14 Leafy Spurge

R. M. Nowierski[1] and R. W. Pemberton[2]

[1]U. S. Department of Agriculture, Cooperative State Research, Education, and Extension Service, Washington, D.C., USA
[2]Invasive Plant Research Laboratory, U. S. Department of Agriculture, Agricultural Research Service, Ft. Lauderdale, Florida, USA

PEST STATUS OF WEED

Nature of Damage

Leafy spurge, *Euphorbia esula* L., is an invasive, deep-rooted perennial herb that is native to Eurasia (Watson, 1985; Pemberton, 1995). The plant spreads through explosive seed release and vigorous lateral root growth, forming large, coalescing patches that can dominate rangeland, pastures, prairies and other noncrop areas in the Great Plains region of North America (see Fig. 1, a and b, and Fig. 2).

Economic damage. Leafy spurge has infested more than one million hectares in North America since its introduction approximately 200 years ago (Alley and Messersmith, 1985), and threatens to invade more areas (Lacey *et al.,* 1985). All parts of leafy spurge produce milky latex that can cause dermatitis in humans and cattle (Lacey *et al.*, 1985), and can cause death in cattle if sufficient quantities are consumed (Kronberg *et al.*, 1993). Leafy spurge reduces forage production and wildlife habitat, and causes considerable monetary losses to the livestock industry (Messersmith and Lym, 1983; Watson, 1985; Lacey *et al.,* 1985; Nowierski and Harvey, 1988; Bangsund, 1993; Leitch *et al.,*1994). Cattle carrying capacity in rangeland can be reduced by 50 to 70% (Alley *et al.,* 1984), and in some cases, by 100 percent (Watson, 1985) through loss of grasses from competition, and the tendency of cattle to avoid spurge-infested grass (Lacey *et al.*, 1985; Hein and Miller, 1992; Kronberg *et al.,* 1993). Direct and secondary economic losses from leafy spurge, due to lost cattle production, for the Dakotas, Montana, and Wyoming in 1994 were estimated to approach $120 million annually (Leitch *et al.,* 1994). In addition, Wallace *et al.* (1992) estimated nonagricultural losses (e.g., watershed and recreation impacts) from leafy spurge at $10 million annually over the same four-state region. Leafy spurge is much less abundant in the eastern United States, although it can be weedy enough in pastures to require control.

Figure 1. (a) Flowering stems of leafy spurge, *Euphorbia esula* L. and (b) dense patch of leafy spurge, *Euphorbia esula* L. (Photograph [a] courtesy of Montana State University Extension Service; and [b] by USDA, ARS.)

Figure 2. Rangeland severely infested by leafy spurge, *Euphorbia esula* L. (Photograph courtesy of USDA, ARS.)

Ecological damage. Although leafy spurge is most commonly associated with more mesic sites, it is adapted to a broad range of habitats, ranging from xeric to riparian sites (Nowierski and Zeng, 1994; Lym 1998; Kirby *et al.,* 2000). The percent cover of grasses and forbs may be significantly reduced at medium to high densities of leafy spurge (Nowierski and Harvey, 1988). Studies by Belcher and Wilson (1989) have shown that native plant species may be severely affected by leafy spurge. Such reductions in native plant diversity also may have a negative impact on wildlife populations (Wallace *et al.,* 1992; Trammell and Butler, 1995). Population declines in a number of native grassland bird species have been documented in the Great Plains Region of North America at sites with moderate to high densities of leafy spurge (D. Johnson, pers. comm.).

Geographic Distribution

Leafy spurge is native to Eurasia and is widely distributed from Spain to Japan (Ohwi, 1965; Radcliff-Smith and Tutin, 1968; Pemberton, 1995). Since the first recording of this weed in North America at Newbury, Massachusetts in 1827 (Britton, 1921), it has become widespread in certain regions of the United States and Canada. Leafy spurge has been recorded in 35 states within the United States, but has yet to be recorded in Oklahoma, Texas, Arkansas, Louisiana, Kentucky, Tennessee, North Carolina, Mississippi, Alabama, Georgia, South Carolina, and Florida (USDA, NRCS, 2001). The most extensive infestations of the weed occur in the northern Rocky Mountain and Great Plains states (Idaho, Montana, Wyoming, North Dakota, South Dakota, Nebraska, and Minnesota), and in the Canadian provinces of British Columbia, Alberta, Saskatchewan, Manitoba, and Ontario (USDA, APHIS, PPQ, CAPS, 1994). In the upper Mississippi River drainage, leafy spurge occurs primarily in riparian habitats (R. Hansen, pers. comm.). In the eastern United States, the plant is an occasional weed of pastures, roadsides, and riparian habitats (R. Hansen, B. Blossey, J. Wickler, and P. Wrege, pers. comm.). The weed can be locally abundant, but usually is limited to discrete patches. Fifteen New York counties were known to be infested with leafy spurge in the early 1980s (Batra 1983).

