Status and Management Recommendations

for

Leafy Spurge

Euphorbia esula **L.**
Euphorbiaceae (The Spurge Family)

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History and Distribution

Leafy spurge is native to Europe and Asia (Moore 1958). First recorded in North America in a Massachusetts garden in 1827, leafy spurge is now found throughout the US and southern Canada, except for the southeastern and south central US (USDA-NRCS 2009, Best et al. 1980). In the western US, leafy spurge is a notorious ecological and economic pest, inhabiting more than 1.1 million acres (Di'Tomaso 2000). Direct and secondary economic losses to grazing and wildlands from leafy spurge in the Dakotas, Montana, and Wyoming have been estimated at $129 million annually (Leitch et. al. 1994).

Because of climatic and vegetational differences, leafy spurge tends to be less common in eastern North America. Leafy spurge is sporadically established across the ceded territory, including northern Wisconsin, Upper Michigan, and northern Minnesota (Voss 1985, GLIFWC 2009, WIS 2009, MINN 2009), and appears to be increasing in abundance in the region. It is listed as a "prohibited and restricted noxious weed" in Michigan, a "noxious weed" in Wisconsin, and a "prohibited noxious weed" in Minnesota (MIDA 2005, WDNR 2008, MDA 2009a).

Characteristics

Leafy spurge is a strongly rhizomatous, herbaceous perennial (Figure 1). Shoots appear in dense clumps, from the woody root crown. Plants may reach more than a meter tall, but are usually shorter. They are pale bluish-green during the summer, turning orange and then red in the fall (Selleck et al. 1962). As with all spurge species, a milky, sticky latex sap is found throughout the plant (Best et al. 1980, Gleason and Cronquist 1991) (Figure 2).

Leafy spurge begins flowering as early as May and continue through June to mid-July (Gleason and Cronquist 1991, Selleck et al. 1962). Lateral branches may continue to produce flowers and seeds into the fall (Best et al. 1980).

Spurge species have a unique floral arrangement. The flowers are small and inconspicuous, greenish, and imperfect (containing only male or female parts), and are arranged in clusters. Each cluster consists of one female flower, with its ovary on a short stalk, closely surrounded by several male flowers, each having one stamen. This cluster of flowers is surrounded by a cup-shaped structure called a cyathium. Yellow-green heart-shaped bracts surround each cyathium, giving the whole thing the appearance of a single greenish-yellow "flower" (Figure 3).

Pollination is facilitated almost entirely by insects, including ants, that are drawn by the large

Figure 1. Leafy spurge in bloom. (*S. Garske, GLIFWC*)

Figure 2. Milky sap. (*S. Garske, GLIFWC*)

amounts of nectar produced by glands of the cyathium (Selleck et al. 1962). Leafy spurge has mechanisms to promote outcrossing (Selleck et al. 1962), but can produce seeds autonomously as well, either through self fertilization or pseudogamy (asexual seed production, stimulated by self-pollination) (Selbo and Carmichael 1999). As they mature, seed color changes from yellow to brown to grey, and finally to brown-mottled, with the last two color phases viable (Wicks and Derscheid 1958, in Selleck et al. 1962).

Figure 3. Cyathium of flowers (*S. Garske, GLIFWC*)

Dispersal generally begins when the capsules burst on warm sunny days, propelling the seeds as much as 4.6 m from the parent plant (Bakke 1936, in Selleck et al. 1962, p. 25). The seeds may then be spread further by a number of biotic and abiotic

vectors. They are sometimes cached by small mammals, and ants may also have a role in their dispersal (Selleck et al. 1962). The seeds float and are able to germinate on top the water, allowing plants to become established in areas of occasional flooding, such as riverbanks and low prairies (Selleck et al. 1962).

Most seeds germinate the following spring, though some sprout throughout the growing season (Selleck et al. 1962). Selleck et al. (1962) found that 99% of the seed germinated by the end of the second year, but a few seeds waited as long as 5 years. A small percentage of seed may remain viable in the soil for as long as 13 years (Selleck et al. 1962).

Seedlings begin to develop an extensive root system as early as 7-10 days after germination (Selleck et al. 1962). Often the seedling's original shoot dies, to be replaced by new shoots from the root system (Selleck et al. 1962). Roots can reach a depth of a meter or so by the end of the first season (source in Selleck et al. 1962). Seedlings generally don't produce seed of their own until the second year (Selleck et al. 1962), though some first-year plants can produce seed when grown free of competition (Morrow 1979). Shoot density has been measured at over 1000 per square meter in heavy clay soil (Selleck et al. 1962).

