resprout, many of the mechanical means of control will most likely result in many vigorous sprouts that require repeated cutting. Methods to reduce sprouting include removal of the roots or treatments with herbicide.

Chemical

Several types of herbicides have been tested on Osage orange. Glass (1992) found triclopyr (trade name Garlon 4 or 3A) to be effective as a cut-surface treatment or bark treatment. Garlon 3A is a water-based herbicide (diluted with water), while Garlon 4 is oil-based (diluted with oils). Oil diluents recommended by the manufacturer include mineral oil, diesel fuel, No. 1 and No. 2 fuel oils, or kerosene; vegetable oils may also be suitable. Diesel fuel, fuel oil, and kerosene are not recommended on natural or sensitive areas because of their potential to damage surrounding, non-target vegetation (Illinois Nature Preserves Commission 1990). The following information concerning Garlon 3A and Garlon 4 treatment methods is taken from the label information for each herbicide and from Glass (1992).

Both Garlon 3A and Garlon 4 are effective as cut-surface treatments. Cut surfaces include either stumps or girdles. A 50% solution of Garlon 3A or a 20% solution of Garlon 4 should be sprayed or wiped onto the cut surface, the sides of the stump, and the root collar as soon as possible after cutting. Garlon can be applied any time of year, but use during the dormant seasons reduces the potential for injury to surrounding vegetation.

For stems less than 6 inches (15 cm) in basal diameter, a 1 to 5% solution of Garlon 4 can be sprayed or painted all around the trunk to a height of 12 to 15 inches (30 to 38 cm) above the ground. This is referred to as basal bark treatment.

A thin-line basal bark treatment can also be used on stems less than 6 inches (15 cm) in diameter. For this treatment, a thin stream of undiluted Garlon 4 should be used to create a thin band of herbicide around each stem or clump.

Other herbicides found effective in controlling Osage orange include AMS (ammonium sulfamate) and 2,4,5-T ([2,4,5-trichlorophenoxy] acetic acid) (Dunham 1970, Coulter 1951). Dunham (1970) found Osage orange to be susceptible to treatments of AMS and 2,4,5-T but intermediate in response to 1,1-dimethyl-3-phenylurea (trade name Fenuron) and 2-(2,4,5-trichlorophenoxy) propionic acid (trade name Silvex). "Susceptible" is defined to mean the plant can be killed with moderate rates of the herbicide and "intermediate" is defined to mean that the plant is severely injured or partially controlled at higher rates.

Coulter (1951) compared effects of various concentrations of 2,4-D [(2,4,-dichlorophenoxy) acetic acid] and 2,4,5-T. Each herbicide was tested in concentrations of 4, 8, 16, 32, and 64 lb acid equivalent per 100 gal of spray in fuel oil. Sample trees were between 15 and 20 ft tall. The trunk of each tree was thoroughly wetted with herbicide to a height of 18 inches above the ground. The mixtures of 2,4,5-T at 16 lb A.H.G. or higher showed 80 to 100% control with no regrowth two summers later. Lower concentrations were effective but erratic.

Both studies (Dunham 1970 and Coulter 1951) found 2,4-D to be ineffective at all concentrations tested.

Aerial applications of herbicides from helicopters or airplanes have been used to control large populations of woody brush or populations that occur in areas that are difficult to access. Anderson et al. (1971) tested a solution applied per acre which consisted of 5 gal of water, 1 gal of number 2 diesel oil, and 1 gal of herbicide containing 2 lb of 2,4,5-T plus 2 lb of 2,4-D. The herbicide solution was applied by helicopter during late June and early July in West Virginia. Osage orange is one of 10 species in the study that was susceptible to the treatment (controlled 80 to 100%) after one application. Maple, oak, and hickory species were damaged by the solution but were not controlled.

Because of the potential damage to surrounding, non-target species and areas, aerial or other broadcast applications of herbicides are not recommended in environmentally sensitive areas.

Biological

No published information was found concerning biological control agents for Osage orange. Grazing by cattle at Midewin National Tallgrass Prairie often keeps sprouts and small trees cropped to a very small shrub level, often just above ground level or less than a meter tall. But these "shrubs" sometimes grow shoots that extend beyond the reach of grazing animals. Additional control methods would need to be incorporated along with grazing to eliminate the trees.

Grazing by cattle on *Maclura* fruit at Midewin National Tallgrass Prairie has been noticed to aid in the species' dispersal through the cattle's droppings. In this sense, removal of grazing, or removal of the seed producing trees, could improve the control of Osage orange.

Burning

Periodic prescribed burning can hinder establishment of young Osage oranges. Small trees can be controlled with a combination of burning and cutting, and possibly herbiciding. The thick bark on larger, older trees renders them resistant to flames. Fire is not adequate to control large individuals unless combined with another control method such as girdling, cutting, and herbiciding (Glass 1992).

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INTEGRATED PEST MANAGEMENT FOR

WHITE SWEET CLOVER, *Melilotus alba* Desr.

INTRODUCTION

White sweet clover (*Melilotus alba*) is native to Europe and western and central Asia (Georgia 1914; Turkington et al. 1978). It has been cultivated for centuries as a forage and honey plant in Europe. Sweet clover has been introduced and is naturalized in many lands, including Europe, North America, Australia, South Africa, and Argentina (Turkington et al. 1978). The genus *Melilotus* was first reported in North America in 1664. White sweet clover was reported in the *Flora Virginica* in 1730 by Gronovius (Stevenson 1969, in Turkington et al. 1978). A similar species, yellow sweet clover (*M. officinalis*), also occurs widely in the United States. Both species have been reported from every county of Illinois (Mohlenbrock 1986).

Sweet clovers have been planted for many purposes, mainly as forage and hay, as honey plants, and for soil improvement and erosion control. Sweet clovers' recurring popularity for various uses has contributed greatly to its distribution and spread (Turkington et al. 1978). It easily invades open areas and competes for resources with native species (Eckardt 1995). Heitlinger (1975) noted that sweet clover is often planted to stabilize fresh road cuts, which may serve as a major source of migration into natural areas.

HABITAT

White sweet clover is adaptable to a wide range of environmental conditions. It is very drought-tolerant and winter-hardy, but it cannot tolerate prolonged flooding. It is found in a variety of soils ranging from clay or loam to sand dunes and river gravel. It most commonly occurs on calcareous soils. Because of its strong taproot, sweet clover can grow well on soils of low fertility (Turkington et al. 1978).

Sweet clover is an invasive species that quickly colonizes freshly disturbed soils on well-drained riverbanks, construction sites, etc., and in these circumstances it can help reduce soil erosion (Turkington et al. 1978). It is found in a range of plant communities, including old pastures and abandoned fields, cultivated and idle grounds, roadsides, railroad rights-of-way, and streambanks (Turkington et al. 1978; Swink and Wilhelm 1994). Sweet clover grows best in open areas and does not persist well in shaded areas (Turkington et al. 1978). It will often invade adjacent degraded prairies or openings in natural areas that have experienced disturbance.

LIFE HISTORY

White sweet clover is an annual or biennial herb which develops a strong taproot that can exceed 120 cm (47 inches) in depth. Plants that act as annuals overwinter as seeds, and those that are biennial overwinter as seeds or as thick taproots with a crown and winter buds (Turkington et al. 1978). According to Cole (1991) and Klemow and Raynal (1981), sweet clover is an obligate biennial. It stays in a vegetative state during the first growing season, building root reserves. During the second season it flowers, sets seeds, then dies.

Seedlings can appear at any time of the growing season, but most germination and seedling development occurs from March to April. Some seedlings continue to emerge until the fall, sometimes with another peak in September to October (Turkington et al. 1978; Klemow and Raynal 1981). Most seedlings that emerge later in the year die during the winter (Turkington et al. 1978).

White sweet clover flowers from the beginning of June until the middle of November in northern Illinois (Swink and Wilhelm 1994). Seeds of white sweet clover ripen from early August to late fall in Ontario (Rempel unpublished, in Turkington et al. 1978). Plants generally produce one seed per fruit, but occasionally two or three. Coe (1917) estimated that a plant can produce an average of about 350,000 seeds. Stevens (1932) estimated that an average of 14,235 seeds are produced on each plant that averages 5 stems. No vegetative reproduction has been observed in sweet clover (Turkington et al. 1978).

Seeds are dispersed mainly by water in streams or by surface runoff. Strong winds can disperse seeds for a few meters. The fruits readily adhere to wet and dry surfaces, such as clothing, and can be dispersed in this manner (Turkington et al. 1978).