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

In North America, leafy spurge occurs as a complex of forms, species, and hybrids and has been most commonly referred to as *Euphorbia esula* L. (Euphorbiaceae) (Pemberton, 1985). The most problematic type appears to be *E.* x *pseudovirgata*, which is a hybrid of *E. esula sensu stricto* and *E. waldsteinii* (=*E. virgata*) (Dunn and Radcliffe-Smith, 1980), hereafter referred to as leafy spurge, *E. esula* L. (Harvey *et al.,* 1988). Harvey *et al.* (1988) examined the leaf morphology and triterpenoid composition of leafy spurge accessions from Montana and five related European spurge species and concluded that all the Montana leafy spurge and three of the five European species could not be distinguished from *Euphorbia esula*.

Leafy spurge populations show a high degree of genetic, chemical, and morphological variability, and as a consequence the taxonomic identity of the United States populations and their affinities to other species is unclear (Shulz-Schaeffer and Gerhardt, 1987; Watson, 1985; Harvey *et al.,* 1988; Torell *et al.,* 1989; Nissen *et al.,* 1992; Pemberton, 1995; Rowe *et al.,* 1997). This genetic variability, combined with other traits, including the plant's possession of both sexual and asexual reproduction, a deep underground root system, an ability to infest xeric, mesic, and even hydric sites across a wide range of soil types (Nowierski and Zeng, 1994; Nowierski *et al.,* 1996; Nowierski *et al.,* 2002), along with the existence of many native spurge species (Euphorbiaceae) in North America (Pemberton, 1985), makes both conventional management and classical biological control of this weed complex and potentially difficult (Shulz-Schaeffer and Gerhardt, 1987).

Biology

Leafy spurge is an aggressive, deep-rooted perennial herb that reproduces from seed and from numerous vegetative buds along its extensive vertical and horizontal root system (Watson, 1985). Seeds of leafy spurge are released explosively by dehiscence of the seed capsules, and may be projected up to 4.6 m from

the parent shoot (Hanson and Rudd, 1933; Bakke, 1936). Seeds are dispersed by ants, birds, grazing animals, humans, and water (Hanson and Rudd, 1933; Bowes and Thomas, 1978; Messersmith *et al.,* 1985; Pemberton, 1988; Pemberton, 1995). Germination of leafy spurge seed can occur throughout the growing season whenever adequate moisture is available, but the most favorable conditions for germination occur in early spring (Bakke, 1936; Messersmith *et al.,* 1985). The roots of leafy spurge reportedly can reach a depth of 9 m (Best *et al.,* 1980).

Stems of leafy spurge are erect, tough and woody and range from 0.1 to 1.0 m in height (Lacey *et al.,* 1985). The showy yellow-green inflorescences produce an average of 140 seeds per stem. Leafy spurge leaves are highly variable in shape, ranging from broadly linear-lanceolate to ovate (Watson, 1985). Additional details on the morphology and anatomy of leafy spurge can be found in Raju (1985).

Leafy spurge is one of the first plants to emerge in the spring, and its appearance has been recorded as early as March in Iowa and Wisconsin and early April in North Dakota (Messersmith *et al.,* 1985). Vegetative development and stem elongation occurs rapidly as the temperatures increase during late April through early June. The swelling of the stem apex signals initiation of the leafy spurge inflorescence, which occurs approximately one week after stem emergence. The first yellow to yellowish-green bracts appear at the base of the terminal inflorescence from early to late May depending on environmental conditions (Messersmith *et al.,* 1985). The showy yellow bracts of the leafy spurge inflorescence are most visible from late May through June. Flowering in the terminal inflorescence ends between late June and early July. Seed development and maturation continue for approximately one month post flowering. As the plants mature, the stems and leaves often turn from a blue-green to a reddish brown, red, or yellow, either during hot, dry periods after seed production in midsummer or due to senescence in the fall (Messersmith *et al.,* 1985). Plant phenology may vary greatly within and among locations due to local microclimatic differences.