Part of what makes leafy spurge such an aggressive competitor is its extensive, dimorphic root/rhizome network. The initial (primary) root is an indeterminate, long root that travels more or less downward (vertically) through the soil, producing secondary long roots along the way (Raju et al. 1963). These long roots are woody and are protected from water loss by thick, corky bark (Raju et al. 1963). Long roots have been found as deep as 9 m below the soil surface (Holmgren 1958, in Best et al. 1980). Pink buds, capable of producing new shoots, are formed along nearly all of the long root network (Best et al. 1980). Long roots typically persist for several to many years (Raju et al. 1963). Lateral short (determinate) roots are produced from both the primary and secondary long roots, and live for one growing season at most (Raju et al. 1963).

Local spread of leafy spurge is primarily accomplished vegetatively. Selleck et al. (1962) measured the average vegetative rate of spread at 0.6 m per year in ungrazed native grassland. The fastest yearly advance was 3.4 m. In most years vegetative growth continues throughout the summer, though growth slows significantly while the plants are flowering (Selleck et al. 1962).

Other Spurge Species in Eastern North America

The genus *Euphorbia* is large and diverse (Voss 1985). Approximately 107 species are native to the continental United States and Canada, with about 45 of these occurring east of the

Mississippi River (Nowierski and Pemberton 2002). A number of *Euphorbia* species occur in the upper Great Lakes region, some of which are native or adventive from further south or west. A few species are listed as rare in Wisconsin and Michigan.

The following information is taken from WIS 2009, Voss 1985, and Gleason and Cronquist 1991, unless otherwise noted. Nomenclature follows Gleason and Cronquist 1991.

Subgenus *Esula*

Like leafy spurge, cypress spurge (*Euphorbia cyparissias*) is introduced from Eurasia. It tends to be a shorter, bushier plant than leafy spurge, with shorter leaves and numerous axillary (side) branches near the tops of the main stems (Stahevitch et al. 1988). It reaches a maximum of about 0.4 m tall. Cypress spurge is known to cross with leafy spurge in Europe (Moore 1958). Cypress spurge is a strongly rhizomatous perennial, and can produce dense colonies in some habitats.

Tinted spurge (*Euphorbia commutata*) is a perennial species native to the southern US, whose range extends north into southern Wisconsin and Michigan. It is listed as "threatened" in Michigan and as "special concern" in Wisconsin.

Woodland spurge (*Euphorbia obtusata*) is an annual native to woods in the eastern US, south to South Carolina and Texas. Its range extends north into extreme southern Wisconsin and lower Michigan, where it is considered native and adventive, respectively. It is listed as "special concern" in Wisconsin.

Wartweed (*Euphorbia helioscopia*) is introduced from Eurasia. It is an annual species that is sporadically introduced to the upper Great Lakes states, in disturbed areas and along shorelines.

Petty spurge (*Euphorbia peplus*) is an annual introduced from Eurasia. It is an early-successional annual sporadically established across the region.

The only member of the subgenus Esula that is found in the ceded territory is *Euphorbia commutata*, which barely reaches the southwestern 1836 Treaty area in southwestern lower Michigan (Voss 1985).

Subgenus *Agaloma*

Flowering spurge (*Euphorbia corollata*) is native to the eastern half of the US and Ontario, Canada, including the upper Great Lakes region. This species has white, petal-like appendages

subtending the cyathium glands, making the plant appear as though it has numerous small, white flowers. The stem leaves are alternately arranged, but with leaves below the primary branches in whorls (groups of 3 or more) at each node, and those of the inflorescence small and opposite. The main leaves are 3-6 cm long, generally wider than those of leafy or cypress spurge, and often elliptical or nearly so. Though it is a deep-rooted perennial, flowering spurge is not rhizomatous, often forming loose colonies of scattered plants.

Six-angled spurge (*Euphorbia hexagona*) is native to the Great Plains region, from Minnesota south and westward. This annual is sporadically introduced eastward, including one county in western Wisconsin.

Snow-on-the-mountain (*Euphorbia marginata*) is an annual, native to prairies and barrens from Minnesota south and westward. A popular horticultural plant, it is locally established eastward, including the upper Great Lakes states.

Subgenus *Poinsetta*

Fire-on-the-mountain (*Euphorbia cyathophora*) is an annual native to southern and central North America, northward as far as southwestern Wisconsin and Minnesota.

Toothed spurge (*Euphorbia dentata*) is an annual found mostly in the southern parts of the upper Great Lakes states (Minnesota, Wisconsin, and Michigan). It is native south and west of these states, and is considered adventive in the region. A form of this species (considered by some authors to be a separate species, *E. davidii* Subils) is introduced to the US, including southern Wisconsin.

