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Entomophauna associated with leafy spurge: Field and laboratory studies on competition behavior between two defoliator moths (*Simyra dentinosa* Freyer and *Oxicesta geographica* F.) and two gall midges (*Spurgia esulae* Gagné and *Dasineura* sp. nr. *capsulae* Kieffer)

M. CRISTOFARO, A. C. PASTORINO, V. DI ILIO, G. CAMPOBASSO, and L. KNUTSON.

The introduction in the U.S. of two noctuid moths, *Simyra dentinosa* and *Oxicesta geographica*, active defoliators of spurges in Eurasia, is subordinated to their possible interspecific competition with two released gall midges, *Spurgia esulae* and *Dasineura* sp. nr. *capsulae*.

Three different approaches have been used:

i) three-year field observations in the moth collection areas, mainly in Romania and Southern Russia, to record the presence of the gall midge populations;

ii) two-year field tests, at the gall midge collection site (Northern Italy), to study the feeding behavior of the two moth in the presence or absence of the galls; and

iii) one-year laboratory tests, to quantify the time spent by the moth larvae on different target parts of the plant.

The field tests have been periodically inspected and the observations have been recorded with a video camera.

The laboratory tests (still in course) are carried out using an event recorder computerized program to confirm and quantify (in terms of time) the data and the behavior observed during the field experiments.

The results showed that, despite to a no-preference of the moths regarding the choice between "healthy" and galled stems, *S. dentinosa* and *O. geographica* showed preferences in the larval feeding behavior. The larvae start the nebbling on the upper part of the plant, but in the presence of the gall the larvae suddenly moved down to the leaves under the galls, where they started the real feeding.

This behavior, more evident for *O. geographica* than for *S. dentinosa* seems to be confirmed by the laboratory observations, but additional replications must be carried out, in order to significantly confirm the data.

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How do weeds affect us all?

K. G. BECK

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Editor's note: Below is the full text of a later paper on the same topic presented by Beck at the Grazing Lands Forum VIII, "An Explosion in Slow Motion: Noxious Weeds and Invasive Alien Plants on Grazing Lands."

What is a weed?

Many definitions of weeds have been created and historically, all definitions are centered around human activities. For example, the Weed Science Society of America defines a weed as 'a plant out of place'; Emerson thought a weed was 'a plant whose virtues have yet to be discovered'; and Toffell defined a weed as 'a plant that interferes with the management objectives of a given area of land at a given point in time'. Anthropomorphic definitions of weeds are not inherently bad as humans evolved on earth and we use our natural resources and weeds are plants that inhibit our efficient use of natural resources. However, there are physiological and biological characteristics of the group of plants that we call weeds and careful examination of these factors will help one to better understand why weeds are problematic.

Grime (1979) indicated that two basic external factors limit the amount of plant material found in any given environment; i.e., stress and disturbance. Stress includes environmental phenomena that reduce production such as limiting light intensity, water availability, nutrients, or optimal temperatures for growth. Disturbance is the partial to total disruption of plant biomass typically caused by fire, flooding, mowing, tillage, grazing, etc. If one considers the four extremes of stress and disturbance (e.g. high and low stress v. high and low disturbance) four outcomes for plant production ensue. Plant death occurs under high stress and high disturbance; the development of a population of stress tolerators occurs under high stress and low disturbance; a population of ruderal plants establishes under low stress and high disturbance; and competitor species dominate under low stress and low disturbance.

Thus, in an environment limited by abiotic (physical factors such as climate, fire, flooding, etc.) and biotic (insect predators, plant pathogens, plant competition, etc.) factors, three evolutionary strategies for plants occur. Stress tolerators are those plants that reduce allocations to vegetative growth and reproduction to ensure a population of relatively mature individuals in a limiting environment; competitors maximize resource capture in productive but relatively undisturbed environments; and ruderals are plants with short life cycles and high seed output that are found in highly disturbed environments and occupy the early stages of secondary succession. Few plants fall into these extreme categories and most are combinations of the three evolutionary strategies. Many herbaceous annual, biennial, and perennial weeds can be characterized as competitive ruderals. These plants occupy sites where dominance by true competitors does not occur because of disturbance; occasional disturbance is expected but frequent or severe disturbance would favor ruderal plants.

Environments favoring competitive ruderals would include meadows, seasonal grasslands, rangeland subject to seasonal disturbance (e.g. grazing), floodplains, eroded areas, lake and ditch margins, and arable lands. Thus, most weedy species occupy land in early to intermediate stages of secondary succession.

Weed impacts; So what's the big deal?

Noxious weeds are typically plants of foreign origin and, thus, did not evolve in North America. When these plants were inadvertently or otherwise imported into the United States, biotic factors, such as insect predators and plant pathogens, that evolved with the weed at its points of origin were not imported. Thus, in their 'new home', alien plant populations are regulated only by abiotic factors and this is not enough to keep their populations from increasing exponentially. For example, leafy spurge (*Euphorbia esula*) was introduced into the Red River Valley of North Dakota and Minnesota in the 1880's and this plant infests over 1 million acres in North Dakota alone today (Lacey *et al.*, 1985). Spotted knapweed (*Centaurea maculosa*) was introduced into Gallatin County, Montana, in the 1920's; by 1984 it had spread to all 56 Montana counties occupying over 2 million acres and today, over 4.7 million Montana acres are infested with this weed (Lacey *et al.*, 1986). Yellow Starthistle (*Centaurea solstitialis*) was introduced into California in 1869 near Oakland; by 1965 over 1.9 million acres were infested with yellow starthistle and by 1985, infestations increased to 7.9 million acres (Thomsen *et al.*, 1989). Purple loosestrife (*Lythrum salicaria*) infestations were studied from 1965 through 1978 at the Montezuma National Wildlife refuge in New York and biomass yield of purple loosestrife increased over this time from 0 percent of that harvested in 1965 to 90 percent in 1978 (Thompson *et al.*, 1987). A recent study in Colorado assessing the encroachment of Dalmatian toadflax (*Linaria genistifolia spp.* dalmatica) on rangeland showed over 4 years that this weed increased 322 percent in cover, 1250 percent in shoot density per acre, while crested wheatgrass cover decreased 172 percent (K.G. Beck unpublished data, Colorado State University, Ft. Collins).

We have significant alien plant infestations occupying rangeland and other natural resource areas in the United States and Canada today. Spotted knapweed occupies over 7.2 million acres in nine states and 2 Canadian provinces (Lacey, 1989). Diffuse knapweed (*Centaurea diffusa*) occupies over 3.2 million acres in 10 states and 2 Canadian provinces (Lacey, 1989). Russian knapweed (Acroptilon repens) occupies over 1.4 million acres in 9 states and 2 Canadian provinces (Lacey, 1989). Yellow starthistle occupies over 9.4 million acres in 10 states and 2 Canadian provinces (Lacey, 1989; Maddox and Mayfield, 1985). Leafy spurge infested over 2.5 million acres in 30 states in 479 U.S. counties as of 1979 (Lacey et al., 1985). Downy brome or cheatgrass (*Bromus tectorum*) infests over 101 million western U.S. acres and is listed as the dominant plant in the Intermountain West (Mack, 1981). A recent article in the Atlantic (Devine, 1993) laments the displacement of native bunchgrasses from downy brome encroachment in the west.

Cropland and forage production impacts:

In 1984, the average annual yield loss in 64 U.S. and 36 Canadian crops caused by weeds was $7.4 billion and $909 million, respectively (WSSA, 1984). Leafy spurge reduces the cattle carrying capacity of rangeland in North Dakota and Montana by 75 (Thompson *et al.*, 1990) and 63 percent (Bucher, 1984), respectively. Forage losses in Montana from spotted knapweed infestations were valued at $4.5 million in 1984 and if spotted knapweed continues to spread in Montana at its current rate, at least 33 million acres will be infested by 2009 causing $155 million in annual forage losses (Bucher, 1984).

Soil stability and water quality impacts:

Soil and water losses have occurred and continue to occur on millions of acres where grass communities have been replaced by tap-rooted plants. Lacey *et al.* (1989) measured surface water runoff and sediment yield (soil erosion) during a 30 minute simulated rainfall event on spotted knapweed dominated rangeland compared to native bunchgrass dominated sites. They found surface water runoff and soil erosion were 56 and 192 percent higher, respectively, on spotted knapweed dominated sites. This indicates that the presence of spotted knapweed on Montana rangeland is detrimental to soil and water resources. Soil on spotted knapweed dominated sites is eroded to a much higher degree compared to bunchgrass communities and water infiltration into the soil profile is less. This could and most likely has contributed to the displacement of native grasses because soil-water relationships have been altered due to the presence of spotted knapweed. This equates to greater sedimentation of streams, rivers, and lakes and will negatively impact fisheries.