Analysis of Related Native Plants in the Eastern United States

Risks to native plant species as a result of biological control of leafy spurge were analyzed by Pemberton (1985). The analysis was limited to the genus *Euphorbia*, in the tribe Euphorbieae, subfamily Eurphorbioideae, family Euphorbiaceae (Mabberley, 1997). The genus is divided into five subgenera, four of which are represented in the native flora of the eastern United States. Of the approximately 107 native *Euphorbia* species in the continental United States and Canada, about 45 occur east of the Mississippi River. These include 23 species in the subgenus *Chamaesyce*, 13 species in the subgenus *Agaloma*, and three species in the subgenus *Poinsettia*. The remaining six species belong to the subgenus *Esula*, to which leafy spurge belongs. Of these six, four are broadly sympatric with leafy spurge. These are *E. commutata* Engelm., *E. obtusa* Pursh, *E. purpurea* (Raf.) Fern., and *E. spatulata* Lam. *Euphorbia purpurea* is the only perennial of these four, and it also is the only rare eastern species growing in the general region where leafy spurge is more common. This perennial species is under review for legally protected status by the U.S. Fish and Wildlife Service (1993). The plant occurs in both dry and moist woods (Gleason and Cronquist, 1963) in Delaware, Maryland, North Carolina, New Jersey, Ohio, Pennsylvania, Virginia, and West Virginia (Federal Register, 1993). There are four other rare species of *Euphorbia* s.l. east of the Mississippi River, but all occur in Florida (Federal Register, 1993). *Euphorbia telephioides* Chapm. is formally listed as a threatened species (U.S. Fish and Wildlife Service, 1997) and is a member of the subgenus *Esula* that is restricted to the Florida panhandle. The other three rare spurges belong to the subgenus *Chamaesyce*, within the genus *Euphorbia*. Subgenera of *Euphorbia* appear to be natural groupings and most *Euphorbia*-feeding insects that have been evaluated as biological control agents distinguish among subgenera, accepting plants within some subgenera as hosts while rejecting potential host plants found in other subgenera (Pemberton, 1985).

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Area of Origin of Weed

The native range of leafy spurge is Eurasia and extends from Spain to Japan (Ohwi, 1965; Radcliff-Smith and Tutin, 1968; Watson, 1985; Pemberton, 1995). More precise geographic origins for populations invasive in the United States have not been

determined. In its native range leafy spurge is typically just a scattered plant in the ecosystem. R. M. Nowierski has observed the occasional use of leafy spurge in flower arrangements in Europe.

Areas Surveyed for Natural Enemies

European surveys for natural enemies of leafy spurge began in the early 1960s by the Commonwealth Institute of Biological Control (CIBC; name subsequently changed to the International Institute of Biological Control [IIBC]; now called CABI-Bioscience), through their European Station in Delémont, Switzerland. In the 1970s, surveys were initiated by the USDA, ARS Biological Control Laboratory in Rome, Italy (which is now the USDA, ARS European Biological Control Laboratory in Montpellier, France). All of the natural enemies released in North America to date against leafy spurge were discovered during these extensive European surveys. Additional surveys for spurge natural enemies, conducted in China from 1987 to the early 1990s, identified additional promising agents, including several *Aphthona* species that are still under study (Pemberton and Wang, 1989; Fornasari and Pemberton, 1993).

Natural Enemies Found

Manojlovic and Keresi (1997) reported that 121 insect species (23 species of Homoptera, six Heteroptera spp., 37 Lepidoptera spp., four Hymenoptera spp., 14 Diptera spp., and 37 Coleoptera spp.) are able to develop on plants of *E. esula*, *Euphorbia virgata* Waldstein-Wartemberg and Kitaibel, and *E. cyparissias* L. in Europe. Additional discussion of the spurge fauna was provided by Gassmann and Schroeder (1995). Through surveys for natural enemies of leafy spurge conducted by personnel of the IIBC laboratory in Delémont, Switzerland, between 1961 and 1990, two rust species and 39 insect species were found that were thought to be specialized on leafy spurges (Gassmann, 1990). Of these, 22 insect species were screened as potential biological control agents of leafy spurge. Additional insects have been screened by personnel at the USDA, ARS Biological Control of Weeds Laboratory, Rome, Italy; the USDA, ARS Biological Control Laboratories in Albany, California, USA; the Montana State University Insect Quarantine Laboratory, Bozeman, Montana, USA (Pemberton, 1995); and more recently the USDA, ARS Laboratory in Sidney, Montana, USA.