Subgenus *Chamaesyce*

Seaside spurge [*Euphorbia polygonifolia,* also known as *Chamaesyce polygonifolia* (L.) Small] is a small, sprawling annual native to the Lake Michigan coastlines of Wisconsin and Michigan, and eastward to the Atlantic. It is listed as “special concern” in Wisconsin.

Dune spurge [*Euphorbia geyeri*, or *C. geyeri* (Engelm.)] and ridge-seeded spurge [*E. glyptosperma*, or *C. glyptosperma* (Engelm.) Small] are also small, sprawling annuals. Both are native to at least the western portion of the upper Great Lakes region, and southward and westward.

Habitats Threatened

Leafy spurge is tolerant of a broad range of climates and environmental conditions. Common habitats include roadsides, pastures, old fields, and other disturbed areas, as well as prairies, savannas, dry woodlands, and riverbanks (Figures 4 and 5). It readily invades and dominates native grasslands, and flourishes in the open oak woods of southern Wisconsin (Selleck et al. 1962). Barrens habitats such as the Moquah Barrens of Bayfield County are particularly vulnerable to invasion by leafy spurge. Leafy spurge lives in similar habitats in its native European range, but is only a minor agricultural weed there (Selleck et al. 1962).

Leafy spurge tolerates a wide variety of soil types, but is most aggressive on course, well-drained soils (Selleck et al. 1962). Its shoots are adapted to dry habitats, and its deep and extensive root system may reach down to the water table, thus avoiding the effects of drought (Lym and Zollinger 1995). Nonetheless plants can withstand weeks of flooding, as long as the shoots are able to grow above the water surface (Selleck et al. 1962). Flooding on the scale of years, however, will kill the plants. Worldwide, leafy spurge has colonized wide variety of habitats, ranging from very dry to humid and seasonally wet, and from subtropical to subarctic (Selleck et al. 1962).

Leafy spurge has low shade-tolerance, limiting its ability to invade forested habitats (Selleck et al. 1962). It is capable of persisting in open woods, but flowering and seed set is greatly reduced. It is unable to persist in closed- canopy forest.

Spurge commonly reaches a density of over 200 shoots per square meter, and can reach more than 2000 per square meter (Selleck et al. 1962), leaving little room for other plants. In a native

Figure 4. Leafy spurge patches on dry hillside. (*S. Garske, GLIFWC*)

Figure 5. Dense roadside patch of leafy spurge. (*S. Garske, GLIFWC*)

Manitoba prairie, Belcher and Wilson (1989) found that abundance of the 5 most common native grasses were all significantly reduced within leafy spurge patches, and that overall native plant richness and diversity was greatly reduced there as well. In the densest spurge patches, most native plants had been entirely eliminated. Leafy spurge has reached "epidemic proportions" in some national parks and wildlife refuges in the western US.

Leafy spurge is generally unusable as forage for native ungulates. Trammell and Butler (1995) found that in Theodore Roosevelt National Park in North Dakota, use of leafy spurge-infested grassland sites by bison (*Bison bison*) was reduced by 83% compared to sites dominated by native grasses. Deer (*Odocoileus* spp.) use of spurge-infested juniper-grassland habitat (their preferred habitat in the Park) was 70% less than in similar uninfested habitat, with elk (*Cervus elaphus*) showing a similar decline in the use of spurge-infested areas. Cattle generally avoid pastures infested with live leafy spurge, but may ingest dry plants (e.g., in hay). Large amounts of spurge cause the potentially fatal disease of "scours" in cattle and horses (Kingsbury 1964, in Stahevitch et al. 1988), and native ungulates would probably be similarly affected (Trammell and Butler 1995). Grazer avoidance of infested areas may lead to increased grazing intensity and disturbance in relatively weed-free areas, making it easier for spurge and other exotics to gain a foothold. Even if leafy spurge is eventually controlled, productivity of formerly-infested rangelands often remains suppressed for years afterward (Bangsund et al. 1999).

While spurge is poisonous to cattle and horses, sheep (*Ovis* spp.) and goats (*Capra* spp.) graze it with no ill effects, and these creatures are even being used as biocontrols in some agricultural and natural environments (Olson and Wallander 1998, Kirby et al. 1997). Spurge sap can cause dermatitis and blisters in humans (Johnston and Smoliak 1965, in Stahevitch et al. 1988).