Wildlife forage and habitat impacts:

The influence of noxious weeds on wildlife is not well understood or documented, but a few facts exist and the impact appears mostly to be detrimental. In western Montana, elk (Cervus canadensis) use of rangeland was estimated by counting pellet groups and there were 1575 pellet groups per acre in bunchgrass sites compared to 35 pellet groups per acre in spotted knapweed dominated sites (Hakim, 1975). Several studies indicated that spotted knapweed was not found in elk diets (Kufield, 1973; Lovaas, 1958; Mackie, 1970; Morris and Schwartz, 1957; Stevens, 1966). However, a recent study by the University of Montana indicates that elk grazed spotted knapweed in early winter, but in late winter, their diets were primarily grasses (Bedunah and Carpenter, 1990). Little to no spotted knapweed was found in their diets during February, March, or April even though the study area was dominated by spotted knapweed. Elk and deer eat spotted knapweed seedheads in winter and rosettes leaves in spring in the Bitteroot Valley of Montana; however, they may do so because of availability and not because of preference. In another study, spotted knapweed was common on mule deer (Odocoileus hemionus) range in Montana although the plant was not detected in their diets (Guenther, 1989). A game damage survey to alfalfa was conducted in 1986 in northeastern Wyoming, an area badly infested with leafy spurge; feces were examined histologically to determine which plant species were being consumed and they found no leafy spurge in deer diets. In North America, purple loosestrife encroaches upon and displaces desirable food plants and waterfowl nesting sites (Thompson, 1987). Cattails (*Typha latifolia*) were displaced by purple loosestrife competition, exacerbated by the selection pressure placed on cattails by muskrat feeding; and when these sites are dominated by purple loosestrife, muskrats move out. Purple loosestrife infestations make waterfowl broods more susceptible to predation because of the increased cover provided by tall purple loosestrife and the lack of a direct route from water to nesting sites. Certain waterfowl species, e.g. canvasback (Aythya valiisineria) and black tern (Chlidonia niger) prefer to nest on relatively open sites such as abandoned muskrat nests built from cattails. With purple loosestrife encroachment and displacement of cattails and other riparian plants that provide these sites, suitable nesting sites are decreased.

Noxious weeds are not entirely harmful to wildlife. A Montana Outdoors article indicates that weeds provide cover, habitat diversity, and a source of feed for many game and non-game birds (Wiegand, 1977). It is worth noting, however, that the tendency of noxious weeds to form monocultures would decrease habitat biodiversity once this occurred. In British Columbia, knapweed rosettes were found to be important components in the diets of deer and elk in early spring (Miller, 1990). A recent study in Colorado and Wyoming indicates that three times as many small mammals frequented Russian knapweed infested rangeland compared to adjacent noninfested sites (R. Olson, University of Wyoming, personal communication). Adaptation occurs as evidenced by one small mammal, a harvester mouse, using the Russian knapweed infested sites and this mamumal may serve to spread the weed as they cache seeds.

Species diversity and impact on native plant habitat:

Many noxious weeds dominate plant communities and tend to form monocultures and this obviously negatively impacts native biological diversity in the United States. Downy brome communities in the Intermountain West are poor in species composition compared to steady state (climax) sagebrush/bluebunch wheatgrass (*Artemisia tridentata*/*Agropyron spicatum*) communities (Rickard and Cline, 1980). Displacement of native plants by spotted knapweed was assessed in Glacier National Park in Montana from 1984 through 1987 (Tyser and Key, 1988). These sites were originally classified as Idaho fescue (*Festuca idahoensis*) and rough fescue (*Festuca scrabella*) dominated plant communities. Spotted knapweed impacts to native plant communities were assessed on perimeter, fringe, and core weed infestations. These researchers found the species richness gradient to be inversely proportional to spotted knapweed stem density; i.e., the more spotted knapweed stems per unit area, the fewer number of plant species present. Species richness declined as one moved along the transects from the perimeter to the core infestations (species richness ranked perimeter> fringe> core). Spotted knapweed stem density was the only variable associated with the species richness effect. These researchers further classified plants in the fringe infestations as common, uncommon, or rare. Of the 38 species evaluated in 1984, 31 were reclassified at the same frequency in 1987. However, seven of the original species were reclassified into lower frequency categories in 1987 (*Galium boreale*, *Hieracium umbellatum*, *Potentilla arguta*, *Potentilla gracilis*, *Silene parryi*, *Stipa occidentalis*, and *Tragopogon dubuis* - note the last species was an uncommon, weedy, alien). Six species were classified as common in 1984 and five of these remained in this category in 1987. Of the 21 uncommon species in 1984, only 16 remained as such in 1987 with six being reclassified as rare in 1987. Additionally, five rare and two uncommon species found in 1984 were not present in 1987 (*Agropyron spciatum*, rare; *Castilleja cusickii*, rare; *Collomia linearis*, rare; *Heuchera cylindrica*, rare; *Lithospermum ruderale*, rare; *Stipa occidentialis*, uncommon; and *Tragopogon dubius*, uncommon and alien). Additionally, native plants are being displaced in Utah by dyer's woad (*Isatis tinctoria*) (West and Farah, 1989) and in California by yellow starthistle (Maddox and Mayfield, 1985).

The impact of noxious, alien weeds on rangelands and other natural resource areas are not well understood nor documented. The weed science community has spent a lot of time leaming how to control weeds v. understanding their biology, ecology, and impacts. This trend is changing and with increased opportunities for grant supported research in these areas, a greater understanding will occur. Nonetheless, aggressive, alien plants will continue to displace native plants in their habitats primarily due to a lack of biotic pressure placed on alien plant populations (no biological control - in the absence of other control measures). This is further exacerbated by the rapid rate of spread by alien weedy species and the difficulty associated with effectively managing all infestations in any given year because infestations are very large and scattered across landscapes.

Open space and wilderness area impacts:

Open spaces are prime areas for alien plant invasion. Open spaces associated with cities and counties typically are former grazingland or abandoned farmland. Thus, open spaces have been disturbed to one degree or another and subject to secondary succession - weed invasion. Open space infestations serve as sources for new infestations on adjacent land and land farther away. For example, open spaces along Colorado's Front Range communities are dominated by alien plants. Boulder City and County Open Space ground is infested with diffuse knapweed, spotted knapweed, Russian knapweed, Canada thistle, field bindweed (*Convolvulus arvensis*), Dalmatian toadflax, downy brome, and musk thistle; Cherry Creek State Park in the greater Denver Metropolitan area is badly infested with diffuse knapweed, leafy spurge, musk thistle, Canada thistle, and field bindweed and these infestations are spreading along Cherry Creek into the South Platte River which flows into Nebraska; Fort Collins open space areas are infested with leafy spurge, Canada thistle, musk thistle, diffuse knapweed, field bindweed, downy brome, puncturevine

(Tribulus terrestris), and these plants are particularly troublesome along the Poudre River corridor which flows into the South Platte, thus, these infestations are spreading into Weld, Morgan, Logan, and Sedgwick Counties in Colorado and into Nebraska.

Backpackers and horsepackers inadvertently spread alien plants into wilderness areas. Seeds on clothing, packs, animals, or in contaminated hay brought into wilderness, or excreted in feces by domestic animals, are sources for new infestations. For example, the Rawah Wilderness in Colorado is infested with musk thistle and it is spreading rapidly because of the plant's biology and lack of weed management input. Canada thistle infestations in Rocky Mountain National Park have been the object of interest for the past 3 years. Infestations started along horse and foot trails and have spread from there into native plant communities (T. Mclendon, Colorado State University, personal comununication). Dry, upslope conditions, thick canopies from woody species, and well-established grass meadows (especially wet meadows) inhibited Canada thistle invasions. Canada thistle populations appear to thin with time and become part of the plant community in many instances, in the absence of further disturbance. However, even minor disturbance from elk grazing promoted Canada thistle invasion and establishment into grasslands.

Plant succession dynamics impacts:

Weeds (alien or native) would be classified under 'natural systems' as pioneers, invaders, or increasers. Disturbance creates an opportunity for secondary succession to occur and weeds will occupy the site initially. Depending upon the degree of disturbance, annual weeds will occupy the site first and be replaced with time by herbaceous perennial weeds. In abandoned farmland, the systematic replacement of early and intermediate plant seral stages occurs over time until a steady state community develops - not necessarily identical to the pristine community before fanning was practiced; this is termed old field succession. The time associated with these changes varies with climate, soil nutrient status, weed species present, availability of native plant propagules and species composition thereof.