Seeds of sweet clover usually develop a hard, impermeable outer layer as the plant dehydrates in its last stages of development. Immature seeds have permeable coats (Turkington et al. 1978). Stoa (1933) documented that hard-coated seeds of sweet clover remain viable in soil for 14 years, at which time he suspected seeds would continue to germinate for several more years. A later article by Stoa (1941, cited by Turkington et al. 1978) indicated that seeds with hard coats remain viable in the soil for more than 20 years.

Sweet clover possesses many weedy attributes which contribute to its invasiveness. It reproduces in large numbers, it is persistent, and it readily establishes along roadside edges and railways, and in pastures and disturbed areas (Turkington et al. 1978).

CONTROL METHODS

Mechanical

Hand-pulling is an effective control for small patches of sweet clover if done when the ground is moist enough to allow removal of the roots (Georgia 1914; Cole 1991). The best time to pull sweet clover is during late fall, after the first-year root crown buds have developed. Fall is a good time because 1) sweet clover remains green while most native surrounding vegetation is dormant, and 2) moist fall conditions and an immature root system aid pulling. Early spring, before the second-year plants have developed flower buds, is also a good time (Cole 1991).

For large, dense colonies of sweet clover, first and second-year stems should be cut close to the ground. This method is most effective if it is done after the lower leaves on the stems have died, but before the plants have set seed. Resprouting is minimal if sweet clover is cut during this time period (Cole 1991).

Smith and Graber (1948) found that sweet clover plants complete most of their top growth by mid-September, after which time the roots accumulate most of their reserves for overwintering and early spring growth. Several researchers have found that cutting sweet clover plants during the fall can reduce the root's carbohydrate reserves, decrease winter resistance, and result in a less vigorous stand in the following spring.

The most recommended time to cut is mid-September, but can range from late August to mid-October (Badger and Snider 1933; Smith and Graber 1948; Turkington et al. 1978). On the other hand, Georgia (1914) recommended that plants be cut close to the ground as soon as the first flowers open. The plants will immediately resprout thick stools of flowering stalks requiring a second and perhaps third cutting. If seed production is prevented, plants will die after flowering, and eventually the population and seedbank will be exhausted.

Chemical

In the spring before native plants emerge, sweet clover seedlings and individuals may be hand sprayed with 2,4-D amine according to the label instructions. The amine formulation should be used rather than the ester to reduce vapor drift of the herbicide. A 1% solution of Mecamine (2,4-D plus dicamba) applied as a foliar spray is also very effective (Cole 1991).

Turkington et al. (1978) offered a brief review of herbicides that are effective against sweet clover (see their article for references). Sweet clover is extremely susceptible to phenoxy-type herbicides such as 2,4-D at 0.42 kg per ha, MCPA, MCPB, 2,4-DB, and 2,4-DP. Sweet clover is also extremely susceptible to dicamba (Banvel-D).

If sweet clover is allowed to persist until its second year, it is more difficult to control (Greenshields 1957, in Turkington et al. 1978). Aflon (linuron 50%) at 5 kg per ha has controlled sweet clover in wheat; Tordon (picloram) at 5.6 liters per ha has prevented establishment of sweet clover; white sweet clover was killed with neburon or dalapon at 7.5 to 10 kg per ha.

Schwendiman et al. (1943) found sweet clover to be very susceptible to the herbicide Sinox. A 1% solution of Sinox was broadcast sprayed at rates of 60, 80, or 100 gal per acre on grain fields in Wisconsin between late May and early June, resulting in a 60 to 100% reduction in sweet clover stands. The seedlings were 1 to 3 inches tall and had 4 to 6 leaves.

Grichar et al. (1993) tested the effectiveness of five herbicides on sweet clover and other clovers. They found that 2,4-D amine at 0.75 and 1.5 lb ai (active ingredient) per acre, and Rhonox 2E at 1 lb ai per acre provided 100% control of sweet clover. Other herbicides (Butyrac 200, Basagran 4E + Agridex, and Rhonox 2E) at various rates provided controls ranging from 80% to 98%. All results were observed 65 days after herbicide application.

A spring or fall burn conducted in the target area will remove accumulated litter and increase completeness of foliar coverage with the herbicide.

Biological

No published information was found concerning biological control agents for white sweet clover. Turkington et al. (1978) mentioned that Smith and Gorz (1965) and Conners (1967) presented a comprehensive review of parasites of sweet clover. Future research could determine whether these organisms would provide a reasonable biological control for sweet clover. Since sweet clover is a desirable plant in some situations, it may be difficult to develop a biological control that can be applied in areas where it is undesirable without affecting nearby planted populations.

Burning

Sweet clover's response to burning varies according to the time and frequency of burning (Eckardt 1995).

Early spring burns often encourage seed scarification and germination of sweet clover (Heitlinger 1975; Kline 1983). Graber (1927) noted that burning can aid in the establishment of sweet clover in grasslands.

Prescribed burning generally enhances the health of many natural communities. In areas where native species occur, either vegetatively or in the seedbank, fire may improve the ability of local species to compete and possibly displace *Melilotus*. Turkington et al.

(1978) noted that both white sweet clover and yellow sweet clover can be eliminated from an area within 2 years if the ground is covered by perennial species.

Heitlinger (1975) outlined three burn strategies to suppress sweet clover:

> 1) Annual burns about early May when second-year shoots are visible reduces the number of shoots. An increase in first-year seedlings may initially result because of scarification of the hard seed coat by fire.
>
> 2) Burning every second year in early July (before second-year plants go to seed) reduces both first-year and second-year seedling populations.
>
> 3) Annual burns in early September when sweet clover is in its "critical growth period" should interfere with the plant's resource storage processes and should increase winter mortality.

Heitlinger determined that the first two approaches worked well. He was not able to test the third strategy, but the expected results follow well with those of cutting sweet clover plants during the same time period.

Kline (1983) found that the least successful burns to control sweet clover are those timed in early spring (March or April) or in fall. These burns stimulate germination, probably by scarifying the hard seed coat, and appear to increase a germinated individual's chance of survival during the first year. Late fall burns have this effect as well (Eckardt 1995).

Kline (1983) achieved the best control by conducting an early spring burn one year, followed by a May burn the next year, or mowing in July the second year. The second-year May burn kills the emerging shoots before they can go to seed (Eckardt 1995). Kline conducted this sequence of burns twice, with a 2-year interval between fires with very high success.

The areas burned should be rechecked on a regular basis. The above-mentioned method used by Kline (1983) is most effective if the colony is even-aged. If the colony of sweet clover is uneven-aged or if burns are patchy, some second-year shoots may escape damage from the fire and grow to set seed. Patches or individuals that are left unburned should be hand-pulled or otherwise eradicated so they do not set seed and replenish the seedbank (Kline 1983; Cole 1991).

Fall mowing can also facilitate the burn program. For an even-aged colony of sweet clover, Cole (1991) recommended the following: 1) burn in April, 2) mow in August, then 3) leave stems to dry, and burn again in mid-to-late September.

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INTEGRATED PEST MANAGEMENT FOR

WHITE MULBERRY, *Morus alba* L.

INTRODUCTION

White mulberry (*Morus alba*) and a variety, Russian mulberry (*Morus alba* var. *tatarica*), are native to China (Read and Barnes 1974; Ebinger 1993). White mulberry was introduced into the United States during colonial times in an attempt to establish a silkworm industry. Russian mulberry was introduced in 1875 by Russian Mennonites (Read and Barnes 1974; Harlow et al. 1979). Mulberries have been planted throughout the United States for fruit, shade, and windbreaks. Both varieties have become naturalized throughout Illinois (Mohlenbrock 1986; Ebinger 1993), and are common in many habitats (Swink and Wilhelm 1994).

Many authors no longer separate the two varieties taxonomically (Swink and Wilhelm 1994), although some differences do occur. For the purpose of this report, the two varieties are collectively referred to as "mulberries," but differences will be discussed when significant.

HABITAT

Mulberries have spread from cultivation and plantings to become a common weed in wooded floodplains and old clearings, and along roads, railroads, and streambanks (Swink and Wilhelm 1994).

LIFE HISTORY

White mulberry is a small tree that can reach heights of about 45 ft. Russian mulberry is more shrubby and usually grows between 10 to 25 ft tall (Read and Barnes 1974).

Flowers of mulberries are generally dioecious, but can be monoecious on different branches of the same tree. The flowers produce an aggregate fruit which is composed of many small, appressed drupes (Read and Barnes 1974). Mulberries flower from about the first of May until about the middle of June in northern Illinois (Swink and Wilhelm 1994). Fruits generally ripen and drop from the trees during June to August (Read and Barnes 1974). Fruits are readily eaten and dispersed by birds and other animals. Each fruit contains a dozen or more seeds. White mulberry usually begins bearing fruit at about 5 years of age, while Russian mulberry begins bearing fruit between 5 and 10 years of age (Read and Barnes 1974).