Mourning doves (*Zenaida macroura*) freely eat seeds of several spurge species, including leafy spurge (Blockstein et al. 1987, Selleck et al. 1962). Blockstein et al. (1987) found that while spurge and other seeds were efficiently digested, seeds could be distributed in "pigeon milk" while the birds are feeding their young. Selleck et al. (1962), however, points out that the birds must also destroy large amounts of spurge seed.

Apparently no formal research has been done on the impacts of leafy spurge on native vegetation or wildlife in Wisconsin or the upper Great Lakes region. This may be due in part to its somewhat later arrival in the region. Also, the heavily forested environments that once dominated the Great Lakes states are resistant or impervious to invasion, limiting the spread of leafy spurge across the landscape. Although it is now more common southward, scattered small to fairly large patches of leafy spurge are now found across the ceded territory (GLIFWC 2009, WIS 2009).

While deer and other wildlife across the region are unlikely to be impacted for some time, dryland plants and the ecosystems they compose may be at more immediate risk. Plants that are common in or depend upon habitats susceptible to invasion and are culturally valued by the Ojibwe include blueberries (primarily *Vaccinium angustifolium* and *V. myrtilloides*), bearberry (*Arctostaphylos uva-ursi*), sand cherry (*Prunus pumila*), and white sage (*Artemisia ludoviciana*).

Control

General considerations

Control of leafy spurge requires persistence. In some cases complete eradication is not possible, and a more realistic goal may be to limit spurge's abundance and spread (Sell et al. 2000). An integrated pest management approach based on biologically-based controls has emerged as the foundation of a successful control effort for leafy spurge (Merritt et al. 2002).

Manual control

Because of its extensive root system and ability to regenerate repeatedly after cutting, mowing and other manual control methods have generally proven ineffective in controlling established leafy spurge populations. Manual methods can be useful for reducing seed production and to prepare stands for treatment with other methods, though (Merritt et al. 2002). Controls aimed at reducing seed production must be implemented before the seeds become viable. If seeds are present, they may inadvertently be transported on mowers or other equipment to new locations.

Digging and hand-pulling is very labor-intensive and impractical to impossible for all but very young plants. Any long root pieces (which are perennial) left in the soil can resprout. For the vigorous and determined, digging might prove effective for very small stands and for isolated plants, but only if repeated for years, until the deeper roots starve and the seed bank is completely exhausted. Lapses in treatment will allow the population to quickly recover (Best et al. 1980). Buried roots have been known to resprout as much as 7 years after soil sterilization with methyl bromide (Senft and Cooke 1994).

Very small patches (on the order of several square meters) might be covered with some sort of light-impermeable barrier (e.g., sheet metal). This barrier would probably need to be left in place for several years or more, until the roots starved. Barriers would have to be checked periodically to make sure they had not been moved.

Chemical control

Leafy spurge is resistant to most herbicides (Lym 1998). Those that do affect leafy spurge are generally most effective in spring when the shoots are in the flowering stage, followed by late summer when shoots have again begun to grow (Lym and Messersmith 1994). Follow-up treatments will be needed for several years or more, until the seed bank is exhausted. While established patches can be contained or even reduced with herbicides, the complete elimination of infestations is often elusive (Sell et al. 2000).

Imazapic (“Plateau”, “Plateau Eco-Pak”, “Cadre”) is probably the most effective herbicide in controlling leafy spurge. Spot spraying of 0.5oz/gallon has been successfully used in TNC tallgrass prairie preserves (Tu et al. 2001). Spraying was done during green-up following summer senescence, but a few weeks prior to killing frost. GLIFWC has had some success controlling leafy spurge with imazapic in the Moquah Barrens region of Bayfield County (M. Falck, pers. comm., 2009).

Picloram (available commercially as "Tordon") is one of the most effective herbicides in combating leafy spurge (Hoffman and Kearns 1997). It has some serious drawbacks, though - it readily travels through the soil and can be taken up by tree roots as much as 9 m away. Therefore picloram is not recommended for leafy spurge control.

Fosamine ("Krenite") has also proven effective against leafy spurge (Hoffman and Kearns 1997). Fosamine is a bud-inhibitor that generally affects only woody plants. At the University of Wisconsin Arboretum, fosamine applied at 3% active ingredient, in early summer, provided 90% control after one application (Hoffman and Kearns 1997). Formulations of the nonselective herbicide glyphosate ("Roundup" and "Rodeo") have been effective, when applied for several seasons (Hoffman and Kearns 1997).

Dicamba ("Banvel", "Vanguish") has been found to be effective when spring-applied as a liquid formulation, and when fall-applied as a granular formulation (Lym and Messersmith 1985). Despite its relatively rapid breakdown in the soil, dicamba's high solubility and low affinity for soil particles presumably means that it has the potential for groundwater contamination. It also has the potential to kill other plants (including trees) when applied to the soil.