The impact of noxious weeds on plant succession dynamics of grazinglands is not well understood. Patches of noxious weeds, such as leafy spurge or Russian knapweed, survive for extended periods. For example, a Russian knapweed stand in Saskatchewan has survived over 75 years (Watson, 1980). Presumably because these plants are competitive ruderals, they should be replaced over time by those plants that occupy later stages of succession. However, the time frame is unknown and apparently may be long relative to a human perspective. Alien plant persistence is further exacerbated by the lack of biotic pressure on these plant communities in North America. Furthermore, if alien plant species eventually yield to later successional species (presumably desirable native species), the time that they occupy an area may render that area less useful to useless for productive purposes (e.g., interfere with any agricultural operation, forestry, wildlife foraging, or recreational use).

Human health hazard impacts:

Virtually any pollen producing plant has the potential of affecting hay fever sufferers. In Colorado for example, ragweed (*Ambrosia spp.*) - native plants - cause significant problems for those with respiratory allergies. However, kochia (*Kochia scoparia*) and Russian thistle (*Salsola iberica* and *S. collina*) cause equivalent problems for those with hay fever. Latex in leafy spurge can cause irritation to broken skin, eyes, or simply may cause a dermal rash. Several volunteers in Boulder County, Colorado that hand-pulled diffuse and spotted knapweeds contracted a dermal rash from these weeds. This is another area where weed impacts are not well understood or documented.

Economic impacts:

The common denominator for human endeavors is our means of barter - i.e., money. Economic impacts caused by alien weeds on grazinglands has not been thoroughly documented but some information is available. Scotch thistle (*Onopordum acanthium*) infestations in northern California cause annual losses to ranchers equating to $60.50/acre on wet meadows, $39.50/A on wheatgrass stands, and $20.16/A on cheatgrass rangelands (Hooper *et al.*, 1970).

The most thorough study on weed impacts on grazinglands was conducted by the Agricultural Economists at North Dakota State University. They determined the direct impacts caused by leafy spurge on North Dakota grazinglands and wildlands then used an input-output model to determine secondary effects (Leistritz *et al.*, 1993). Direct annual losses from leafy spurge included $8.7 million in reduced personal incomes for North Dakota cattle producers and an additional $14.4 million reduction in rancher spending (i.e. lost cash outlays) due to reduced livestock production. In 1990, leafy spurge infestations reduced cattle carrying capacity by approximately 580,000 animal unit months (AUMs) or enough to support 63,100 cows for 7.5 months. Total annual direct grazingland losses were valued at $23.1 million. Indirect grazingland losses caused by leafy spurge infestations totalled $53.2 million and these losses were incurred by businesses outside of livestock production but caused by reduced income and expenditures from the cattle industry. Annual direct losses due to leafy spurge on North Dakota wildland totalled $2.9 million because of reduced wildlife associated recreation. An additional $0.7 million direct wildland loss was estimated in reduced soil and water conservation caused by leafy spurge infestations. Indirect annual losses to North Dakota wildland from leafy spurge were caused by reduced expenditures within their economy from direct losses and totalled $7.4 million. Therefore, total direct and indirect annual losses to North Dakota grazingland and wildland caused by leafy spurge were valued at $87.3 million! The majority of indirect losses in grazingland and wildland was in the household sector and totalled $28.7 million annually and equated to approximately $26.00/A infested with leafy spurge. Additionally, current infestations cause a reduction in over 1,000 jobs per year in North Dakota.

Summary and recommendations

The negative impacts caused by noxious weeds are very real and clear where recognized. Unknown impacts exist and must be determined so we can better decide where to focus our attention. Grazingland, wildland, farmland, native habitat, open spaces, and urban landscapes all are negatively impacted by the presence of alien plant species. The domino effect from the economic impacts caused by the presence of alien plant species indicates that our daily lives indeed are negatively impacted by this 'mundane' group of plants.

We can choose to act and invoke integrated weed management strategies to reduce infestations and their impacts. Or, we can choose not to act and allow alien plants to continue to displace desirable plants thus, destroying the native biological diversity of our country and the value of our grazinglands and wildlands and further negatively impact our nation's economy. It seems very unnecessary and illogical for this latter scenario to occur!

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Using remote sensing for detecting and mapping leafy spurge (*Euphorbia esula*)

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Leafy spurge is a troublesome weed in the northern Great Plains of the United States that is difficult to control. During June, leafy spurge produces showy yellow bracts that give this weed a conspicuous appearance. We conducted a study to determine the feasibility of using remote sensing techniques to detect leafy spurge in this phenological stage. Study sites were the Theodore Roosevelt National Park near Medora, North Dakota, and a rangeland area near Lewistown, Montana. Plant canopy reflectance measurements showed that leafy spurge had significantly higher (P=0.05) visible (0.63- to 0.69-m) reflectance than several associated plant species. The conspicuous yellow bracts gave leafy spurge distinct yellow-green and pink images on conventional color and color-infrared (CIR) aerial photographs, respectively. Leafy spurge could also be distinguished on conventional color video imagery where it had a golden yellow image response. Quantitative data obtained from digitized video images showed that leafy spurge had statistically different digital values from those of associated vegetation and soil. Computer analyses of video images showed that leafy spurge populations could be quantified from associated vegetation. This technique permits area estimates of small leafy spurge populations. Large format conventional color photographs of Theodore Roosevelt National Park were digitized and integrated with a geographic information system (GIS) to produce a map of leafy spurge populations within the park. The GIS can be useful to monitor the spread or contraction of leafy spurge.

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The control of leafy spurge with initial and retreatments of picloram

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This research was conducted near Devil's Tower, Wyoming to compare the efficacy of various rates of picloram for leafy spurge control. Plots were retreated to maintain or attain 80% control with light rates of picloram or picloram/2,4-D tankmixes. Initial treatments were 0.25 lb picloram to 2.0 lb picloram in 0.25 lb increments and 0.25 lb. picloram + 1.0 lb 2,4-D. Retreatments were 0.25 or 0.5 lb picloram or 0.25 lb picloram + 1.0 lb 2,4-D. The initial treatment of 0.25 lb picloram was retreated only with 0.25 lb picloram and the initial treatment of 0.25 lb picloram + 1.0 lb 2,4-D was retreated only with 0.25 lb picloram + 1.0 lb 2,4-D. Plots were 10 by 27 ft. with four replications arranged in a randomized complete block. The initial herbicide treatments were applied broadcast with a CO_2 pressurized six-nozzle knapsack sprayer delivering 30 gpa at 40 psi May 24, 1989 (air temp. 56°F, soil temp. 0 inch 87°F, 1 inch 77°F, 2 inch 76°F, 4 inch 75°F, relative humidity 45%, wind west at 3-5 mph, sky partly cloudy). Retreatments were applied broadcast with CO_2 pressurized six-nozzle knapsack sprayer delivering 20 gpa at 40 psi June 6, 1990 (air temp. 72°F, soil temp. 0 inch 87°F, 1 inch 85°F, 2 inch 83°F, 4 inch 75°F, relative humidity 51%, wind south at 10 mph, sky partly cloudy); June 13, 1991 (air temp. 72°F, soil temp. 0 inch 82°F, 1 inch 80°F, 2 inch 79°F, 4 inch 77°F, relative humidity 60%, wind northwest 5 mph, clear); June 10, 1992 (air temp. 86°F, soil temp. 0 inch 100°F, 1 inch 95°F, 2 inch 90°F, 4 inch 80°F, relative humidity 30%, wind north at 5 mph, sky 20% cloudy); and September 22, 1993 (air temp. 56°F, soil temp. 0 inch 65°F, 1 inch 63°F, 2 inch 60°F, 4 inch 58°F, relative humidity 35%, wind north at 3 mph, sky 50% cloudy). The soil was a silt loam (22% sand, 58% silt, and 20% clay) with a 1.8% organic matter and a 6.3 pH. Leafy spurge was in full bloom and 12 to 14 inches in height, for the initial treatments and in full bloom, 12 to 20 inches in height for spring retreatments and 16 to 24 inches in height for fall retreatments. Infestations were heavy throughout the experimental area. Visual weed control evaluations were made June 6, 1990; June 13, 1991; June 10, 1992; June 21, 1993; and June 15, 1994.