Host Range Tests and Results

See "Host Range Tests and Results" for cypress spurge for details regarding the host range tests for natural enemies attacking both leafy spurge and cypress spurge.

Releases Made

Since 1965, 12 insect species have been released against leafy spurge or cypress spurge in the United States, and 17 species have been released in Canada. The first insect released in the United States against leafy spurge was the spurge hawkmoth, *Hyles euphorbiae* L. (Lepidoptera: Sphingidae) (Figs. 3 and 4), which was first released in Idaho, Montana, Oregon, Utah, and Washington during the mid-1960s (Julien 1987). The release material was collected from an established population on cypress spurge in Braeside, Ontario, from stocks originating from cypress spurge, *Euphorbia cyparissias* L, and *E. seguieriana* Necker, from Switzerland, France, and Germany (Harris, 1984).

Figure 3. Adults of the leafy spurge hawkmoth, *Hyles euphorbiae* L. (Photograph courtesy of USDA, ARS.)

Figure 4. Larva of the leafy spurge hawkmoth, *Hyles euphorbiae* L. (Photograph courtesy of USDA, ARS.)

Hyles euphorbiae also was the first natural enemy of spurge to be released in the eastern United States beginning in 1978 in New York, with releases directed against both leafy and cypress spurge (Batra, 1983). Although the insect was released against leafy spurge in numerous states (California, Colorado, Idaho, Nebraska, Montana, North Dakota, Nevada, New York, Oregon, Wyoming) from 1964 to 1986, the insect only has become established in New York (Batra, 1983), in Wyoming (Coombs, 2000), and at a number of sites in Montana (R. M. Nowierski, unpub. data). Researchers have attributed the poor rates of establishment of this insect to predation by ants, carabids, and mammalian predators (Harris *et al.,* 1985; R. M. Nowierski, S. J. Harvey, and J. M. Story, unpub. data), and to the possible existence of different moth host races (Harris, 1984).

The clearwing moth, *Chamaesphecia tenthrediniformis* (Denis and Schiffermüller) (Lepidoptera: Sesiidae), was released against leafy spurge in Idaho, Montana, and Oregon during 1975 to 1979. None of the releases resulted in establishment (Pemberton, 1995). This and two other species, *C. hungarica* (Tomala) (Fig. 5) and *C. crassicornis* Bartel (Fig. 6), were released against leafy spurge in the western United States in 1975, 1993, and 1994, respectively. At present, it appears that none of these releases were successful, except for one population of *C. crassicornis,* which has established on leafy spurge in Oregon (Coombs, 2000).

The first coleopteran species released against leafy spurge in the United States was the stem boring beetle, *Oberea erythrocephala* (Schrank) (Coleoptera: Cerambycidae) (Fig. 7). Releases of the beetle were made in Montana, Oregon, North Dakota, and Wyoming during 1980 to 1986. Additional releases of *O. erythrocephala* were made by APHIS, PPQ in Colorado, Iowa, Idaho, Michigan, Minnesota, Montana, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Dakota, Oregon, Rhode Island, South Dakota, Utah, Washington, Wisconsin, and Wyoming during 1988 to 1995. *Oberea erythrocephala* establishment has been documented in Montana (Rees *et al.,* 1986; Hansen *et al.,* 1997), Oregon and Wyoming (Coombs, 2000), North Dakota (Pemberton, 1995), and Colorado and South Dakota (Hansen *et al*., 1997).

Figure 5. Adult of the clearwing moth, *Chamaesphecia hungarica* (Tomala). (Photograph courtesy of USDA, APHIS.)

Figure 6. Adult of the clearwing moth, *Chamaesphecia crassicornis* Bartel. (Photograph courtesy of USDA, APHIS.)

Figure 7. Adult of the stem boring beetle, *Oberea erythrocephala* (Schrank). (Photograph courtesy of USDA, APHIS.)