If flea beetles (see below) are present, spraying should only be done after August 15, in order to avoid eliminating the shoots that the adults need to survive (Merritt et al. 2002). Combining flea beetles with late summer/early fall spraying has proven more effective than using either method alone (Lym 1998).

Finally, large-scale use of herbicides can have unintended consequences. Rinella et al. (2009) found that after picloram was applied to a large population of spurge, the amount of spurge in sprayed test plots was initially reduced. By the end of the 16-year experiment, however, spurge was even more abundant and dominant in these sprayed plots than in the unsprayed control plots. Meanwhile populations of a number of picloram-susceptible broadleaf native plants fell dramatically in the sprayed plots and never recovered. Rinella et al. (2009) do note that there are many instances where herbicides have been used successfully against spurge, most notably on small populations or the advancing edges of large populations.

Cultural control

Fire alone has generally proven ineffective against leafy spurge. It does force the plants to make new, more tender shoots that are more vulnerable to herbicides, however. If flea beetles or other organisms (see below) are established on the site, burning should be conducted in early spring or in fall.

While leafy spurge is poisonous to most grazers, sheep and goats can graze it freely (Walker et al. 1994, Sedivec et al. 1995). Indeed, it provides a nutritious, high protein diet for these creatures, especially in spring. On western rangelands, Sedivec et al. (1995) recommend a stocking rate of 12-16 goats or 4-8 sheep per acre of spurge, for one month. For stocking rates over multiple months, they recommend dividing these numbers by the number of months the animals are pastured in the area. Goats are more effective than sheep at low spurge densities, because goats prefer spurge to grasses, while sheep prefer grasses to spurge (Walker et al. 1994).

Biological control

In Europe, leafy spurge is associated with a wide variety of insect and fungi species. At least 17 insect species have been released for biocontrol of leafy and cypress spurge in North America so far (Nowierski and Pemberton 2002). The more successful and widely-established of these insects are listed in Table 1.

Surveys for natural enemies of leafy spurge in Europe began in the early 1960s (Pemberton 1995). This research was conducted by the Commonwealth Institute of Biological Control (CIBC-IIBC), now the Centre for Agricultural Bioscience International (CABI), based in Delémont, Switzerland, on behalf of the Canadian Department of Agriculture (now Agriculture Canada). Additional surveys were initiated in the 1970s by the US Department of Agriculture-Agricultural Research Service (USDA-ARS) Biological Control Laboratory in Rome, Italy (now the USDA-ARS European Biological Control Laboratory in Montpellier, France). All of the

Table 1. Insects that attack leafy spurge in North America. Dates of first release are for Canada and the US, respectively. (From Gassmann and Schroeder 1995; Hansen 2002)

Species Name	Type	Order: Family	First release
Oberea erythrocephala	defoliating/root-boring beetle	Coleoptera: Cerambycidae	1979; 1980
Hyles euphorbiae	defoliating moth	Lepidoptera: Sphingidae	1965; 1968
Spurgia esulae	stem-galling midge	Diptera: Cecidomyiidae	1987; 1985
Chamaesphecia hungarica	root-boring moth	Lepidoptera: Sesiidae	1991; 1993
Aphthona abdominalis	defoliating/root-feeding beetle	Coleoptera: Chrysomelidae	------; 1993
Aphthona cyparissiae	defoliating/root-feeding beetle	Coleoptera: Chrysomelidae	1982; 1986
Aphthona czwalinae	defoliating/root-feeding beetle	Coleoptera: Chrysomelidae	1985; 1987
Aphthona flava	defoliating/root-feeding beetle	Coleoptera: Chrysomelidae	1982; 1985
Aphthona lacertosa	defoliating/root-feeding beetle	Coleoptera: Chrysomelidae	1990; 1993
Aphthona nigriscutis	defoliating/root-feeding beetle	Coleoptera: Chrysomelidae	1983; 1989

natural enemies released in North America against leafy spurge so far were discovered during these extensive European surveys (Nowierski and Pemberton 2002).

Of the approximately 121 species of insects found to mature on leafy and cypress spurge in Europe, 39 were thought to be highly host-specific, meaning that they could develop to maturity only on these two spurge species. Of these, 22 were selected for screening by the CIBC-IIBC and the USDA-ARS. Additional agents were later chosen for screening by the USDA-ARS (Nowierski and Pemberton 2002). Eighteen insects were eventually approved for release in North America for control of leafy spurge, 12 of which were released in the United States (Faubert and Casagrande 2002).