Plots with initial treatments of 1.25 lb/A picloram or greater gave 80% or better leafy spurge control and did not require retreatment in 1990. All other plots required retreatment. Initial treatments maintaining 80% control or better in 1991 were two 1.5 lb picloram treatments, one 1.75 lb picloram treatment and all 2.0 lb picloram treatments. The only 1990 retreatment attaining 80% control or better in 1991 was 0.5 lb picloram over an initial 1.0 lb picloram. Plots with less than 80% control in 1991 were retreated. None of the treatments applied in 1991 or 1992 attained 80% control in 1992 or 1993. Two of the three initial 2.0 lb picloram treatments applied in 1989 continued to maintain 80% leafy spurge control through 1992. The control in these treatments dropped below 80% in 1993. In 1994, eight months after fall treatment, all rctreatments of 0.5 lb picloram attained 80% control or better. The only other retreatment to attain 80% control was 0.25 lb picloram + 1.0 lb 2,4-D, applied in the fall, over an initial treatment of 1.5 lb picloram.

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A model for the regulation of crown and root buds of leafy spurge

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A part of the tenacious vegetative character of leafy spurge is due to the production of numerous lateral root and crown buds. The regulation of the growth and development of these buds has been the primary interest of this investigator and after close to fifteen years of observation, research, and study of the related literature, a functional model is emerging which describes the role of internal and external factors, interacting to control the growth and development of these buds. An overview of seasonal changes, in relation to observable growth habit, along with experimental data, indicate classical apical bud dominance controls bud development in the spring through late summer.

In contrast to this type of summer growth habit, late in autumn, crown buds begin to elongate, and regulation of this growth and the cold hardening of the tissues comes from other mechanisms. The stimulus for this control consists, in part, of changes in the intensity, duration and quality of the day light. It appears that changes in the ratio of red to far red light is perceived by a phytochrome. Once activated, the phytochrome then is involved in cold hardening of the developing buds as well as the limitation of bud elongation. The later, is mediated by the phytochrome regulation of the conversion of inactive to active forms of gibberellic acid. The gibberellic acid in turn mediates the production of hydrolytic enzymes that control the reallocation of carbon and nitrogen reserves of the root during the winter, so that these elements and energy reserves are available to support new shoot growth early in the spring. Support of each component in this model will be presented as well as some additional parameters that may be involved. The role of temperature in this system has yet not been addressed.

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Phenology of leafy spurge biocontrol agents

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The seasonal occurrence of "collectable" life stages of leafy spurge biocontrol agents must be known to schedule sampling and redistribution collections at field insectary sites (FIS). Since 1992, I have been quantifying the occurrence of adult leafy spurge flea beetles (*Aphthona cyparissiae*, *A. czwalinae*, *A. flava*, and *A. nigriscutis*) at sites in southwestern Montana (Gallatin Co. and Sweet Grass Co.). Eight emergence cages per release were employed in 1992, while sweep-net samples (120 sweeps/release) were used in 1993 and 1994. Samples were collected once or twice a week, from early June through September. On-site weather stations recorded daily minimum and maximum temperature of 0 C and a Jan. 1 starting date.

Peak *A. czwalinae* and *A. nigriscutis* populations were observed at about 1250 accumulated degree-days (ADD), while peak *A. cyparissiae* and *A. flava* populations occurred at about 1450 and 1650 ADD, respectively. Generally, 200 degree-days (>O°C) are accumulated in a 6-10 day period, depending on location. We schedule three sampling visits to each FIS; sampling during the week when 1450 ADD are "expected", two weeks previous, and two weeks after should adequately bracket peak populations for all *Aphthona* spp. Local temperature data are used to estimate the occurrence of 1450 ADD and, hence, schedule sampling visits in the 15 states involved in the APHIS redistribution project.

The occurrence of larvae, pupae, and adults of the gall midge *Spurgia esulae* has also been monitored from 1992 through 1994 at a site in Gallatin Co. Beginning in early May and continuing into September, the site was visited at least weekly, and, if present, 5-10 *S. esulae* galls were randomly collected. Galls were dissected and all larvae, pupae, and adults (pupal exuviae) counted. Degree-day data were collected as described above.

Three larval but only two pupal (and adult) "peaks" were observed in 1992 and 1993, demonstrating three generations per year in Montana (third-generation larvae overwinter in the soiI). Pupal peaks were observed at about 1000 and 1600 ADD. Experience has shown that galls collected during the "peak" first-generation pupal stage are best suited for redistribution collections, so this effort will be scheduled around the anticipated accumulation of 1000 degree-days.

Plants can be reliable monitors of air and soil heat accumulation (hence, degree-days) and thus may serve as useful indicators of biocontrol agent activity in the field. Since

1992, I have also attempted to quantify vegetative, flowering, and fruiting developmental patterns for selected wild and cultivated plants in southwestern Montana. Generally, adult *Aphthona emergence* appears to begin concurrently with bloom initiation in Wood's rose (*Rosa woodsii*); unfortunately, there is a dearth of recognizable plant phenological events during adult population "peaks". First-generation *Spurgia esulae* galls first appear around the beginning of flowering in chokecherry (*Prunus virginiana*), while first-generation pupal "peaks" seem to coincide with "full" flowering of death camas (*Zygadenus gramineus*).

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Response of leafy spurge to defoliation and competition

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Leafy spurge (*Euphorbia esula* L.) is an aggressive introduced perennial weed invading nonirrigated pasture and rangeland habitats. The objective of the study was to examine the overall impact of simulated herbivory on leafy spurge production. The interaction between herbivore damage and interaspecific competition under a combination of intensity, frequency and timing of defoliation were also studied over a three-year period. The study was conducted on a leafy spurge-infested rangeland in Clark County, located on the upper Snake River Plains of southeastern Idaho. The defoliation regime consisted of three intensities 0% (control), 40%, and 80% removal of the aboveground standing crop. Defoliation was applied on $1m^2$ plots at different phenological stages (vegetative stage, flowering stage, and seed stage) and either to leafy spurge only or to both leafy spurge and associated vegetation to determine leafy spurge competitive ability. Aboveground biomass of leafy spurge and associated vegetation, and leafy spurge stem numbers and average heights were measured. Undefoliated biomass was determined using leafy spurge stem numbers and average height via multiple regression. Leafy spurge biomass production was significantly lower ($p<0.001$) on all the defoliated plots compared to the control. The highest reduction was observed when the plots were defoliated at higher intensity (80% compared to 40%) and three times during the growing season, especially under high intensity (80%). In addition, leafy spurge biomass obtained from plots where only spurge was defoliated was significantly lower ($p<0.001$) compared to the plots where both leafy spurge and associated vegetation were defoliated at both intensities. This study indicates that the most effective management strategy to reduce leafy spurge biomass would be one that uses multiple grazing and heavy utilization. The competitive disadvantage placed upon leafy spurge by defoliation can be further enhanced if the herbivore selectively grazes leafy spurge and avoids associated vegetation.

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Integration of herbicides with *Aphthona* spp. flea beetles for leafy spurge control

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The timing of herbicide treatments on *A. nigriscutis* and *A. czwalinae* survival and establishment was evaluated. Two locations of *A. nigriscutis* and one location of *A. czwalinae* were established. The treatments included picloram plus 2,4-D at 4 plus 16 oz/A spring applied picloram plus 2,4-D at 8 plus 16oz/A fall applied, and *Aphthona spp.* alone. Stem density was evaluated in the spring, and adult sweep counts were conducted through the summer. For the first experiment, *A. nigriscutis* were released in the 1989 and herbicide treatments were initiated in spring (June) of 1992 at Cuba. Stem density in the insect-only treatment declined by 47% from 1992 to 1994. The greatest leafy spurge stem density was reduced 97% by the insect plus fall applied herbicide treatment. The spring applied herbicide plus insect treatment reduced leafy spurge less than the insects alone. The *A. nigriscutis* population in the non-herbicide treatments increased from 11 beetles/m^2 in 1992 to 28 beetles/m^2 in 1994. The *A. nigriscutis* population in 1994 declined to less than 1 beetle m^2 when herbicides were spring applied. When herbicides were fall applied 37 beetles/m^2 were found. Similar experiments were started in 1993 with 3,000 *A. nigriscutis* released at the Ekre Research Station near Walcott and 30,000 *A. czwalinae* released at Camp Grafton south of Devils Lake. Herbicide treatments were fall applied and stem density and adult beetle sweep counts are currently being conducted.