Flea beetles in the genus *Aphthona* have been the most successful biocontrol agents released against leafy spurge in North America. *Aphthona abdominalis* Duftschmidt (Coleoptera: Chrysomelidae) (Fig. 8), *Aphthona cyparissiae* (Koch) (Fig. 9), *Aphthona czwalinae* (Weise) (Fig. 10), *Aphthona flava* Guillebeau (Fig. 11), *Aphthona lacertosa* Rosenhauer (Fig. 12), and *Aphthona nigriscutis* Foudras (Figs. 13 and 14), were first released in the United States in 1993, 1986, 1987, 1985, 1993, and 1989, respectively, and all but *A. abdominalis* have established in the United States (Pemberton, 1995; Hansen *et al.,* 1997). In 1994 and 1995 USDA, APHIS, PPQ transferred *Aphthona* beetles from established populations in the western United States to a number of eastern states (Hansen *et al.,* 1997). Releases of individual species or mixed collections of several species (*A. flava, A. cyparissiae, A. nigriscutis, A. lacertosa* and *A. czwalinae*) were made in Iowa, New Hampshire, Michigan, Minnesota, New York, and Wisconsin.

The shoot tip gall midge, *Spurgia esulae* Gagné (Diptera: Cecidomyiidae) (Figs. 15a,b), is the only fly species released against leafy spurge in the United States. Releases were made in Montana, Oregon, North Dakota, and Wyoming during 1985 to 1988, and establishment was later recorded in Montana and North Dakota from these releases (Pemberton, 1995). Additional releases were made by USDA, APHIS, PPQ in Colorado, Idaho, Iowa, Michigan, Minnesota, Montana, North Dakota, Nebraska, Nevada, New Hampshire, New Mexico, New York, Oregon, Rhode Island, South Dakota, Utah, Washington, Wisconsin, and Wyoming from 1988 to 1996 (Hansen *et al*., 1997). As of 1997, establishment of the midge from these releases has been documented in Colorado, Montana, New York, Oregon, Rhode Island, South Dakota, and Wyoming (Hansen *et al.,* 1997). The midge also has been recorded as established on leafy spurge in Idaho (Coombs 2000).

Informal human transport of leafy spurge biological control agents from Canada to the United States and vice-versa has probably resulted in additional releases (R. Hansen, pers. comm.). In addition, some biological control agents of leafy spurge, such as the tortricid moth *Lobesia euphorbiana* (Freyer), that have been released in Canada but not in the United States, may move into the United States on their own.

Figure 8. Adult flea beetle, *Aphthona abdominalis* Duftschmidt. (Photograph courtesy of USDA, APHIS.)

Figure 9. Adult flea beetle, *Aphthona cyparissiae* (Koch). (Photograph courtesy of USDA, APHIS.)

Figure 10. Adult flea beetle, *Aphthona czwalinae* Weise. (Photograph courtesy of USDA, APHIS.)

Figure 11. Adult flea beetle, *Aphthona flava* Guillebeau. (Photograph courtesy of USDA, APHIS.)

Figure 14. Larvae of the flea beetle, *Aphthona nigriscutis* Foudras. (Photograph courtesy of USDA, APHIS.)

Figure 12. Adult flea beetle, *Aphthona lacertosa* Rosenhauer. (Photograph courtesy of USDA, APHIS.)

Figure 15. (a) Adult of the shoot tip gall midge, *Spurgia esulae* Gagné; (b) shoot tip gall made by midge larvae (inset). (Photograph courtesy of USDA, APHIS.)

Figure 13. Adult flea beetle, *Aphthona nigriscutis* Foudras. (Photograph courtesy of USDA, APHIS.)

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

Hyles euphorbiae (L.) (Lepidoptera: Sphingidae)

The leafy spurge hawkmoth feeds on the leaves and flowers of *Euphorbia* species in the subgenus *Esula* (Harris, 1984). Adult females lay from 70 to 110 eggs singly or in clusters on the plant surface, and the small black larvae emerge a week or two later depending on temperature. A generation is completed in about six weeks (Pemberton, 1995). Larvae go through a series of color changes as they grow, from black as they first eclose, to greenish-yellow during the next couple of instars, to a showy combination of black,

white, red, and yellow during the last two instars. The larval integument and hemolymph contains triterpenoids derived from feeding on leafy spurge (P. Mahlberg and R. M. Nowierski, unpub. data). Larvae are believed to use these compounds for chemical protection against predators, and field studies in Montana have shown larval predation to be low (N. H. Poritz, R. M. Nowierski, and S. J. Harvey, unpub. data). In contrast, rates of predation on pupae, measured using different levels of exclusion, are high and are most likely due to field mice (*Peromyscus* spp.) and shrews (R.M. Nowierski, S. J. Harvey, N. H. Poritz, and J. M. Story, unpub. data). High pupal predation by animals may explain the extreme differences in hawkmoth populations among years, as populations of small mammalian predators typically are quite variable over time.