The first insect introduced to combat leafy spurge was a hawk moth, *Hyles euphorbiae*, in Canada in 1965. The larvae (caterpillars) feed on the foliage of leafy and cypress spurge. Though established in several states and provinces, populations of this colorful moth remain low due to predation and disease, and it has had little effect on spurge populations (Hansen 2002).

A stem-boring beetle, *Oberea erythrocephala,* was approved in 1980 and has so far been released in 15 states (Hansen 2002). Adults feed on the foliage and flowers, while the larvae burrow through the roots. The multicolored adults are about 1 cm long, with a narrow body and long, dark antennae (Figure 6). The whitish, segmented larvae grow to about 2 cm, passing at least one winter in the roots before pupating and becoming adults. Releases have been made across much of the US, including the upper Great Lakes region.

The gall midge *Spurgia esulae* was approved for release in 1985 and had been released in

19 states by 1995 (Hansen 2002). The larvae form galls of up to 4 cm long on leafy spurge stems. Larvae emerge from the galls in the fall and overwinter in the soil. This gall midge has been most successful near wooded areas.

The moth *Chamaesphecia hungarica* was approved for release in 1993. The larvae bore into the stems and roots, where they overwinter and finish development in the spring (Hansen 2002).

Figure 6. *Oberea erythrocephala* beetle. *(R. D. Richard, USDA-ARS)*

Some of the most successful biological control agents for leafy spurge so far have been flea beetles in the genus *Aphthona* (Figures 7-9). Adults of these flea beetles feed on the foliage of leafy spurge. They are only 1-4 mm long (depending on species), and tend to hop rather than fly when disturbed. The larvae are 0.04-0.24 in long (again depending on species), whitish and wormlike, with three pairs of short legs just behind the head. Larvae of all of these species are root feeders, feeding on progressively larger roots and root buds as they grow (Figure 7).

Except for *A. abdominalis,* which completes several generations per year, all of these flea beetles complete only one generation per year. Six of these flea beetle species have now been released in North America (Table 1), and several have become widely established.

To test these flea beetles for host-specificity, leafy and cypress spurge were first grown by CIBC-IIBC in secure facilities along with 50 to 56 other plant species, including close relatives spurge

Figure 7. *Aphthona* larvae. (*R. D. Richard*, *USDA-ARS*)

Figure 8. *Aphthona nigriscutis*. (*R. D. Richard*, *USDA-ARS*)

Figure 9. *Aphthona lacertosa*. (*R. D. Richard*, *USDA-ARS*)

and a variety of other plant species from 19 to 22 families (Faubert and Casagrande 2002). Six *Aphthona* species were tested to see whether they could survive and reproduce on leafy and cypress spurge alone (no-choice tests) and whether they used leafy and cypress spurge when other plants were growing with them (choice tests). To test for larval survival, 50 to 100 newly hatched larvae of each *Aphthona* species were transferred onto the stem bases of the potted test plants. All test plants were later dissected to see whether the larvae could use them as hosts. All 6 *Aphthona* species tested were found to use only members of *Euphorbia* subgenus Esula as hosts (Gassman et al. 1996, Faubert and Casagrande 2002).

The second round of flea beetle testing was done by a USDA-ARS lab in California, using 10 native North American *Euphorbia* species from all four subgenera (Gassmann and Schroeder 1995, Gassman et al. 1996). The only North American member of subgenus Esula tested during this round was Mojave spurge (*Euphorbia incisa* Engelm., included under *Euphorbia schizoloba* Engelm. by USDA-NRCS 2009) (Gassman et al. 1996).

At least two more species in subgenus Esula have been investigated for host-suitability by *Aphthona* beetles. One of these is purple spurge (*Euphorbia purpurea*). Purple spurge is native to a triangular region from Ohio to New Jersey, and south to North Carolina (USDA-NRCS 2009). A species of dry to moist woods (Gleason and Cronquist 1991), purple spurge is a candidate for federal listing under the Endangered Species Act (Faubert and Casagrande 2002). None of the four *Aphthona* species tested on purple spurge were able to use it as larvae (Pemberton and Rees 1990, Pemberton 1995).

Another native member of the subgenus Esula subsequently studied for susceptibility to *Aphthona* beetles is horned spurge [*Euphorbia brachycera* Engelm, syn. *Euphorbia robusta* (Engelm.) Small ex Britton & A. Br.]. Horned spurge is a short-lived perennial that is widespread across the Great Plains. Wacker and Butler (2006) released *A. nigriscutis* and *A. lacertosa* into patches of horned spurge. They found only temporary feeding by the adult beetles, which disappeared completely from the patches after one field season. Baker and Webber (2008), however, found some feeding on horned spurge by both larval and adult *A. nigriscutis*, where it grew in the midst of a large population of leafy spurge. Despite this feeding, the horned spurge population increased substantially over the 8-year study, while leafy spurge population dramatically declined. The authors attributed this increase in horned spurge to the release from suppression by leafy spurge.