CONTROL METHODS

Little information is available concerning the control of mulberries. Mulberry belongs to the Moraceae (mulberry family) as does Osage orange (*Maclura pomifera*). Mulberry's responses to control methods are most likely be very similar to those of Osage orange; therefore, many methods for controlling Osage orange are summarized and recommended for use with mulberries.

Mechanical

As with Osage orange, white mulberry sprouts vigorously after cutting (Suzuki and Kohno 1987). Cutting during the summer months usually provides the best results by affecting the plant when energy reserves in the roots are low. Two cuttings per year are more effective than one. Repeated cuttings may be necessary for complete control of the sprouts.

Similar to Osage orange, extraction of the roots may be necessary to prevent resprouting from stumps or roots. Bulldozing is often used to eradicate old fencerow plantings of Osage orange (Burton and Barnett 1995).

If girdling is attempted, the phloem should be removed without damaging the xylem. Two parallel cuts 7 to 10 cm apart should be made, cutting through the bark slightly deeper than the cambium. Girdles should be rechecked every several weeks to make sure bark does not grow back over the cut area (Glass 1992).

Because of the strong tendency of mulberries to resprout, mechanical control will most likely result in many vigorous sprouts that will require repeated cutting. Additional methods to reduce sprouting include removal of the roots and treatments with herbicide.

Chemical

Garlon 4 (active ingredient: 61.1% triclopyr) and Garlon 3A (active ingredient: 44.4% triclopyr) are labeled for controlling mulberries.

Garlon 3A is a water-based herbicide (diluted with water), while Garlon 4 is oil-based (diluted with oils). Oil diluents recommended by the manufacturer include mineral oil, diesel fuel, No. 1 and No. 2 fuel oils, or kerosene; vegetable oils may also be suitable. Diesel fuel, fuel oil, and kerosene are not recommended on natural or sensitive areas because of their potential to damage surrounding, non-targeted vegetation (Illinois Nature Preserves Commission 1990). The following information concerning Garlon 3A and 4 treatment methods is taken from the label information for each herbicide and from Glass (1992).

Both Garlon 3A and 4 are effective as cut-surface treatments. Cut surfaces include either stumps or girdles. A 50% solution of Garlon 3A or a 20% solution of Garlon 4 should be sprayed or wiped onto the cut surface, the sides of the stump, and the root collar as soon as possible after cutting. Garlon can be applied at any time of year, but use during the dormant seasons reduces the potential for injury to surrounding vegetation.

For stems less than 15 cm (6 inches) in basal diameter, a 1 to 5% solution of Garlon 4 can be sprayed or painted all around the trunk to a height of 30 to 38 cm (12 to 15 inches) above the ground. This is referred to as basal bark treatment.

A thin-line basal bark treatment can be used on stems less than 15 cm (6 inches) in diameter. For this treatment, a thin stream of undiluted Garlon 4 is applied in a thin band around each stem or clump.

Dunham (1970) reported that *Morus* spp. are susceptible to the herbicide Fenuron (1,1-dimethyl-3-phenylurea), intermediate in response to Silvex (2-[2,4,5-trichlorophenoxy] propionic acid), and resistant to Amitrole (3-amino-s-triazole), 2,4-D ([2,4,-dichlorophenoxy] acetic acid), and 2,4,5-T ([2,4,5-trichlorophenoxy] acetic acid). "Susceptible" is defined to mean the plant can be killed with moderate rates of the herbicide and "intermediate" means that the plant is severely injured or partially controlled at higher rates.

Biological

No information concerning biological control for mulberries was located. According to Carter (1955), mulberry is among several native and naturalized trees of Illinois that are relatively free of diseases, but Gray and Gray (1987) cited the *Index of Plant Diseases in the United States* (1960) as stating that mulberries are susceptible to many pathogens. Perhaps few organisms affect *Morus* spp. severely or selectively enough to be used as a biological control agent.

Popcorn disease of white mulberry is caused by a fungus (*Ciboria carunculoides*). It appears to be limited to white mulberry and has been reported only from the southern parts of the United States (Gray and Gray 1987). Symptoms of the disease include swollen fruits, the fruits and drupelets becoming larger than normal. Not all fruits on diseased trees show symptoms. This disease affects the appearance of fruits; Gray and Gray (1987) did not discuss whether the disease affects seed production or viability.

Future research could determine whether *Ciboria* or other organisms would provide a reasonable biological control for mulberry. Since mulberry is a desirable plant in some situations, it may be difficult to develop a biological control that can be applied in areas where it is undesirable without affecting nearby planted populations.

Burning

Glass (1992) reported that periodic prescribed burning can hinder establishment of young Osage oranges; and small trees can be controlled with a combination of burning and cutting, and possibly herbiciding. Mulberries would most likely respond similarly to the same treatments. Because of mulberry's tendency to sprout, fire alone would probably prove an inadequate means of control unless combined with another method such as herbiciding.

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INTEGRATED PEST MANAGEMENT FOR

WILD PARSNIP, *Pastinaca sativa* L.

INTRODUCTION

Wild parsnip (*Pastinaca sativa*) is native to Eurasia. A cultivated variety of *Pastinaca sativa* has an edible root, but wild parsnips are inedible (Baskin and Baskin 1979). Wild parsnip is a common weed throughout the northern United States and Canada (Baskin and Baskin 1979; Kennay and Fell 1990). It has been recorded from every county of Illinois (Mohlenbrock 1986).

HABITAT

Wild parsnip grows best in moist, calcareous soils, but can adapt to a wide range of edaphic conditions (Kennay and Fell 1990; Eckardt 1995). It usually grows on dry to mesic soils, and is commonly found in fallow fields and pastures, and along roadsides and railroads (Kennay and Fell 1990; Swink and Wilhelm 1994; Eckardt 1995).

Wild parsnip invades disturbed bare areas, especially those with calcareous soils (Eckardt 1995). High quality or well established prairies are not likely to be heavily invaded, but parsnip often becomes very abundant along prairie edges (Kennay and Fell 1990), especially where some disturbance has occurred. Once established it can spread into adjacent natural areas. Wild parsnip has become a serious problem in some mesic prairies in Illinois (Kennay and Fell 1990).

LIFE HISTORY

Wild parsnip is a monocarpic perennial in the Apiaceae (umbel family), meaning that the plants stay in a vegetative state until root resources are adequate to produce a flowering stalk. Plants die after producing seeds. In Illinois the seeds germinate in spring and early summer and form rosettes. Baskin and Baskin (1979) found that some seeds germinate in the fall and winter in Kentucky, but the majority germinate in the spring between February and April. Plants remain in the rosette stage for at least one growing season while developing a large taproot (Thompson 1978). Wild parsnip often flowers in the second year, so it is often classified as a biennial. However, as with *Dipsacus* (Werner 1975), flowering of wild parsnip is related to the size of the rosette rather than the age (Thompson 1978), and it may not flower until after the second year. Thompson found that fall rosettes must attain a minimum diameter of 14 cm before flowering in the spring. Vernalization is required for flowering (Baskin and Baskin 1979).

Flowering plants bolt (develop an aerial shoot) in early April. The yellow-flowered, flat-topped umbels appear about mid-May in Illinois, and flowering continues until fall (Mohlenbrock 1986; Swink and Wilhelm 1994). Hendrix and Trapp (1992) found that the secondary and tertiary umbels flower sequentially at 10 to 14 days following the primary (terminal) umbel. The fruits (mericarps) begin maturing in early July, but usually are not dispersed until late summer and fall, unless mowed or otherwise disturbed (Baskin and Baskin 1979). Wild parsnip does not reproduce vegetatively (Thompson 1978; Hendrix and Trapp 1992). Parsnip seeds remain viable in the soil for no more than 4 years (Kennay and Fell 1990, 1992).

CONTROL METHODS

Wild parsnip plants produce furanocoumarins (phototoxins) which can cause severe dermatitis in some people upon contact with the leaves or sap, especially in full sunlight. Effects are most irritating at flowering time. Reactions include blistering, severe itching, redness, and even scarring in some cases (Kennay and Fell 1990, 1992; Eckardt 1995). One should take care to avoid contacting the plants by wearing gloves, long sleeves, and long pants.

Mechanical

Hand-pulling is an effective control method for small patches or individual parsnips. The roots should be pulled to prevent resprouting. Pulling wild parsnip is easiest after a good rain when soil is moist, or during a drought period, when roots shrink (Kennay and Fell 1990). Plants can also be cut below the root crown before seed-set. This is best done after the plant has flowered but before seeds mature (Kennay and Fell 1990, 1992; Eckardt 1995). Treated areas should be rechecked every few weeks because plants do not flower all at once. Seeds can continue to develop and mature on the cut stalks, so plants should be removed from the site after pulling or cutting.