In Montana, hawkmoth larvae are generally present during the last week or so of June and are most abundant the first week of July. Larvae pupate in the soil in July and August and a significant proportion of pupae eclose for a second generation.

Oberea erythrocephala (Coleoptera: Cerambycidae)

The longhorn beetle, *O. erythrocephala,* is native to Eurasia where it feeds within the stems and roots of several *Euphorbia* species. Adults appear in early to mid-summer when spurges are in flower, and feed on the young leaves, flowers, and stem tissue for approximately two weeks before beginning oviposition (Pemberton, 1995; Hansen *et al.,* 1997). Adult beetles girdle the upper part of the stem, chew a hole in it just above the girdle, insert an egg and cover it with latex (Pemberton, 1995; Hansen *et al.,* 1997). Larvae take approximately one month to mine their way down the stem into the crown and roots (Pemberton, 1995). Larvae feed within crowns or roots until March or April and pupate within cells in the root crown in May.

Aphthona spp. (Coleoptera: Chrysomelidae)

The flea beetle genus *Aphthona* (Coleoptera: Chrysomelidae) contains approximately 40 species that are known to feed on leafy spurges (*Euphorbia* spp.) in Europe and Asia (Harris *et al.,* 1985; Fornasari and Pemberton, 1993; Fornasari, 1996). All of the established flea beetle species released against leafy spurge in the United States are univoltine, with some of the species showing phenological differences in adult emergence during the course of the growing season (Hansen, 1994). *Aphthona abdominalis*, which has not yet been documented as established in North America, reportedly may produce more than one generation per year (Fornasari, 1996). Early larval instars feed in/on root hairs of the host plant, while later instars feed in/on yearling roots. Larval feeding contributes to leafy spurge mortality by disrupting water and nutrient transport and may provide entry points for pathogenic soil inhabiting fungi (Hansen *et al.,* 1997). Adult flea beetles feed on leaves and flower bracts of leafy spurge. *Aphthona* species overwinter as larvae, and generally pupate within the spurge roots in late spring to early summer (Rees *et al.,* 1996).

Aphthona cyparissiae (Coleoptera: Chrysomelidae)

The native range of *A. cyparissiae* extends from southern Spain and France through central and eastern Europe to western Russia (Pemberton, 1995). In Eurasia, this species occurs at higher altitudes and in areas with cool, rainy summers (Pemberton, 1995). The species has a relatively broad ecological amplitude and has been recorded from xeric to mesic sandy loam sites in Eurasia (Müller, 1949; Maw, 1981; Fornasari, 1996; Gassmann *et al.,* 1996). However, this species has been less successful in establishing on leafy spurge in the United States than *A. nigriscutis* and *A. lacertosa*.

Aphthona czwalinae (Coleoptera: Chrysomelidae)

This blue-black flea beetle species is native to central and eastern Europe (Germany, Austria, Poland), the lower Danube region, parts of Russia, central Asia, and eastern Siberia (Gassmann, 1984). It is most commonly found at mesic sites where *Euphorbia* is intermixed with other vegetation, and is thought to have the potential to colonize sites such as stream margins, where leafy spurge is often most abundant (Pemberton, 1995). The biology and host range of *A. czwalinae* is similar to that of *A. cyparissiae* and *A. flava*, although it is limited to fewer species in the subgenus *Esula* than the other two species (Gassmann, 1984; Pemberton 1987). Because the

releases of *A. czwalinae* have typically been reported as an *A. czwalinae/A. lacertosa* mix (Hansen *et al.,* 1997), the actual establishment and impact of this species on leafy spurge in various states in the United States is unclear.

Aphthona flava (Coleoptera: Chrysomelidae)

This flea beetle species is found from northern Italy east and north through the former Yugoslavia, Hungary, Czechoslovakia, Bulgaria, Romania, and Russia (Sommer and Maw, 1982). In Eurasia, this species occurs in xeric to mesic habitats in areas with drier and warmer summers (Pemberton, 1995). Like *A. cyparissiae*, this species has been less successful than *A. nigriscutis* and *A. lacertosa* in establishing on leafy spurge in North America.