The establishment and movement of *A. nigriscutis* on leafy spurge patches is currently being evaluated. *A. nigriscutis* was released as 100, 200, 300, 400, or 500 adults per site along a 2.5 miles stretch of the Burlington Northern railroad right-of-way near Buffalo. The insects were released in dense stands of leafy spurge on June 28, 1993. Stem density was evaluated in the spring and adult sweep counts are currently being conducted through the summer. A. nigriscutis flea beetles were at all release sites in 1994, which is 1 year after release, but stem density has remained the same at 17 stems/0.25m^2 from 1993 to 1994.

The survival of *A. czwalinae*, *A. flava*, and *A. nigriscutis* were evaluated on leafy spurge biotypes from Austria, Manitoba, Montana, Nebraska, North Dakota, South Dakota, and Wyoming. The seven biotypes were grown in a greenhouse for 4 to 5 months in

2.5 by 8 inch pots. These pots were planted directly outside in April. The pots were arranged in a RCBD with 12 replications in a 36 ft^2 area. Cages were placed over the experiments and 200 *Aphthona* spp. were released. The pots were dug in November, placed in a cooler at 3°C for 8 weeks, and then placed under greenhouse lights (16 hours) at 24°C. Adult emergence was evaluated for biotype preference but too few adults emerged to provide accurate data. The study is being repeated in 1994.

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Root-associated microorganisms of leafy spurge as potential biocontrol agents

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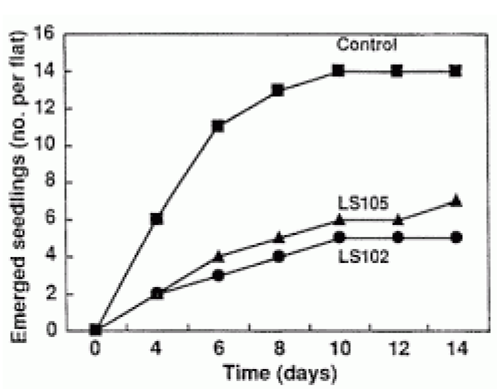
Current biocontrol of leafy spurge involves host-specific insects that have successfully reduced infestations in specific habitats and fungal pathogens that require specific conditions to function as mycoherbicides to effectively control established plants. Bacterial components of the rhizosphere that inhibit plant growth, (deleterious rhizobacteria; DRB), and root-associated fungi have not been intensively examined for potential biocontrol activity. We are investigating DRB and root fungi isolated from leafy spurge accessions for growth-suppressive activity toward seedlings and established plants.

Two DRB isolates, LS102 (*Pseudomonas fluorescens*) and LS105 (*Flavobacterium balustinum*), with consistent growth-suppressive activity were selected through primary screening on leafy spurge tissue culture and seedling bioassays (2). Secondary screening of the isolates in soil in the greenhouse resulted in 65 and 50% reduction in seedling emergence by LS102 and LS105, respectively, applied as liquid formulations (Fig. 1). The isolates reduced root development >65% and shoot growth ≈80% at 21 days after inoculation. Both isolates colonized leafy spurge roots based on culturing on selective media. Root colonization is an important attribute for DRB to persist in the rhizosphere and sustain growth suppression (1).



To further enhance survival and establishment of DRB, calcium alginate formulations have been prepared for delivery of high cell concentrations to the soil and rhizosphere in the field. Preliminary trials in the greenhouse on leafy spurge seedlings and potted plants indicate that the DRB were able to colonize roots and reduce root growth and shoot development comparable to or better than liquid formulations.

Combinations of DRB with selected detrimental root fungi will be examined to assess any improvement of biocontrol efficacy. We plan to field test DRB formulations at sites with high leafy spurge seed/seedling densities and on established plants. DRB and root fungi are primarily growth-suppressive; integrated or "multiple agene" approaches to include these agents with other microorganisms and insects (i.e., *Aphthona* spp.) may be the most effective means for successful biocontrol of leafy spurge.

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Potential aversion-inducing compounds in leafy spurge

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It has been demonstrated that leafy spurge can elicit a conditioned food aversion in cattle, sheep and laboratory rats and suggested that this may explain why cattle seldom graze this nutritious plant and why sheep may not readily consume it at some locations. The identity of the aversive compound(s) in leafy spurge is unknown, but several different diterpenoid ingenol esters have been isolated from its tissues, and we suspect that one or more ingenol esters may be aversion-eliciting compound on leafy spurge. The objectives of this study were to determine whether or not a crude acetone extract of leafy spurge, presumably containing ingenol esters, could generate an aversive response in sheep and laboratory rats. And further, to determine whether or not a particular ingenol monobenzoate, which may be similar to ingenol esters in leafy spurge, might also elicit an aversive response from laboratory rats. An acetone extract of leaf spurge induced a mild conditioned aversion in both rats and sheep. The ingenol 3-monobenzoate also induced a mild conditioned aversion in rats. We interpret these data to suggest that one or more ingenol esters may be aversion-inducing agents in leafy spurge. However, other compounds may exist in leafy spurge that are aversive to certain livestock.

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Process for developing a leafy spurge strategic management plan within Theodore Roosevelt National Park

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Theodore Roosevelt National Park is managed to represent a primitive vignette of the area as it appeared before extensive settlement of the region. This includes representation of native flora and fauna, as well as other natural and cultural resources values. Leafy spurge is one of 59 species of exotic plants that are known to occur in the park. National Park Service (NPS) policy requires the containment, control and management of exotic species to the greatest degree possible, particularly those with serious ecological effects. Intensive management is required to reduce and contain these infestations while comprehensive and integrated approaches are needed to restore this habitat.

Current research shows that leafy spurge is a serious invader into the park's native vegetation communities, resulting in significant ecological disruption of these communities, and in some instances replacement of all native species in a given locality. Habitat loss also has the potential to adversely affect native ungulate species.

Theodore Roosevelt National Park and Forest Service convened a workshop and special advisory panel of interdisciplinary experts to develop a strategy for control of leafy spurge within the park and adjacent lands. Previous research in the park and management actions were evaluated.

Interagency coordination with USDA-Agricultural Research Service (ARS)-Remote Sensing Research Unit (RSRU) led to the use of an integration of high resolution aerial color photography and airborne video with Global Positioning System (GPS) technologies for detecting and mapping leafy spurge. Preliminary analysis of the data indicated that 1,358 acres were infected in the park's 46,000 acre South Unit. The ARS base map serves as a reference point from which to develop specific recommendations geared to future management implementation and control actions. Advisory panel members used the data in recommending a strategy to implement a variety of integrated pest management (IPM) techniques.

The mapping project helped foster interagency/private cooperation in the management of leafy spurge locally. The NPS, Forest Service, ARS, two county weed boards, a grazing association and twenty-eight private individuals are partners in a North Dakota

Department of Agriculture Weed Innovation Network (WIN) grant. This noxious weed knows no jurisdictional boundaries. Through joint cooperative efforts a strategy will be developed for managing different levels of infestations within identified watershed basins.

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Integration of herbicides with grazing for leafy spurge control

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An experiment to evaluate herbicide treatment with grazing to improve long-term leafy spurge control compared to either control method alone was established in May 1992 on the Sheyenne National Grasslands and the Gilbert C. Grafton South State Military Reservation. The six treatments included: a) grazing alone, b) picloram plus 2,4-D at 0.5 plus 1 lb/A fall applied, c) grazing in spring followed by picloram plus 1,4-D at 0.5 plus 1 lb/A fall applied, d) picloram plus 2,4-D at 0.25 plus 1 lb/A spring applied, e) picloram plus 2,4-D at 0.25 plus 1 lb/A spring applied followed by grazing of all regrowth, and f) an untreated control. Leafy spurge was rotationally grazed at the Sheyenne National Grasslands but grazed season-long at Camp Grafton South.

The fencing necessary to prevent or delay grazing was established in May 1992 and leafy spurge density evaluated. The herbicides were applied in June or September in 1992 and 1993 for the spring-and fall-applied treatments, respectively. Leafy spurge root material for carbohydrate and protein content analyses was harvested in October 1992 and 1993.

Grazing combined with fall-applied herbicide treatment reduced leafy spurge density more than grazing alone. Also, season-long grazing as used on Camp Grafton South, either alone or combined with herbicides, reduced leafy spurge more than rotational grazing used on the Sheyenne National Grasslands. The best treatments averaged over both locations was picloram plus 2,4-D applied in the fall alone or proceeded by spring grazing. These treatments reduced the stem density from an average of 16 stems/0.25m^2 in 1992 to 0.3 stem/0.25m^2 or 99% control in 1994.