For large patches of parsnip, mowing or scything plants at the base of the stem can be effective if done when the plants are blooming but before seeds have matured (Kennay and Fell 1990, 1992). Cut plants should be removed and the area should be rechecked often for resprouts and small flowering shoots near the ground. Timing of cutting or mowing is very important. If cut too soon, plants have a higher chance of resprouting and producing seeds. If cut too late, the primary umbel may have seeds mature enough to ripen after cutting (Kline 1986; Eckardt 1995).

The suitability of this method will depend on the site conditions and other plant species present. In a degraded section of a prairie where both wild parsnip and tall goldenrod (*Solidago altissima*) were abundant, Kline (1986) found that annual mowing in July (for 6 years) resulted in an increase of flowering parsnip individuals and a decrease in goldenrod density, while the unmowed plots showed a decrease in parsnip density.

Results were partially influenced by a mowing too late in 1982 when seeds were too well developed. Kline suggested that mowing increased the sunlight to immature parsnip plants, creating favorable conditions for their maturation while reducing competition from the goldenrod. Poorly timed mowing (as is likely along roadsides) may increase both the number of seedlings and the percentage surviving to maturity (Kline 1986).

The competitive ability of the surrounding plants should be taken into consideration prior to implementing a management activity. In some situations, the best parsnip control may be to do nothing (Kline 1986).

Chemical

Where mechanical methods are not effective or feasible, spot application of a 2% solution of Roundup (active ingredient: 41% glyphosate) can be applied to the basal rosettes. In high quality natural areas or where safety of surrounding vegetation is of concern, Roundup should be applied to individual plants with a hand sprayer during late fall when most native vegetation is dormant (Kennay and Fell 1990, 1992). Annual retreatment may be necessary until the seedbank is depleted.

On buffer or severely disturbed areas 2,4-D, mixed according to the label, is effective when applied to individual basal rosettes between March and May or between August and October. Repeated early spring applications of this herbicide before the flowering stalk begins to elongate will reduce wild parsnip infestation (Kennay and Fell 1990, 1992).

Dunham (1970) found that wild parsnip can be killed with applications of Atrazine, 2,4-D, or 2,4,5-T at moderate rates.

Biological

Depressaria pastinacella (parsnip webworm), a lepidopteran, is a dominant herbivore on wild parsnip. The species lays its eggs on unopened umbels from mid-May to early June. Webworm larvae are more commonly found on the terminal umbels of larger, often isolated parsnip individuals (Thompson and Price 1977). Thompson (1978) found that larval attack within patches lowers seed production in some plant size classes. Hendrix (1979) and Hendrix and Trapp (1992) found that seed production is lowered in the primary (attacked) umbel, but plants compensate by producing more tertiary umbels or by increasing seed output of tertiary umbels.

Although the parsnip webworm can severely damage individual plants, it is not known to destroy or damage whole patches; therefore it is not likely to be useful as a biological control agent (Kennay and Fell 1990, 1992; Eckardt 1995).

Burning

After a spring burn, wild parsnip rosettes are among the first plants to emerge. During this time the rosettes can easily be detected and dug out (Kennay and Fell 1987; Eckardt 1995). Other than aiding early detection, prescribed burning is not an effective means of controlling wild parsnip (Kennay and Fell 1990; Eckardt 1995). Burning tends to provide favorable conditions for the rapid development of parsnip rosettes by removing litter and taller plants (Kennay and Fell 1990; Eckardt 1995). However, burning in a high quality or well established natural grassland community usually increases and maintains the vigor of the native plants, allowing them to better compete against and possibly displace the parsnip (Kennay and Fell 1990).

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INTEGRATED PEST MANAGEMENT FOR

REED CANARY GRASS, *Phalaris arundinacea* L.

INTRODUCTION

Reed canary grass (*Phalaris arundinacea*) is a sod-forming, cool-season, perennial grass that is native to the temperate regions of Europe, Asia, and North America. It has adapted to much of the northern half of the United States (Phillips Petroleum Company 1963). The native variety is considered endemic to parts of Illinois. Deam (1940) commented that reed canary grass may be native to the Lake Michigan area, but otherwise had most likely spread from plantings.

Reed canary grass has long been promoted and planted as a forage and hay crop, even though many researchers comment on its lack of palatability to cattle late in its growing season. Swedes first recognized the grass as good forage in 1749 (Phillips Petroleum Company 1963). Reed canary grass and common reed (*Phragmites australis*) are often used in wastewater disposal wetlands and for erosion control.

Reed canary grass is aggressive and spreads rapidly to form persistent, monotypic stands that can crowd out native species (Apfelbaum and Sams 1987; Henderson 1991; Gillespie and Murn 1992). Reed canary grass reportedly will crowd out even cattails (Hutchison 1992). This aggressive tendency threatens the diversity of many native ecosystems, particularly wetlands, and is a major concern for land managers (Apfelbaum and Sams 1987; Gillespie and Murn 1992).

HABITAT

Reed canary grass grows best on fertile, moist or wet soils, but it occurs in a wide range of conditions from wet lowlands to dry uplands (Phillips Petroleum Company 1963). This species inhabits many types of wetlands, including marshes, wet prairies, wet meadows, fens, streambanks, and swales (Hutchison 1992). Reed canary grass readily invades and dominates many wetlands such as sedge meadows and wet prairies, especially those degraded by overgrazing or silt deposition (Henderson 1991; Apfelbaum and Sams 1987). Henderson (1991) observed that reed canary grass slowly invaded and eventually dominated many shaded areas in an oak savanna restoration.

The species has become prevalent along ditches and waterways which serve as dispersal corridors. Seeds are often dispersed into natural areas from these plantings and adventive populations.

Reed canary grass can survive long periods of inundation (Brandle 1983, in Apfelbaum and Sams 1987; Rice and Pinkerton 1993).

Plants spread vegetatively forming a dense monotypic sod that can be very shade tolerant and highly competitive (Henderson 1991), although the grass generally grows densest in open areas.

LIFE HISTORY

Reed canary grass reproduces from seed or vegetatively by rhizomes (Hutchison 1990, 1992). Most leafy shoots develop during the early spring or fall, and most new rhizomes develop during May through August in northern Ohio (Evans and Ely 1941). Apfelbaum and Sams (1987) reported that the rhizomes grow downward for 5 to 7 weeks after germination in the spring, then expand laterally. Growth peaks in mid-June and declines in mid-August. Little development of either shoots or rhizomes occurs in their "off" seasons (Evans and Ely 1941). New rhizomes develop from nodes of older rhizomes near the junction with their terminal shoots. They occasionally develop near the base of the above-ground stem from buds in the leaf axils.

Rhizomes of plants grown in row plots grew to a maximum depth of 6 inches. Some were near the surface of the soil, but the average depth was 2 inches (Evans and Ely 1941).

Inflorescences begin to develop about the middle of April, and flowering beings in early June in northern Ohio. Flowering can occur from about the middle of May to the first of July in northern Illinois (Swink and Wilhelm 1994). Seeds mature in late June and early July (Evans and Ely 1941; Apfelbaum and Sams 1987); the seed heads shatter when ripe (Hutchison 1990, 1992). No dormancy appears to be required, and reed canary grass seeds can germinate immediately after dispersal (Apfelbaum and Sams 1987).

CONTROL METHODS

Several types of control or management activities have been tested on reed canary grass. Apfelbaum and Sams (1987) offered a literature review of many methods that might be employed to control this species.

Seeds of nearby native grasses and forbs should be planted after patches of reed canary grass have died to prevent re-invasion of reed canary grass or other undesirable species (Hutchison 1992).

Mechanical

In small patches of reed canary grass, hand-pulling can be a feasible control method (Hutchison 1990, 1992). Henderson (1990) found selective hand-pulling to be very effective if done on the entire patch and done two to three times a year over a 5-year period. Drake (1994) has created a tool to aid hand-weeding reed canary grass and cattails in small wetlands. The tool is similar to a garden hoe with four tines instead of a blade. The tines are curved back toward the handle about 5 degrees more than the blade of a typical hoe. Drake uses the tool to work loose small clones of reed canary grass, finding that the rhizome mat can then be removed as a unit.

Henderson (1990) found that patches of reed canary grass can be killed by covering them with black plastic for at least 3 consecutive years. But Gillespie and Murn (1992) did not have success with this method (using plastic or paper) because the grass shoots grew up through the material.