Aphthona lacertosa (Coleoptera: Chrysomelidae)

This species is native to Eurasia where it is associated with loamy or loamy-clay soils, in either dry or wet habitats (Gassmann, 1990; Fornasari, 1996; Gassmann *et al.,* 1996; Nowierski *et al*., 2002). However, Maw (1981) reported that it preferred moist sites. *Aphthona lacertosa* establishment and its impact on leafy spurge has been greatest at moderately dry to mesic sites in the United States (Rees *et al.,* 1996). Unlike *A. nigriscutis*, which appears to be restricted to drier sites, *A. lacertosa* has a broader ecological amplitude and may have greater potential for controlling leafy spurge across a broad range of habitats. *Aphthona lacertosa* can be distinguished from *A. czwalinae* by its light-colored hind femur, whereas in *A. czwalinae* the hind femur is black (A. Gassmann, pers. comm.).

Aphthona nigriscutis (Coleoptera: Chrysomelidae)

This *Aphthona* species is native to Europe and is adapted to drier sites and sandier soils. This species has been most successful in establishing and controlling leafy spurge in dry, open, sandy-loam sites in Canada and the United States (Rees *et al.,* 1996). It generally has done poorly when released in high density leafy spurge infestations occurring in heavier clay soils (R. M. Nowierski, Z. Zeng, and B. Fitzgerald, unpub. data).

Spurgia esula (Diptera: Cecidomyiidae)

This small midge causes shoot-tip galls on leafy spurge, which prevents flowering and thus seed production of the attacked shoot. *Spurgia esula* is multivoltine and produces two or three generations per year in Montana (Hansen *et al.,* 1997) and up to five generations per year in its native European range (Pecora *et al.,* 1991). This gall midge overwinters as a mature larva and the first adults appear in mid- to late spring. Adult females deposit groups of eggs on leafy spurge leaves, typically near the apical buds (Hansen *et al.,* 1997). Upon eclosion, first instar larvae migrate to leafy spurge buds and begin feeding within the meristematic tissues. Larval feeding causes hypertrophy in the bud tissues and the formation of a bud gall, within which the larvae feed. Larvae require two to four weeks to complete development, depending on environmental conditions (Hansen *et al.,* 1997). Larvae of the non-diapausing summer generation construct silken cocoons inside the bud galls, from which adult flies later emerge. Mature larvae of the diapausing generation exit the galls, drop to the ground, and overwinter in the soil. No major impacts on leafy spurge populations have been reported for this biological control agent. However, Lym (1998) reported greater suppression of leafy spurge when *S. esulae* was combined with herbicides than when either approach was used alone.

EVALUATION OF PROJECT OUTCOMES

Establishment and Spread of Agents

The spurge hawkmoth, *H. euphorbiae*, is established on spurges in New York (Batra, 1983) and is locally common in the state (B. Blossey, pers. comm.). Coordinated natural enemy releases by the USDA, APHIS, PPQ during the mid 1990s have resulted in the establishment of many biocontrol agents of leafy spurge east of the Mississippi River. Five *Aphthona* species (*A. cyparissiae, A. czwalinae, A. flava, A. lacertosa,* and *A. nigriscutis)* have established in Iowa, Michigan, Minnesota, New York, and Wisconsin (Hansen *et al.,* 1997). The gall midge, *S. esulae,* has established in New York (Hansen *et al.,* 1997), and in Michigan and Wisconsin (R. Hansen, pers. comm.).

Oberea erythrocephala has established in Michigan (J. Winklar, pers. comm.) and in Minnesota (R. Hansen, pers. comm.). At present, it is unclear whether any of these agents have established on leafy spurge in New Hampshire. As of 1997, populations of *S. esulae* and the *Aphthona* species in New York were not sufficiently large to provide insects for redistribution (Hansen *et al.*, 1997). But more recently, populations of the *Aphthona* species have reached adequate levels for redistribution in New York (P. Wrege, pers. comm.).

Suppression of Target Weed

The effects of imported natural enemies on leafy spurge densities in the eastern United States have not been formally evaluated, but there is some evidence that the *Aphthona* beetles are having an effect. The beetles have provided control over large areas in Minnesota (R. Hansen, pers. comm.), and are significantly reducing the weed at some sites in Michigan (J. Winklar, pers. comm.) and New York (P. Wrege, pers. comm.). More information is available about the impact of these biological control agents against leafy spurge in the Northern Great Plains region.