Several other flea beetle species have also been released in North America. *Aphthona cyparissiae* was approved for release in the US in 1986, and is established in Wisconsin and several western states. It has successfully controlled leafy spurge on some drier sites.

Aphthona flava was approved for release in 1986, and is now widely established on the Great Plains. This species has probably been less effective overall than the other flea beetles, though it has been very effective on some mesic sites (Senft and Cooke 1994, Hansen 2002).

Aphthona nigriscutis (Figure 8) was approved for release in 1989, and is now widely established on the Great Plains and across the upper Great Lakes region (Hansen 2002). It seems to do better on very light, sandy soils than do the other species introduced so far, but does poorly on clay soils (Nowierski and Pemberton 2002). It appears best suited to warmer, dryer, sandier sites.

Aphthona lacertosa (Figure 9) was approved for release in 1993, and is now widely established on the Great Plains and in the upper Great Lakes region (Hansen 2002). It appears to have a wider habitat tolerance than the other flea beetles, doing well on moist to moderately dry sites, but tolerating more moisture, coolness, and shade than the other flea beetles (Nowierski and Pemberton 2002, Merritt et al. 2002). *Aphthona lacertosa* has also done well on some very sandy sites (up to 88.5% sand) in Minnesota (M. Chandler, pers. comm., 2009).

Aphthona czwalinae is nearly indistinguishable from *A. lacertosa*. The most easily recognizable difference is that *A. czwalinae* has a dark hind femur, while *A. lacertosa* has a yellowish hind femur (LeSage 1996, p. 597). As *Aphthona czwalinae* has often inadvertently been introduced along with *A. lacertosa*, its effectiveness is unclear (Nowierski and Pemberton 2002).

Finally, *Aphthona abdominalis* was approved for release in the US in 1993 and has recently been introduced to the northern Great Plains. Its effectiveness is not yet well understood.

Of all these beetles, the most effective to date have been *A. lacertosa* and *A. nigriscutis*. (In mixed populations of *A. lacertosa* and *A. czwalinae, A. czwalinae* often drops to very low levels.) Mixed *A. lacertosa* / *A. czwalinae* populations appear to have controlled leafy spurge on a number of sites in the west and Midwest.

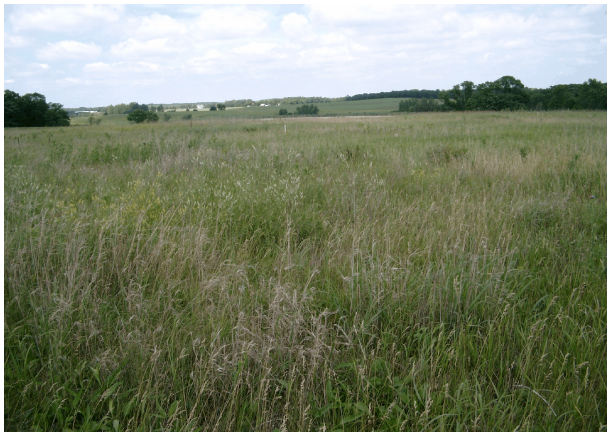
In 2003 and 2004 a local landowner released a total of three biocontrol insect species at two adjacent leafy spurge sites in northeastern Bayfield County, Wisconsin (T49N, R5W, NE Section 32) (W. Stein, pers. comm., 2009). Beetles for these releases were obtained from the Minnesota Department of Agriculture (MDA) in St, Paul, MN. In 2003, 5000 *A. lacertosa*, 5000 *A. nigriscutis*, and 50 *O. erythrocephala* adults were released at this site, with 4500 adults of each flea beetle released at one location and 500 released at another. In 2004, an additional 20,000 *A. lacertosa* were released, with 5000 released at two locations and 10,000 at a third. Though the site has not been formally monitored, *Aphthona* beetles were observed at low levels in subsequent years, and at relatively high levels and some distance away from the site in 2008. No

O. erythrocephala beetles have been seen since their release in 2003.

Integrated pest management

Integrated pest management (IPM) uses several control methods, including manual, chemical, and /or biological control, to provide the maximum degree of control of a plant or animal pest in a given situation. For example, mowing, grazing or burning are often used to "open up" dense populations of leafy spurge so that the flea beetles will have a better chance of getting established. (These flea beetles have an easier time establishing in moderately dense than in very dense leafy spurge populations.) Later, herbicides can be used to "knock down" and weaken spurge plants in the fall, after the beetles have completed the aboveground stage of their life cycle. Each method attacks and weakens spurge at different parts of the plant and at different times of the growing season, while complementing (or at least not significantly interfering with) the other methods (Merritt et al. 2002).