Gillespie and Murn (1992) found that mowing helped control reed canary grass by removing seed heads before they matured. Mowing also allowed more light to reach the ground, which promoted native vegetation. This method would be most reliable where native species occur in the canary grass stand or where a viable seedbank remains in the soil. If reed canary grass has persisted for several years, the seedbank may be dominated by its seeds (Apfelbaum and Sams 1987). Soil should be tested to determine the viable species in a seedbank prior to major restoration efforts. If enough native seeds do not seem to be present, seeds of desirable species should be planted immediately after removal of the reed canary grass to prevent its re-invasion or the invasion of other undesirable species (Henderson 1990).

Lyford (1993) found that cutting reed canary grass to a height of 8 cm (3 inches) at 2-week intervals decreased the number of stems in test plots.

Chemical

Apfelbaum and Sams (1987) offered a literature review about the effectiveness of several herbicides tested on reed canary grass. Herbicides that were found effective against reed canary grass include Dalapon, Amitrol, Amitrol-T, glyphosate, TCA (trichloroacetic), Paraquat, and 2,4-D amine. Some were tested alone and some were in mixtures.

Herbicides can control this species in buffer or severely disturbed areas. Rodeo (active ingredient: 53.8% glyphosate) is registered for use in wetlands. Rodeo will kill reed canary grass, especially young plants, when applied as a foliar spray according to the label instructions (Hutchison 1990, 1992). The herbicide should be applied in early spring when reed canary grass is green but most surrounding native vegetation is dormant. Subsequent treatments during the following spring may be necessary to kill surviving plants or new sprouts. Roundup, another glyphosate product (active ingredient: 41% glyphosate), is also effective as a foliar spray. Roundup is not approved for use in wetlands and should be used only in areas where there is no standing water (Hutchison 1990, 1992).

In testing various control methods, Lyford (1993) found that a 5% solution of glyphosate as a foliar spray was the most effective treatment, either alone or in combination with cutting.

Paveglio et al. (1996) found greater dieback of reed canary grass after foliar applications of Rodeo at 5.26 liters per ha (2.25 qt per acre) combined with a 0.5% solution of LI-700 surfactant. Herbicide was applied in late May and again in late August (prior to senescence). Several combinations of mechanical and herbicide treatments were tried in their study. They observed a diverse community of native aquatic plants emerging after an area was disked and treated with Rodeo in late May.

Marquis et al. (1984) found reed canary grass to be sensitive to several concentrations of boron. The strongest treatment of 300 parts per million of boron resulted in complete necrosis of foliage after 3 weeks. Further study is needed to test the effectiveness of this method in the field and to assess the effect of such high doses of boron in natural settings (Marquis et al. 1984).

Biological

No biological control methods are known that are feasible in natural areas (Hutchison 1990, 1992).

Phillips Petroleum Company (1963) mentioned that reed canary grass cannot survive extremely close grazing. But, as noted by Hutchison (1990, 1992), grazing probably is not a practical means of control in wetlands, where reed canary grass usually is a problem.

Burning

Prescribed burning appears to aid in reducing the density of reed canary grass and suppressing its spread, but is not very effective in controlling dense monocultures (Hutchison 1990, 1992). If native species are present, burning usually increases and maintains the vigor of native communities which may enable the species to compete better against and possibly displace reed canary grass.

Henderson (1990) found that early spring burning did not control reed canary grass, and may have accelerated its spread. Late spring burning (mid-to-late May) weakened the canary grass and prevented seed production, but did not eliminate it. Late spring burns were often harmful to many of the native plants blooming at that time.

In areas where other species are present, Hutchison (1992) recommended late fall or late spring burns repeated for several years to control reed canary grass. Annual burning may be needed for 5 or 6 years before good control is apparent.

Apfelbaum and Rouffa (1983) found that prescribed burns conducted on a 2 to 3-year rotation restricts the spread of reed canary grass, but does not eradicate it.

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INTEGRATED PEST MANAGEMENT FOR

COMMON REED, *Phragmites australis* (Cav.) Trin. ex Steud.

INTRODUCTION

Common reed (*Phragmites australis*) is found on every continent except Antarctica and may be the most widely distributed flowering plant in the world (Davis and Briggs 1986; Tucker 1990). It is widespread throughout the United States and typically inhabits such natural communities as marshes, swamps, fens, and prairie potholes (Roman et al. 1984, in Marks et al. 1994). It is commonly planted, along with reed canary grass (*Phalaris arundinacea*), in the reclamation of mine slurry impoundments (Hunt 1990) and in wastewater wetlands.

Common reed is native to the United States (Tucker 1990), but it has been spreading like an aggressive exotic. Within the last few decades, it has spread rapidly into wetlands in parts of North American where it dominates the vegetation. A more aggressive genotype may have been introduced (Marks et al. 1994). Neither Mohlenbrock (1986) nor Swink and Wilhelm (1994) denoted common reed as a non-native species in Illinois.

In many parts of the world and the United States, common reed is not necessarily considered a problem. In some countries, reed stands are still managed for thatching. Some native populations in the United States, such as those in sea-level fens in Delaware and Virginia, and along Mattagota Stream in Maine, are not considered invasive and pose little threat (Rawinski pers. comm. 1985, in Marks et al. 1994). It can be difficult to distinguish stable populations from invasive ones (Marks et al. 1994). Marks et al. recommended examining the disturbance history of an area and historical records or other information concerning the locally indigenous species to determine whether common reed naturally occurred or was introduced.

Common reed typically forms dense, monospecific stands in the areas where it occurs, often to the near exclusion of other species. It is generally considered an aggressive, unwanted invader in the eastern United States and the upper Midwest, as well as in the Mississippi River Delta of southern Louisiana. Populations of common reed occur, but are declining, in many western States and in coastal Louisiana, where there is some concern over loss of its habitat (Marks et al. 1994).

HABITAT

Common reed grows in and near freshwater, brackish, and alkaline wetlands in the temperate zones worldwide (Marks et al. 1994) and grows best at a *p*H of 5.5 to 7.5 (Gorham and Pearsall 1956). It is common along railroad tracks, roadside ditches, dredge spoil deposits, lakeshores, and streambanks where it often forms monospecific stands (Hocking et al. 1983; Marks et al. 1994; Swink and Wilhelm 1994). Common reed grows in fresh or slightly brackish water on mud or organic substrates, and occasionally on sand; it tolerates water depths from a few cm to 2 m, depending on the biotype (Hocking et al. 1983). It seems to be limited by the nutritional status of the substrate and is generally confined to areas of medium fertility (Kershaw 1978).

LIFE HISTORY

Common reed is a perennial grass that produces annual shoots from perennial rhizomes. Shoots generally live for one season and rhizomes persist for 3 to 6 years (Haslam 1972).

Common reed primarily reproduces vegetatively through its extensive root system of underground rhizomes. The rhizomes form a dense mat at the water-substrate interface (Haslam 1972). Mature colonies of common reed usually exhibit a balance between vertical and horizontal rhizomes, whereas colonizing stands have predominantly horizontal rhizomes. The vertical rhizomes bear buds that develop into aerial shoots, or vertical or horizontal rhizomes. Horizontal rhizomes do not produce aerial shoots without first developing vertical rhizomes (Haslam 1972). The horizontal rhizomes can grow to depths of 1.5 to 2 m, but usually grow between 20 and 200 cm below the surface of the substrate (Haslam 1969*a*, in Hocking et al. 1983). Vertical rhizomes bear one aerial shoot during the first year, and up to six in the second year (Haslam 1969*b*, in Hocking et al. 1983). Vertical rhizomes grow most rapidly in late winter and early spring, but horizontal rhizomes grow the most during late summer when root reserves are at their highest (Haslam 1972).

The plants generally flower and set seed between July and September (Marks et al. 1994). Common reed flowers from about the first of September to the first of October in northern Illinois (Swink and Wilhelm 1994). Seeds usually are dispersed between November and January in the northeastern United States (Marks et al. 1994). Common reed can produce more than 1,000 seeds per plant (Bittmann 1953, in Hocking et al. 1983), but most of the seed is not viable (Tucker 1990). Germination is generally very low. Germination occurs in spring or early summer on damp soil or under 1 cm of water. Shoots usually emerge in May, and a full canopy develops by late July; overwintering buds also form in July (Fiala 1976, in Thompson and Shay 1985) and remain dormant until the following spring in Manitoba.

Common reed can colonize new sites by its wind-dispersed seed, but its main source of dispersal is through rhizome fragments that have been transported by humans, machinery, water, or other means. The rhizomes can be fragmented by flood scouring, wave action, disking, or other disturbances. Rhizome segments that are 20 cm long with 3 nodes are capable of producing a new plant (Haslam 1969*a*, in Hocking et al. 1983).

CONTROL METHODS

Areas that have been invaded by common reed have excellent potential for recovery, but it is imperative to monitor the site. Common reed very readily re-invades suitable habitats even after it has been eradicated (Marks et al. 1994).