Rees *et al.* (1996) reported that five *Aphthona* species (*A. cyparissiae*, *A. czwalinae*, *A. flava*, *A. lacertosa*, and *A. nigriscutis*) have established to varying degrees on leafy spurge in the United States and Canada, and in a number of cases have significantly reduced spurge density at the release sites (see Figs. 16 and 17). Reductions in leafy spurge stem densities have been attributed to flea beetle feeding by a number of authors (Hansen, 1993; Baker *et al.*, 1996; Lym *et al.*, 1996; Stromme *et al.*, 1996; and Kirby *et al.*, 2000). Stromme *et al.* (1996) reported that leafy spurge foliar cover decreased from 40 to 1.7%, five years after *A. nigriscutis* was released near Edmonton, Canada. At two sites in North Dakota, *A. nigriscutis* and *A. czwalinae/A. lacertosa* reduced foliar cover of leafy spurge from 45 to 7% over a three year period, and reduced stem densities by nearly forty-fold (Kirby *et al.*, 2000). In other areas, infestations of leafy spurge have been successfully suppressed through a combination of flea beetle herbivory and controlled grazing by sheep (J. Elliott, pers. comm.). Herbicides combined with the leafy spurge flea beetles (*A. nigriscutis* or *A. czwalinae/A. lacertosa*) or the gall midge (*S. esulae*) have controlled leafy spurge better than either method used alone (Lym, 1998).

Figure 16. Leafy spurge infestation on the N-Bar Ranch, Grass Range, Montana 1989, prior to release of the flea beetle *Aphthona nigriscutis* Foudras that same year. (Photograph courtesy of USDA, ARS.)

Figure 17. N-Bar Ranch, Grass Range, Montana leafy spurge site in 1993, four years after release of the flea beetle *Aphthona nigriscutis* Foudras. (Photograph courtesy of USDA, ARS.)

Effects on Native Plants

Neither the impact of introduced biocontrol agents on native, non-target plants nor the recovery of native plant communities following the decline in population levels of leafy spurge (following natural enemy impact) have been reported in the literature. Some leaf feeding by adult *A. nigriscutis* on *Euphorbia robusta* (Engelm.) Small has occurred at one leafy spurge site in Wyoming, and larvae also were found on the roots of this native euphorb (L. Baker, pers. comm.). However, the plant is increasing in abundance at the site due to the beetle's control of leafy spurge (L. Baker, pers. comm.). *Euphorbia robusta* is very closely related to leafy spurge, and prerelease laboratory studies indicated that the plant might become a host of *Aphthona* spp.

Economic Benefits

The economic benefits from the biological control of leafy spurge have not been formerly reported in the literature. However, given the fact that *A. nigriscutis* and *A. lacertosa* have reduced leafy spurge densities at numerous sites in the United States and Canada, this sort of information should be forthcoming.

RECOMMENDATIONS FOR FUTURE WORK

As discussed previously, *A. nigriscutis* and *A. lacertosa* have been the most successful biocontrol agents released against leafy spurge in North America. However, neither of these agents have had a consistent suppressive effect on leafy spurge growing in shaded areas and riparian sites. Hence, additional natural enemy surveys are needed to find specialized natural enemies of leafy spurge that are adapted to such habitats. Pemberton (1995) recommended that only narrow specialists with potential host ranges at or below the level of the subgenus *Esula* should be employed to avoid damage to native North American *Euphorbia* species.

Leafy spurge is currently found in 35 states in the United States (USDA, NRCS) and in all Canadian provinces except Newfoundland (Roslycky, 1972). The potential for further range expansion of this weed warrants the continued redistribution of established biocontrol agents throughout North America. In addition to recent biological control efforts in New Hampshire and New York, biological control programs should be initiated in all other states in the northeast and central United States that have significant infestations of leafy spurge. Before releasing biological control agents in the eastern United States, host specificity data should be obtained for each agent relative to the rare *Euphorbia purpurea* and the endangered *E. telephioides*. The abilities of these spurge natural enemies to live in the southern United States, where additional rare *Euphorbia* occur, also should be considered.

Studies evaluating the effects of natural enemies introduced for the biological control of leafy spurge should be initiated across a wide range of habitat types and geographic areas in the United States. Studies should include the assessment of economic and environmental benefits of biological control, the effect of flea beetles on plant species richness and diversity (including native species), and the assessment of any harmful effects on threatened and endangered *Euphorbia* species. Lastly, integrated weed management strategies need to be developed and implemented on a grander scale to be able to achieve consistent and sustainable management of leafy spurge in North America in the future.

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