Grazing alone reduced leafy spurge 74% at Camp Grafton South but had no effect the Sheyenne National Grasslands. The difference in control is likely due to the type of grazing management. Continuous season-long grazing prevents the plant from restoring root nutrients because they are need to restore topgrowth. However, rotational grazing apparently encourages bud growth from the roots after the first grazing cycle and without immediate regrazing, sustains a stem density similar to the untreated control.

Picloram plus 2,4-D spring-applied proved 96% control at Camp Grafton South, but only 62% control at the Sheyenne Grasslands after two treatments. The average control with picloram plus 2,4-D at 0.25+1 lb/A for many experiments in North Dakota is 65% after two treatments. A spring-applied herbicide treatment followed by fall grazing increased leafy spurge density at Camp Grafton South slightly compared to the herbicides applied alone. At the Sheyenne National Grasslands the stem density increased from an average of 10 to 16 stems/0.25 m^2 when spring applied herbicides were followed by fall grazing compared to the herbicides used alone. The reason for the increase in leafy spurge density when leafy spurge is grazed following a herbicide treatment is not known.

The effect of grazing and herbicide treatments alone or in combination on leafy spurge root nutrient content was minimal after 2 years. All treatments reduced the root protein content at Camp Grafton South compared to the untreated control. The sucrose concentration in leafy spurge roots was similar regardless of treatment. However, the starch concentration declined by 60% in the grazed only and spring grazing followed by picloram plus 2,4-D fall-applied treatments compared to the control.

The sucrose and starch concentration in leafy spurge roots at the Sheyenne National Grasslands in 1993 after two growing seasons was similar regardless of treatment. However, the protein content was reduced by 67% in the grazed only treatment compared to the control even though stem density was high in the grazed plots. No other treatment affect root protein content at the Sheyenne National Grasslands after 2 years.

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Revegetation of leafy spurge-infested rangeland with native tallgrasses

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Leafy spurge is a problematic perennial weed on rangeland in the northern and central Great Plains. Leafy spurge displaces native plants and reduces forage productivity. Research was conducted to determine the feasibility of using imazapyr and sulfometuron to control leafy spurge and to facilitate seeding and establishment of native tallgrasses. Imazapyr at 0.28, 0.56, and 0.84 kg a.i./ha and sulfometuron at 0.1 kg a.i./ha were applied alone and in combination in late September 1992 to leafy spurge-infested range sites near Ainsworth and Ansley, Nebraska. Plant residue on the sites was burned in early April 1993. Big bluestem (*Andropogon gerardii* Vitman var. *gerardii* Vitman) and switchgrass (*Panicum virgatum* L.) were planted at 440 pure live seed/m^2 in late April 1993 into plots treated with herbicides the previous fall. Leafy spurge control and frequency and yield of the planted grasses were measured in August 1993. Imazapyr applied at 0.28, 0.56, and 0.84 kg/ha with sulfometuron and imazapyr applied alone at 0.56 and 0.84 kg/ha provided greater then 80% leafy spurge control. Excellent stands (>20 plants/m^2) of big bluestem and switchgrass were established where imazapyr and sulfometuron had been applied in combination.

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An overview of biological control of leafy spurge in Alberta

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Leafy spurge is estimated to infest around 6,000 hectares in Alberta. Infestations occur throughout Alberta in a wide range of soil and habitat types, but are concentrated along the main river systems in the southern part of the province. Biological control efforts have been conducted since 1982 by the Alberta Environmental Centre, Alberta Agriculture and Agriculture Canada, in cooperation with the International Institute of Biological Control in Delémont, Switzerland. The most successful agent has been the root-feeding beetle, *Aphthona nigriscutis*, which has been released at over 120 research sites and redistributed widely through a program of redistribution clinics. *Aphthona nigriscutis* is giving excellent control on sloping and hilltop sites with lighter soils. At one experimental site leafy spurge above-ground biomass was over 100 g m^{-2} when *A. nigriscutis* was released, and was reduced to less than 1 g m^{-2} five years later. *Aphthona flava* has also been redistributed to 44 research sites, but has so far not reached high population densities at any except the original release site. The main need now is for biological control agents which will be successful in moister and lower-lying sites such as riverbanks, flood plains and mesic pastures. Agents which are currently being tested in these environments include the stem-mining fly *Pegomya euphorbiae*, the moth *Minoa murinata*, and the root-feeding beetles *Aphthona cyparissiae* and *Aphthona lacertosa.*

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Leafy spurge and the GPAC-14 Leafy Spurge Task Force: An historical perspective

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In 1934 the control method of choice for leafy spurge was sodium chlorate – 4 pounds per square rod in June and 2 pounds per square rod six to eight weeks later (Barnett & Hanson, 1934). That's a total of 960 pounds per acre. Cost was a limiting factor – $8 per 100 pound drum would cost $768 an acre. This control method was only recommended for very small areas. Researchers were also looking at cultivation, mowing, hoeing, and replanting areas – so the concept of an integrated approach is not new.

By 1955 2,4-D herbicide plus Ammate (ammonium sulfamate) was recommended at a rate of 4 pounds D and 100 pounds of Ammate for the best control of leafy spurge (Krall, 1955). Several cropping systems were also being tested at this time, with delayed cultivation one year, followed by heavy seeding of winter wheat and a 2,4-D application the next, for a period of four years, giving the best control. Weed scientists have always been into this integrated approach for perennial noxious weeds.

Today scientists are recommending Tordon as the most effective long-term herbicide treatment, but it's not economical at high rates on large infestations because the herbicide cost is often eight to ten times higher than the cash rent value of the land (Lym & Messersmith, 1994). Researchers today are looking at herbicide treatments, revegetation, grazing, and the use of insects and pathogens as biocontrol agents. The rate of increase of spread of leafy spurge has slowed in North Dakota, probably due to long-term herbicide and cultural practices and scientists are recommending long-term management programs that include herbicides, insects, and other biocontrol agents (Moran, 1994).

The changes we have seen in leafy spurge control since the first research in the 30's includes much more effective and environmentally safe use of herbicides. We obviously use much lower rates now. We've seen a more specific approach to the development of competitive vegetation and revegetation efforts. A whole new field of biological control of weeds with insects has developed since the 30's, including more weed scientists working with entomologists to get a better understanding of both biological systems. We're seeing today more work on the development of specific plant pathogens for the control of leafy spurge. In this time period, we've seen researchers take a serious look at what sheep and goat grazing really does to leafy spurge.

We’ve come a long way, but we’re not there yet

Those of you who were not able to attend the Montana Weed Control Association Meeting last November missed hearing a history making leafy spurge talk by the world famous time traveller – Dr. Rodney Lym. Quoting from the National Enquirer article from the year 2001 titled “I broke root bud dormancy and developed a specific chemical for leafy spurge control,” he noted that a massive effort by scientists and local, state, and federal land managers in the late 1990’s led to the implementation of a truly integrated weed management program. Dr. Lym reports that in the year 2020, leafy spurge is generally only a problem in isolated, remote areas (Lym, 1993).

This future solution to the leafy spurge problem in the West did not come about from the discovery of a miracle herbicide or from the establishment of one or two species of especially hungry insects. It came about because successful integrated programs were designed for specific land uses and locations, using many tools developed by researchers over the years.

You are those researchers and your job is not done

Keep in mind that leafy spurge (*Euphorbia esula*) has had over 160 years to adapt to living in North America. And well-adapted it is. Since the first record of the plant in Newbury, MA in 1827, it has moved across the United States and is found in all 48 contiguous states.

The GPAC-14 Leafy Spurge Task force has spent 15 years prioritizing leafy spurge research, extension/education, and coordinated control work. Scientists working on leafy spurge have been remarkably successful in combating this long-lived and tenacious weed.

Starting in 1979, a group of dedicated researchers, educators, and agency personnel have worked together to determine what leafy spurge research would best benefit the Great Plains and western States. An overview of progress up until 1979 showed research had been done on 24 herbicides, but many were not appropriate or effective for use against leafy spurge.

At that time, two insects had been cleared for release into the United States, with one more very close to release. The leafy spurge hawkmoth and a clear-wing moth had been released but had not established well or been particularly effective. The *Oberea* beetle was reported as being very close to release in 1979 and actually released in 1980.

Some research had been done on cultivation and cropping of leafy spurge, but was limited due to the perennial nature of the plant and limitations in the range, woodland and pasture settings where leafy spurge is generally found.