Mechanical

Cutting can control and possibly eliminate common reed, depending on the time of year when it is done. It is generally agreed that the most effective time to cut common reed is midway during the growing season (about mid-June) when the rhizome reserves are at their lowest. This generally results in a low shoot population in the following spring (Haslam 1969*b*, in Hocking et al. 1983). Shoots cut early in the growing season generally resprout, resulting in no major effect on the population. Late in the season rhizomes have replenished their reserves and cutting again has little effect. Mochnacka-Lawacz (1974*b*, in Hocking et al. 1983) reported that cutting three times during the growing season reduces stem biomass by 60%, and repeated annual cutting eventually eliminates stands.

Ailes (pers. comm. 1992, in Marks et al. 1994) mowed a stand of common reed, then spread a thin layer of soil and grass seed over the area. Weekly mowing was conducted for the remainder of the summer. Rhizomes were found to decompose after this treatment, and in the following year, common reed occurred only at the edges of the area.

Huffman (pers. comm. 1992, in Marks et al. 1994) reported that a preferred tool for cutting is an old-fashioned hedge trimmer with an 8-inch flat blade with serrations, manufactured by Union Fork and Hoe. They found that the trimmer works better than loppers and is safer than a sickle. "Weed-whackers" were also used successfully.

Drainage of an area can effectively control common reed, especially if followed by heavy grazing (Haslam 1969*b*, in Hocking et al. 1983). Once the area is drained and the reed eliminated, it is unable to re-invade (Haslam 1965).

Plowing or disking, if done properly, can help control common reed, but if done incompletely will only serve to fragment the rhizomes and spread the population. If the fragments are brought to the surface they will desiccate, or if buried deeper they are likely to exhaust their reserves before the shoots reach the surface (Haslam 1971). Whittet (1958, in Hocking et al. 1983) reported that rotary hoeing followed by spring-tine cultivation is effective in bringing the rhizomes to the surface.

Keene (pers. comm. 1991, in Marks et al. 1994) received 90% success by covering small reed patches (50-ft-diameter) with black plastic. Clear plastic was also used, but black appeared to be more effective. Boone et al. (1987, in Marks et al. 1994) found that black plastic may have been effective, but is much more labor intensive than cutting and burning.

Flooding can be used to control common reed when 3 ft of water covers the rhizomes for an extended period during the growing season, usually 4 months (Beall 1984, in Marks et al. 1994). Beall noted that many areas cannot be flooded to the necessary depth and duration without damaging or destroying the desirable plant species or communities.

Chemical

Amitrole, Amitrole-T, 2.2-DPA, and glyphosate have been successfully used to control common reed (Dunham 1970; Swarbrick 1982, in Hocking et al. 1983). Glyphosate (360 g as the isopropylamine salt per liter) applied using a rope wick application and foam spray at 12 liters per ha gave 98% control (Ripper pers. comm., in Hocking et al. 1983). Application of glyphosate is most effective when the plants are mature and actively translocating resources to the rhizomes. Spraying shoots that are senescing during late autumn is recommended (Hocking et al. 1983). Herbicides containing amitrole (25 g amitrole per liter plus 220 g ammonium thiocyanate per liter) applied at 2.2 to 2.3 liters to 100 liters water, and 2,2-DPA (740 g of 2,2-DPA as the Na salt) applied a 1 to 2 kg per 100 liters of water are effective if sprayed during flowering (Hocking et al. 1983).

Rodeo (active ingredient: 53.8% glyphosate) is registered for use in areas of open water and is often used to control common reed (Marks et al. 1994). Rodeo should be applied after the tasseling stage when plants are actively translocating nutrients to the rhizomes. In dense stands, some plants may not receive adequate exposure to the herbicide, and re-treatment may be necessary. Beall (pers. comm. 1991, in Marks et al. 1994) reported 90% success after Rodeo was applied aerially in late August. A prescribed burn was conducted in the area during the following February to remove litter and allow re-establishment of marsh vegetation.

In large areas where common reed occurs in expansive populations, Rodeo is generally applied by aerial spraying. Treatments are sometimes combined with prescribed burns. Marks et al. (1994) referred to a few studies that initially received favorable results by aerial spraying, but the control effort was discontinued because of lack of funding. In most of these cases, common reed readily re-established itself to pre-treatment densities, illustrating the need for complete eradication and continual monitoring for re-invasions.

In more sensitive areas where protection of surrounding vegetation is a concern, Rodeo can be applied to specific plants or small populations using a backpack sprayer. Johnstone (pers. comm. 1991, in Marks et al. 1994) reported success using Rodeo in tidal areas and using Accord, another glyphosate product, in non-tidal areas. The herbicides were applied from mid-August to mid-October, when the seeds were ripening. Only tasseling plants were treated. After an intensive application during the first year and touch-up spraying in the second, 90 to 95% control was achieved. Areas were rechecked every 3 years for new plants.

Biological

No published information was found concerning biological control agents for common reed. According to Marks et al. (1994), biological control does not seem to be an option at this time. Several naturally occurring parasites feed on common reed (Skuhravý 1978; Toorn and Mook 1982; Mook and Toorn 1982), but do not seem to cause sufficient or consistent damage. Some of these pests are eliminated by management activities such as burning or cutting. Hocking et al. (1983) reported that common reed is relatively immune to natural enemies in Australia.

Grazing has no major effect on shoot density, but trampling by cattle can break shoots and damage rhizomes, which can sometimes reduce shoot density (Haslam 1971).

Burning

Burning of common reed, unlike cutting, generally breaks bud dormancy and often results in rapid shoot emergence (Haslam 1972).

Thompson and Shay (1989) found that spring, summer, and fall burns (conducted in May, August, and October) all resulted in increased shoot density in common reed stands, but the proportion of flowering shoots decreased after both summer and fall fires. Spring burns resulted in the highest increase in shoot density (Thompson and Shay 1985). Summer burns helped to thin the canopy, remove the litter, and slightly increase species richness in the stand. Thompson and Shay (1985) commented that burning in mid-June, when rhizome reserves are at their lowest, may be more detrimental.

Stands of common reed create great amounts of litter each year, which prevents the germination and sprouting of many other species. The canopy of common reed is very effective in intercepting light before it reaches the lower levels. Plants can compete only if they can emerge early in the season and keep pace with the growth of common reed. Very few plants have this capability (Thompson and Shay 1989). Burning can eliminate the litter and encourage germination and sprouting of other species, but it often serves to encourage sprouting of common reed as well.

Beall (1984, in Marks et al. 1994) found that prescribed burning was successful when used after chemical treatment of common reed.

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INTEGRATED PEST MANAGEMENT FOR

COMMON BUCKTHORN, *Rhamnus cathartica* L.

INTRODUCTION

Common buckthorn (*Rhamnus cathartica*) is a Eurasian shrub that was introduced into North America more than a century ago for use as an ornamental, in hedges and shelterbelts, and to provide wildlife cover and food. It has spread and naturalized throughout the northeastern United States. Common buckthorn occurs in the northern three-fifths of Illinois (Mohlenbrock 1986), and it is a serious problem in the northeastern part of the state (Heidorn 1990). Dietz (1930) documented ornamental and naturalized buckthorn in many locations throughout the upper Midwest, North and South Dakota, and Montana.

Common buckthorn readily spreads by bird-distributed seed. It often crowds or shades out native species in the shrub and herbaceous layers (Gourley and Howell 1984; Heidorn 1990; Boudreau 1992; Tenenbaum 1996), especially in woodlands that have been severely grazed or otherwise disturbed (Swink and Wilhelm 1994). It has become a serious problem in several biotic communities in the Midwest. Changes in the native plant composition after invasion of buckthorn present serious management problems (Brown et al. 1985).

The control of buckthorns is also an agricultural problem. Some buckthorn species are winter host plants for a leaf rust (*Puccinia coronata*) that affects oat production. Common buckthorn is the most prevalent host in Wisconsin (Hanson and Grau 1977). Eradication of common buckthorn to control *Puccinia coronata* was first suggested in 1894 (Dietz 1930).

HABITAT

Common buckthorn is frequent in mesic and dry-mesic forests in southern Wisconsin (Harrington et al. 1989) and has become a dominant component in the understory (Brown et al. 1985). It has invaded many plant communities in Illinois and Wisconsin, including woodlands, savannas, and prairies (Gourley and Howell 1984; Heidorn 1990, 1991).

Gourley and Howell (1984) found buckthorn abundance to be closely correlated with disturbance. They found the oldest individuals and densest populations near trails. In areas of high abundance, buckthorn grows most vigorously in open and moist areas. Gourley and Howell found relatively little buckthorn in open dry areas at the University of Wisconsin Arboretum at Madison.