Because leafy spurge is so resilient, an IPM approach that includes biological control provides the only effective way to reduce the abundance and spread of leafy spurge in North America (Merritt et al. 2002). Once established, *Aphthona* beetles can suppress spurge populations with little additional time, effort and expense, greatly reducing leafy spurge vigor and abundance (Figures 10 and 11). On heavily-infested sites, reductions in spurge canopy cover of up to 95% are not uncommon (Merritt et al. 2002). Unlike chemical or manual control methods, these biocontrol agents leave the native plant community intact, and able to reclaim habitat formerly



Figures 10 and 11. *Aphthona lacertosa* and *A. nigriscutis* were released at this heavily-infested leafy spurge site near Madden in western MN in 2000 (left). By 2005, leafy spurge had been greatly reduced (right). Hundreds of thousands of *A. lacertosa* were collected from this site and distributed to new sites. (*Luke Skinner, MN DNR and Monika Chandler, MDA*, *respectively*)

occupied by leafy spurge. While flea beetles cannot completely eradicate leafy spurge from a site, they can hold it at relatively low levels, and allow manual and chemical methods to become more practical and effective.

Guidelines for releasing leafy spurge beetles

Unless otherwise noted, the following guidelines for releasing flea beetles are taken from Merritt et al. (2002):

- Beetles should be gathered from local or regional sources if possible. Local strains are more likely to be well-adapted to the local climate and conditions, and the beetles can also be redistributed promptly, with a minimum of storage time.

- If possible flea beetles should be harvested with a sweep net. Mid-June through mid-July is prime time in the northern Great Plains. Warm, sunny days are much preferred, as the beetles are more active and higher up on the plants than they are in cool, rainy weather. Recently-killed areas of spurge may harbor large populations of newly-emerging adults. The flea beetles can be transported in a paper bag filled ⅓ to ½ full of leafy spurge vegetation, folded and taped shut, and kept in a cooler with sealed ice packs. Unwaxed food containers resist crushing and are a good alternative to paper bags (M. Chandler, pers. comm., 2009).

- Flea beetles can tolerate a wide variety of soil types. But because leafy spurge makes few shallow roots in dry, sandy soils, the beetles may have trouble establishing in these soils. Mesic, well-drained sites are best; sites subject to periodic flooding should be avoided. Adult beetles are sun-lovers, doing best on open, south-facing slopes.

- The best sites for release are those that have a moderate density of leafy spurge (50-75 stems/m^2). Larvae development and adult reproduction is inhibited in very dense patches. When releasing beetles in large, dense patches, thin areas within or at the edge of the patch should be chosen. Shallow spurge roots (within 5-8 cm of the surface) should be present in the release area.

- Large releases of flea beetles are more likely to be successful than small releases. From Merritt et al. (2002):

  "Each "drop" should consist of at least 1,000 flea beetles. Avoid scattering or sprinkling - remember, flea beetles are gregarious, and concentrating releases makes it easier for males and females to find each other when it's time to mate. In some cases, making one drop of

10,000 flea beetles may be more productive than 10 drops of 1,000 each."

- For quick population establishment and suppression of leafy spurge, multiple releases should be made - dropping 1,000+ insects every 21 m in a grid pattern has worked very well at some heavily infested sites.

- Release locations should be marked with stakes or other markers, and the GPS coordinates recorded. Merritt et al. (2002) also recommend photographing release sites and surrounding patch from the same location at the same time each year, to document the effects of the releases.

Minimum patch size is an important consideration when releasing biocontrol agents. According to Merritt et al. (2002), a moderate to dense patch of spurge, a half-acre or more in size, is needed to establish and maintain a population over the long-term. Smaller patches (a half-acre or less) may support large number of flea beetles for awhile, but the beetles may eventually reduce these patches and then crash. Therefore the initial flea beetle release sites should be at least ½ acre, and preferably greater than 1 acre. This will give the beetles a good chance of establishing, and provide a site that can serve as a future source for beetles. Once beetles are established at one or more large sites, they can be gathered and dispersed to smaller sites. Very small sites are probably not suitable for flea beetle establishment.

Excellent information on the biology, collection, release and monitoring of *Aphthona* spp. appears in Merritt et al. (2002) and MDA (2009b), both of which are available online.

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