Every new herbicide released since 1979 has been tested against leafy spurge -- 11 new herbicides have been researched, with limited success in finding new, effective chemicals. In addition, research has included the use of different types of application equipment (rope wick, ATV’s), surfactants, combinations of herbicides, and variation in application timing and sequential timing of herbicide applications. All of this research has given land managers the best information available of the use of herbicides to control leafy spurge.

Reports from 1979 indicated that more than 25 species of *Aphthona* flea beetles that attacked spurge were waiting in Europe, along with 10 other potential insect biocontrol agents. While some of these insects were not appropriate or cleared for release into the United States, to date there are 9 insects that have been released into the United States, with 14 more currently undergoing testing in Europe. It is expected that all foreign screening will be completed within the next three years. Insects have established and scientists have seen a reduction in the density of spurge in some established sites. Research on plant pathogens is also showing promise.

Grazing of spurge with sheep and goats has given land managers an alternative control that can be effective and economical. Research in the use of competitive species is showing promise. Electrocution is showing less promise, but at least you're being creative.

Since 1979 we have seen an increase in research on the basic biology of leafy spurge, including genetic diversity and root bud dormancy. This research is aimed at getting a better understanding of the plant to more effectively control it.

Lots of research had been completed, more is currently underway, but keep in mind that our time traveller from 2020 tells us that poor management and use of only "politically popular" weed control techniques in the mid-1990s led to the overthrow of those espousing the "one control is best" philosophy.

There is an increasing interest in the research community, as well as from land managers, to tie all effective control programs together into an integrated approach for leafy spurge management. The GPAC-14 Task Force has been extremely effective in targeting specific research problems to solve real world problems. It must continue with this work. This can best be done by continuing the Leafy Spurge Task Force as a forum for scientists to meet, discuss, and plan research for the future.

Questions to be answered:

1. Are herbicides and biocontrol agents compatible?

2. Can biocontrol agents be established in areas with a long-term history of herbicide use?

3. Can herbicides be used effectively prior to release of biocontrol agents to aid in establishment?

4. Can herbicides be used after establishment of biocontrol agents without impacting the agents but causing further stress on the spurge plants and making insect stress more effective?

5. Can insects and diseases be used together more effectively?

6. Can native plants be used to compete effectively with leafy spurge after herbicide treatment, in combination with herbicide treatment, or after establishment of biocontrol agents?

7. Does sheep or goat grazing actually reduce spurge infestations, or just allow use of the plant?

8. Can we develop grazing systems for land managers who are managing specifically for leafy spurge control?

9. Can we develop effective controls in sensitive riparian areas?

10. Can fire really be used as an effective set-up treatment for better control with herbicides?

11. Do biocontrol agents cycle with the weed species, cause "good" spurge years or "good" bug years or will the insects reduce the spurge to an "insignificant member of the plant community?"

Research on some of these topics is underway. Other may still need to be addressed. Some may be totally irrelevant. It is imperative that these topics be discussed among GPAC-14 members during the Thursday group sessions and the results recorded.

Contrary to a recent news release, the imminent demise of leafy spurge is not a foregone conclusion based on the success of the *Aphthona* flea beetle. Some researchers firmly believe this. Others feel that several control methods will always be needed to keep spurge in check. Only good research and time will tell. These diverse opinions are what have made this Task Force effective over the years and will add to its continued success.

Always remember, the leafy spurge problem is not solved until it is not spreading and infesting more and more acres in the West and until the populations we have are suppressed. This calls for an integrated research and management approach.

Insects will not stop the spread of spurge, they may suppress infestations. Herbicides can stop the spread of spurge when used in an effective containment program but are not economical and often not particularly effective on large infestations. Sheep and goats will utilize spurge and may suppress it. When spurge has been suppressed, competitive vegetation may help to prevent a resurgence. A healthy plant community with proper grazing may prevent the infestation of spurge.

Landowners must be reminded that leafy spurge management is a long-term commitment that means looking for the plant in out of the way areas were wildlife, birds, man, or livestock may move it. Researchers need to be reminded that leafy spurge isn't just an interesting research topic, but an economic threat to Western lands. Land managers must have effective, economic solutions.

The working members of this Leafy Spurge Task Force have shown the effectiveness of working together to answer questions about leafy spurge and its control. You must be as effective in developing integrated weed management programs on leafy spurge.

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Adult emergence counts from soil samples and laboratory mating crosses of *Aphthona lacertosa* and *Aphthona czwalinae*

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Soil samples were collected in the fall of 1993 along transects which traversed several habitat situations over which these two species of *Aphthona* have established at a site in eastern North Dakota. Sampling was also done on two additional sites which were recently established. Numbers of adults emerging from these samples ranged from 36 to 410 per square foot. At the older site, the proportion of *A. czwalinae* emerging, based on coloration of hind femur and elytra shape, was determined for each transect point. These proportions ranged from 0 to 0.07. Sex ratios for both species appear to approach 1:1.

Adults emerging from these soil samples were paired in cages and observed for oviposition. Egg deposition patterns, total numbers laid and egg hatch were recorded. After the adults died they were sent to the USDA-ARS Systematic Entomology Laboratory at Beltsville for final determination of species. Confirmed pairings of female *A. lacertosa* with male *A. czwalinae* produce 50 eggs/female (9 to 86 / 6 prs.); only 8% of which hatched. Confirmed pairings of female *A. czwalinae* with males *A. lacertosa* produced 70 eggs/female (0 to 247 / 8 prs.); only 10% of which hatched. It was not possible to trace the development of emerged larvae. In contrast, successful interspecies crosses for *A. czwalinae* produced 294 eggs/female with 94% hatch (3 prs.) and for *A. lacertosa*, 168 eggs/female with 81% hatch (11 prs.).

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Molecular approaches to determine genetic diversity of weedy species and their application to biocontrol

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DNA-based molecular markers can provide information about introduced weedy species that could be beneficial to classical biological control efforts. Chloroplast DNA restriction fragment length polymorphisms (cpDNA RFLP) and random amplified polymorphic DNA (RAPD) analysis are two DNA-based marker techniques that can be used to provide estimates of an introduced weed's level of genetic diversity, its possible geographic origins, evidence of multiple introductions and hybrid zones, and potentially identify compatible biocontrol agent/weed relationships. Current criteria for selecting a weedy species as a target for biological control are primarily political and economic. DNA-based markers could be used as the basis for selection criteria by providing an accurate estimate of a plant's level of genetic diversity relative to other potential target species. The success of biological weed control efforts has been limited by the high levels of genetic diversity occurring in target weed species and the lack of biocontrol agent and target weed compatibilities. DNA-based markers can be used to increase our understanding of these factors and contribute to the success of biological weed control.

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Habitat analyses of spurge species from Europe using multivariate techniques

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Ordination analyses were used to examine the relationships between four European spurge species, twenty-one chemical and physical variable from soil layer A (top two inches) and soil layer B (greater than two inches in depth), the % cover of grasses and forbs, and eighteen field sites from Europe. Spurge species included *Euphorbia cyparissias* L., *E. lucida* Waldst. and Kit., *E. seguieriana* Neck, and *E. virgata* Waldst. and Kit. Chemical and physical variables analyzed from the soil included: pH, Ca, Mg, K, Na, Cu, Fe, Mn, Zn, NH_4-N, NO_3-N, soil matrix potential (SMP), Olsen P (P), $CaCO_3$, total Kjeldahl nitrogen (TKN), electrical conductivity (EC), % organic matter, % sand, % clay, and % silt. The field sites comprised of four xeric, six open mesic, four closed mesic (two with low levels of shading and two with high levels of shading), and four riparian sites were located in Italy, Switzerland, Germany, Austria, and Hungary.

Principal Components Analysis (PCA) was conducted first to examine the relationship between each of the eighteen field sites with chemical/physical variables in the two soil horizons an five habitat types. In summarizing the PCA results from soil layer A, Ca, Mg, K, Na, Fe, Mn, Zn, NH_4-N, NO_3-N, SMP, P, TKN, EC, % organic matter, % clay, and % silt increased as one progressed from dry to more moist habitat types, while Cu, pH. and % sand decreased. PCA Aces 1 and 2 for soil layer A were found to explain 36 and 12.5% of the environmental variation (i.e., variation due to chemical and physical variables measured from the soil, plus the weighting by habitat type; $P < 0.0001$ for both axes). Similarly, for soil layer B, Ca, Mg, K, Na, Fe, Mn, Zn, NH_4-N, NO_3-N, SMP, P, TKN, EC, % organic matter, % clay, and % silt increased as one progressed form dry to more moist habitat types, while $CaCO_3$, pH, and % sand decreased. PCA Axis 1 and 2 for soil layer B were found to explain 38.8 and 16.9% of the environmental variation ($P < 0.0001$ for both axes).