Life History

Common buckthorn is a shrub that grows to heights between 2 to 6 m (approximately 6 to 20 ft) at maturity (Rosendahl 1955; Hubbard 1974). The shrubs flower in May and June, and the fruit ripens in August and September (Rosendahl 1955; Swink and Wilhelm 1994). The fruit of buckthorn is a berry-like drupe that contains three to four seeds (Rosendahl 1955; Hubbard 1974). Buckthorn fruits are readily consumed by birds, and their laxative (cathartic) effect results in abundant distribution (Heidorn 1990, 1991).

Gourley and Howell (1984) found that seeds germinate better after scarification and seem not to germinate without removal of the outer fruit. More seeds germinate in bare, roughened soil than in soil with a litter or herbaceous layer. Germination is better in soil that is moist but not saturated, and where light levels are higher than 12.5 percent of total light (Gourley and Howell 1984). Seeds do not appear to need cold stratification to germinate (Hubbard 1974).

As with many exotics, common buckthorn breaks dormancy earlier in the spring and retains its leaves much longer in the fall than most native vegetation (Rosendahl 1955; Brown et al. 1985; Harrington et al. 1989).

Control Methods

Mechanical

Cutting or girdling can provide some control of common buckthorn, but the shrubs usually resprout vigorously from cut or damaged stems and from girdles (Gourley and Howell 1984; Packard 1987; Heidorn 1990, 1991). Repeated cuttings are necessary to control sprouts. To girdle a stem, the phloem should be removed without damaging the xylem. Two parallel cuts 7 to 10 cm apart should be made, cutting through the bark slightly deeper than the vascular cambium. Girdles should be rechecked every several weeks to make sure bark does not grow over the cut (Heidorn 1990, 1991).

Gourley and Howell (1984) found that 73% of buckthorns resprouted after a single cutting in July (after fruiting), and 53% resprouted if the first cut was followed by a second cut 4 hours later.

Because of the strong tendency of buckthorn to resprout, many mechanical means of control most likely will result in abundant sprouts that require repeated cutting. Additional methods to reduce sprouting may include treatments with herbicide.

Chemical

Several herbicides have been tested on buckthorns. Heidorn (1990, 1991) recommended treating cut stumps with Trimec (a formulation of 2,4-D, MCCP, and dicamba), Roundup (active ingredient: 41% glyphosate), or Rodeo (active ingredient: 53.8% glyphosate) to prevent resprouting. Trimec should be diluted 50:50 with water and applied according to the herbicide label instructions. A 20% solution of Roundup can be applied to the stump. Rodeo is a glyphosate product that is approved for use in wetlands. A 50% solution of Rodeo should be applied to cut stumps. Herbicide can be applied with a hand-held sprayer or wiped on the stump with a sponge applicator. Herbicide should be applied immediately after cutting for the best results.

The Roundup label calls for a 50 to 100% solution for stump treatments, but a 20% solution has proven effective for many woody species (Kline 1981; Nyboer 1992; Glass 1994), including buckthorn. According to the herbicide label, Roundup works best if applied during active growth and full leaf expansion. In natural areas and where protection of neighboring plants is of concern, herbicide should be applied during early spring or in the fall when most native vegetation is dormant and potential for injury is reduced. The Rodeo label calls for a 50 to 100% solution for cut stumps; effectiveness of lower concentrations has not been documented for this product (Nyboer 1990, 1992).

Heidorn (1990, 1991) received favorable results with Garlon 3A and Garlon 4 (triclopyr). A 50% solution of Garlon 3A applied to stumps effectively controls resprouting. According to the herbicide label, a 1 to 5% solution of Garlon 4 is effective as a basal bark treatment if applied to stems that are less than 15 cm (6 inches) in basal diameter. The solution of Garlon 4 should be sprayed or painted all around the trunk to a height of 30 to 38 cm (12 to 15 inches). Heidorn (1990, 1991) found a 1.5 to 2% solution to be effective for basal bark treatments. A foliar application of a 1.5% solution of Rodeo can also be used in buffer or severely disturbed wetlands (Heidorn 1990, 1991).

Boudreau (1992) found that treating stumps with undiluted Garlon 3A is very effective (95%); when carefully applied at full strength, it does not seem to adversely affect non-target plants.

Glass (1994) had the most success in treating buckthorn with Garlon 4. Success rates approached 95% for basal bark treatment and 85% using cut-stump treatment. The manufacturer recommends a 20 to 30% solution of Garlon 4 for basal bark treatments. Glass had excellent results with both a 25% solution and a 12.5% solution (diluted with Androc diluent). Glass found that a 6% solution of Garlon 4 works as effectively as the 12.5% solution on basal bark treatments, but not as well on cut stumps.

Garlon 3A is a water-based herbicide (diluted with water), while Garlon 4 is oil-based (diluted with oils). Oil diluents recommended by the manufacturer include mineral oil, diesel fuel, No. 1 and No. 2 fuel oils, or kerosene. Diesel fuel, fuel oil, and kerosene are not recommended on natural or sensitive areas because of their potential to damage surrounding, non-targeted vegetation (Illinois Nature Preserves Commission 1990). Because run-off can damage non-target plants, Garlon should be avoided if rain is in the forecast for the following 1 to 4 days (Heidorn 1990, 1991). Garlon can be applied at any time of year, but use during the dormant seasons reduces the potential for injury to surrounding vegetation.

Hefty (1984) reported a 96% kill rate using Weedone 170 (2,4-D + 2,4,DP). Weedone was mixed at a rate of 40 g of herbicide per liter of diesel fuel and applied to cut stumps. All of the bark was coated with the herbicide mixture.

Apfelbaum (1984) tested various concentrations of Ortho Bush Killer A on another invasive exotic buckthorn (*Rhamnus frangula*). Ortho Bush Killer was applied to freshly cut stumps. He found that the lowest effective concentration is 2:5, which killed 87.5% of the plants.

According to Hanson and Grau (1977), buckthorn can be removed by digging or pulling, but the easiest control is to cut the trunks off near the ground and spray the stumps with 2,4,5-T or a mixture of 2,4,5-T and 2,4-D in oil. They found that early spring, before snow has melted, is a good time to apply the herbicide.

With any herbicide, users should follow the label recommendations for diluents and application rates, unless weaker solutions have been found to be effective.

Biological

Malicky et al. (1970) conducted an extensive survey for biotic control agents of *Rhamnus cathartica*. They conducted studies of insects on *Rhamnus* and a general inventory of phytophagous insects associated with European Rhamnaceae. They compiled an extensive list of these insects and suggested a few that may work as biotic control agents, pending future research.

A lethal phytoplasma disease of common buckthorn has been observed in southwestern Germany. Mäurer and Seemüller (1996) observed diseased plants with unusual witches' broom symptoms. The leaves of diseased trees are often distorted, and the plants steadily decrease in vigor. Severely affected trees and shrubs decline and do not bear fruit. Phloem necrosis is apparent. Mäurer and Seemüller made no mention of the potential of this organism for biological control of buckthorn, but future research may determine its usefulness.

Burning

Burning effectively controls buckthorn seedlings, but only if there is enough fuel to carry the fire (Heidorn 1990, 1991; Boudreau 1992). Boudreau noted that areas with seedlings are often low in fuel. Burning can reduce flowering and seed production, but mature buckthorns readily resprout after a fire, even after top-kill (Post and Klick 1989; Boudreau 1992). In fire-adapted communities, annual or biennial burns may be required for 5 to 6 years or more (Heidorn 1990, 1991). This frequency of burns should not be used in areas where the natural community would be adversely affected (Heidorn 1990, 1991). Because of buckthorn's to resprout, a combination of methods including fire, cutting, and herbiciding may provide the most effective control.

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INTEGRATED PEST MANAGEMENT FOR

MULTIFLORA ROSE, *Rosa multiflora* Thunb.

INTRODUCTION

Multiflora rose (*Rosa multiflora*) is native to Japan and Korea. It was introduced into the United States in the 1860s to use primarily as a grafting rootstock for domestic roses (Krüssman 1986; Dirr 1983). In the 1930s and 40s conservation agencies ardently promoted the use of multiflora rose as a "living fence" and as a wildlife food cover (Dugan 1960; Gill and Pogge 1974). It was planted widely in the northeastern United States and the Midwest (Dugan 1960). In West Virginia alone, more than 14 million plants had been distributed to farmers and other landowners by about 1960 (Dugan 1960).

Multiflora rose was introduced into Illinois in the 1950s. It quickly spread from plantings and has become recognized as one of the most persistent and annoying weeds of the Chicago region (Swink and Wilhelm 1994). It has been declared a noxious weed by many eastern and Midwestern states (Amrine and Stasny 1993). It is listed in the Exotic Weed Act of Illinois.

HABITAT

Multiflora rose thrives in almost every degraded terrestrial habitat (Swink and Wilhelm 1994). It occurs in idle lands, successional fields, and pastures, and along roadsides. It readily invades prairies, savannas, open woods, and forest edges (Szafoni 1990, 1991).

As with most roses, multiflora rose grows best in open areas or along woodland borders (Gill and Pogge 1974).

LIFE HISTORY

Multiflora rose is a perennial shrub in the Rosaceae (rose family) that can grow to heights from 1 to 10 ft (0.3 to 3 m) (Gill and Pogge 1974). It blooms from late May through late June in northern Illinois (Swink and Wilhelm 1994), and the fruit generally ripens in September (Gill and Pogge 1974). The seeds of multiflora rose are achenes borne in a fleshy, berry-like rose hip. The number of achenes per hip varies (Gill and Pogge 1974). A medium-sized rose shrub can produce 500,000 to 1,000,000 seeds in a good year (Amrine and Stasny 1993).

Multiflora rose reproduces and spreads primarily by seeds, but it can also spread by layering, when the tips of the stems touch the ground and develop roots. Songbirds are the main dispersal mechanism, but many other animals consume the fruits (Dugan 1960; Gill and Pogge 1974; Szafoni 1990, 1991; Amrine and Stasny 1993). Seeds of multiflora rose can stay viable in the soil for 10 to 20 years (Szafoni 1990, 1991; Stratford et al. 1995).

CONTROL METHODS

Mechanical

In buffer or highly disturbed areas, repeat mowing can control the spread of multiflora rose (Dugan 1960; Anderson 1977; Szafoni 1990, 1991). Three to six cuttings during the growing season can result in high mortality. Retreatment for 2 to 4 years may be necessary (Szafoni 1990, 1991). Stratford et al. (1995) referred to a West Virginia study in which 3 to 4 years were needed to eliminate multiflora rose infestations by mowing 3 to 6 times per growing season at 4 to 8-week intervals.

Mowing may not be practical or possible in difficult terrain, or for dense stands with large mature shrubs (Evans and Eckardt 1995). For well established stands or fencerows, a bulldozer may be required to effectively and economically eliminate the shrub (Anderson 1977; Stratford et al. 1995).

In high quality areas or where protection of nearby vegetation is of concern, multiflora rose can be controlled by hand-pulling or grubbing individual plants. All of the large roots must be removed or killed; otherwise resprouting occurs. This method is practical for small populations or light infestations, but could be very time-consuming in large, dense stands (Szafoni 1990, 1991).

Chemical

Several herbicides and control treatments have been tested on multiflora rose. Stratford et al. (1995) provided a summary table of herbicides including their recommended rates of application, recommended timing of application, and precautions and instructions for various types of treatments. Herbicide treatments discussed by Stratford et al. include basal bark, dormant stem, soil, and foliar. Evans (1983) provided a literature review of management practices for controlling multiflora rose. His paper includes a table summarizing the effectiveness of several herbicides applied at various rates on multiflora rose.

In natural areas or where protection of surrounding vegetation is of concern, the herbicides glyphosate and triclopyr have been used effectively to control multiflora rose.

A solution of 10 to 20% Roundup (active ingredient: 41% glyphosate) applied directly to cut stems of multiflora rose works as an effective control (Szafoni 1990, 1991). The Roundup label recommends a 50 to 100% solution for cut-stump treatments, but the lower concentration has been proven to be effective (Glass 1992; Kline 1981). This treatment is effective when used late in the growing season (July to September) and during the dormant season (Szafoni 1990, 1991).

A 50% solution of Garlon 3A (active ingredient: 44.4% triclopyr) can be applied to cut stems or canes of multiflora rose. The herbicide can be applied with a hand-sprayer. Garlon should not be used if rain is in the forecast for the following 1 to 4 days.

Herbicides applied during the dormant seasons reduce potential for damage to surrounding vegetation. This is the preferred timing of application on most natural areas.

On degraded areas, Krenite (fosamine) and Banvel (dicamba) have been effective as foliar sprays on multiflora rose. Krenite is preferred because it is selective for woody species. Banvel is selective for broadleaf plants. Foliage should be completely covered for thorough control.

Krenite should be applied in a 2% solution plus surfactant (2.5 oz of Krenite plus 0.5 oz surfactant per gal of water) (Szafoni 1990, 1991). The Krenite S formulation comes ready with the appropriate amount of surfactant. Krenite should be applied only during July to September. Effects will not be apparent during the fall following the application. Slight regrowth may occur during the following spring, but cane mortality will occur during the following summer (Szafoni 1990, 1991).

Banvel should be applied in a 1% solution (1.3 oz per gal of water). Treatments can be applied at any time during the growing season, but the best results are obtained if treatments occur during May and June when the leaves are fully emerged and plants are actively growing and flowering.

Dugan (1960) found that seedlings can be killed with an application of 2,4,5-T.

Derr (1989) found that late spring foliar applications of Metsulfuron (at 22 g per ha, and 67 g per ha) provided 95 to 100% control of multiflora rose 320 days after treatment. Fall applications were effective, but were not as consistent. Spring treatments were applied on May 22 in the first year and May 14 in the second year. Spotgun treatments of Metsulfuron at 20 mg per m of canopy diameter provided 93% control of the shrubs 390 days after treatment. Tebuthiuron applied at 1000 mg per m of canopy diameter completely controlled multiflora rose when applied in the spring. Spring spotgun treatments were applied April 10 in the first year and May 14 in the second year.

Derr (1989) commented that control of multiflora rose needs to be at about 95% or greater to reduce or eliminate the need for re-treatments in the following growing season.

If a significant number of shrubs recover after treatment, the infestation can quickly return to its pre-treatment level. Derr felt that Metsulfuron provided "safer" control than many herbicides that have been used to control multiflora rose and would result in less injury to surrounding vegetation.

Biological

Browsing and trampling by livestock can cause severe damage during the first two to three years of establishment, but multiflora rose has been considered practically immune to livestock damage once it is well established (Dugan 1960).

Goats and sheep graze on multiflora shrubs and can provide satisfactory control (Stratford et al. 1995). Goats can graze and defoliate the vegetation to a height of about 7 ft, above which leaves remain active. This is not a practical method in high-quality natural areas where many desirable species may be eaten as well.

Two agents have been observed that may provide significant biological control of multiflora rose. A chalcid wasp, *Megastigmus aculeatus* var. *nigroflavus*, inserts its eggs into the developing ovules (immature seeds) of the rose hips. Larvae consume the contents of the seed as they develop, usually during July and August. In areas with diseased shrubs, Amrine found that an average of 49.7% to 46.7% of the viable seeds were infested (Amrine and Stasny 1993). The wasps apparently have a poor ability to fly (Shaffer 1987, in Amrine and Stasny 1993), so most dispersal is by movement of infested seed. Amrine and Stasny (1993) estimated that eventually (in 20 or more years) the chalcid wasp would find and use 90% of the multiflora rose seed in West Virginia.

Chalcid wasp larvae suffer 20 to 80% mortality when temperatures fall below -16°F (-26°C) for extended periods of time (Amrine and Stasny 1993). This may decrease the effectiveness of the wasp for use as a multiflora rose biocontrol in northern areas where winter temperatures may fall below the tolerance level of the larvae.

Another agent that has caused high mortality in multiflora rose is a virus spread by an eriphyid mite, *Phyllocoptes fructiphilus*, that causes Rose Rosette Disease (RRD). Symptoms of RRD on multiflora rose include a diagnostic red or purplish vein mosaic, bright red lateral shoots, dwarfed foliage, and premature development of lateral buds producing "witches' brooms" formations (Amrine and Stasny 1993). Populations of *P. fructiphilus* are increasing and spreading across the eastern United States and the Midwest. Amrine and Stasny (1993) estimated that RRD has the potential to eliminate more than 90% of multiflora rose in areas where dense stands occur.

The virus is undergoing tests to determine whether it will spread to other desirable species, rosaceous and otherwise (Amrine and Stasny 1993). Thus far it appears that only plants in the genus *Rosa* are susceptible to RRD. Some native *Rosa* species show resistance to the disease and cannot be infected. *Rosa carolina*, *R. palustris*, and *R.*

setigera are among the resistant species. Miticides are also being tested to determine their effectiveness in controlling *P. fructiphilus* on ornamental roses.

Amrine and Stasny (1993) expected that the combined effects of the above two agents (i.e. the wasp *Megastigmus* and Rose Rosette Disease) will result in substantial reductions in numbers of multiflora rose, but over a long period of time, possibly 20 to 30 years.

Burning

In fire adapted communities, prescribed burning can hinder establishment of multiflora rose, provided enough litter or fuel exists to carry the fire.

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