Detrended Correspondence Analysis (DCA) was used to examine the relationship between fifteen of the eighteen field sites (for which plant community data was taken and at least one of the four species was present), the percent cover of grasses and forbs, and the four spurge species. *Euphorbia virgata* was found to be associated with sites containing relatively high levels of grasses and forbs, with three of the five field sites (where this species was present) containing higher levels of forbs than grasses. In contrast, *E. se-*

guieriana was found to be associated with relatively low levels of grass and forb cover, with the two sites that contained this plant species showing higher levels of grasses than forbs. *Euphorbia lucida* was found to be associated with sites with relatively high levels of both grasses and forbs, with forbs dominating at two of the three sites in which this plant species was found. In contrast, *E. cyparissias* was found to be associated with low to high levels of grass and forb species, with grasses generally dominating the drier sites and forbs generally dominating the more moist sites. DCA Axes 1 and 2 were found to explain 27.2 and 21.8% of the variation in the separation of the four spurge species and the percent cover of grasses and forbs along the ordination axes.

Canonical Correspondence Analysis (CCA) was used to examine the relationship between the four spurge species, chemical and physical variables in the two soil layers, and fifteen of the eighteen field sites (in which at least one of the four spurge species was present). The more xeric sites, *E. cyparissias*, and *E. seguieriana* were associated with lower levels of moisture and higher levels of % sand, soil pH, and $CaCO^3$. In contrast, closed mesic and riparian field sites were generally associated with higher levels of moisture, SMP, and % clay for both soil layers A and B. CCA axes 1 and 2 in soil layer A were found to explain 36.9 and 28.6% of the variation, respectively, in the separation of the four spurge species, grasses, and forbs along the CCA axes ($P < 0.01$ and $P < 0.31$, respectively). CCA axes 1 and 2 in soil layer B were found to explain 35.7 and 25.5% of the variation, respectively, in the separation of the four spurge species, grasses, and forbs along the CCA axes (P , 0.04 and $P < 0.42$, respectively).-N, NO3-N, soil matrix potential (SMP), Olsen P (P), $CaCO^3$, total Kjeldahl nitrogen (TKN), electrical conductivity (EC), % organic matter, % sand, % clay, and % silt. The field sites comprised of four xeric, six open mesic, four closed mesic (two with low levels of shading and two with high levels of shading), and four riparian sites were located in Italy, Switzerland, Germany, Austria, and Hungary.

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Carbon allocation of leafy spurge following defoliation

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Leafy spurge (*Euphorbia esula*) is expanding in North America because it is competitive, because many large animals avoid it while grazing associated species, and because its native enemies were not introduced at the same time. Our objective was to determine how defolating leafy spurge and associated species affect their ability to gain and allocate carbon, an indicator of the competitive ability of a plant. We grew single plants of leafy spurge in pots with single plants of one of three species, the introduced rhizomatous Kentucky bluegrass (*Poa Pratensis*), the native bunchgrass Idaho fescue (*Festuca idaboensis*), and alfalfa (*Medicago sativa*). In a randomized block design (n = 4), leafy spurge plants and their neighbors in each pot were either: 1) defoliated, 2) not defoliated, 3) leafy spurge defoliated, neighbor not defoliated, or 4) neighbor foliated, leafy spurge not defoliated. Twenty-four hours after defoliation, we labeled these plants with the stable $^{13}CO_2$ isotope using small plexiglass chambers placed over the plants. Plants were harvested 1 and 3 days post labeling. Shoots and roots were separated, oven-dried, weighed, and ground. These samples were sent to an analytical laboratory to determine ^{13}C levels. Carbon uptake by shoots or allocation to roots of leafy spurge was not affected by the identity of neighbor species. However, carbon uptake by shoot s and allocation to roots were significantly reduced by defoliation. These reductions were similar whether only the leafy spurge was defoliated, or leafy spurge and its neighbor were defoliated, indicating that leafy spurge was unaffected by the status of the neighbor. Carbon uptake by alfalfa shoots was unaffected by defoliation. However, carbon allocation to alfalfa roots was minimal when the alfalfa plant alone, or the alfalfa and leafy spurge plants within a pot were defoliated. Carbon uptake by shoots and allocation to roots in Kentucky bluegrass, and especially Idaho fescue, were reduced by defoliation. Our results indicate that although leafy spurge gains and allocates carbon similarly when growing with different species, these species have significantly different responses to defoliation when growing with leafy spurge. Using carbon uptake and allocation as an indicator of competitive ability, alfalfa is most competitive, Kentucky bluegrass is intermediate, and Idaho fescue is least competitive with leafy spurge.

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The *Aphthona* pilot study

N. E. REES

The *Aphthona* pilot study consists of seven treatments and matching checks at four sites [Montana (2), Nebraska and North Dakota] and three treatments and matching checks at two sites [Colorado and Idaho]. The study was initiated in 1990 with *Aphthona nigriscutis* as the only test agent. This program studies the impacts on leafy spurge of three flea beetle release rates [150, 450, and 1350 beetles]. Variable studied at the sites include: 1) flea beetle establishment; 2) vegetation complex (a reflection of environmental conditions); 3) soil texture, composition, and aspect; 4) chemical and grazing history; 5) sun versus shade; and 6) density, robustness, and type of leafy spurge plants.

In 1991, *Aphthona nigriscutis* was recovered from 14 of 34 pilot study plots. In 1992, recovery increased to 22 plots. All 1991 established plots contained beetle in 1992. The second year following release [1992], fewer beetles were recovered per sweep at the plots with 450 beetles released than at the plots with 150 beetles released. On average, 1.8 times more beetles were recovered per sweep at the plots with 1350 beetles released than at the plots with 150 beetles released. The area occupied by the beetles averaged 2.32 times greater in the plots with 450 beetles released and 5.66 times greater in the plots with 1350 beetles released that in the plots with 150 beetles released. Leafy spurge plant height and flowering periods were visibly retarded in more than 80% of the plots from which beetles were recovered.

In 1992, *A. cyparissiae*, *A. flava*, and an additional *A. nigriscutis* treatment were added to three of the sites [Montana, Nebraska and North Dakota] at a rate of 450 beetles per species released. The purpose being to compare how the three flea beetle species perform under identical conditions.

In 1993, severe rain and hail storms strongly influenced many plots. Several Nebraska plots were under nearly one foot of water. In Montana, fields hit with hail storms lost the "bomb blast" appearance created by the beetles on the leafy spurge. Of the six new 1992 released, four established [two in Montana and two in Nebraska].

Information obtained in this study is still being processed. However, certain points are apparent. No insects have been recovered from any of the ten North Dakota plots in any sampling year, indicating unidentified detrimental conditions. Release of beetles in very dense spurge greatly reduces the possibility of establishment. Under ideal conditions, the first year following release of the gregarious flea beetles, a depression or "bomb blast" appears in the leafy spurge stand where plants are shorter in height and retarded in flowering. The second year, the canopy cover of leafy spurge decreases to approximately 2% over a limited area averaging 18 x 20 yds. The third year, this area expands to about 53 ×

59 yds. In the fourth year, the area averages 100 × 100 yds. with the beetle located in an area of roughly 500 yds. diameter. Each of the flea beetle species has its own preferred ecosystem. Flea beetle populations can be influenced by many factors including hail, intense trampling or grazing by large animals, or feeding by other insect species. These factors appear to reduce the gregarious habit of the beetles, as evidenced by their reduced "bomb blasts". Shade reduces establishment and population build-up of all three species studied. Some herbicides do not prevent beetle establishment or affect impact.

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A USDA plan to assist in field insectary establishment for biological control of leafy spurge

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The process of foreign exploration and specificity testing that has led to the importation and establishment of effective biological control agents has been long and diligent. Owing to USDA, ARS, Agriculture Canada, and certain state programs, APHIS has had the opportunity to implement biological control of leafy spurge.

APHIS has been involved with the project of implementation of biological control of leafy spurge since 1988. APHIS activities have centered around importation and release of USDA-approved biological control agents for leafy spurge. These releases have been accomplished in 15 states in areas infested with leafy spurge. The objective in releasing these natural enemies has been to initiate self-sustaining populations in classical biocontrol style of these beneficial insects over the broad area of leaf spurge infestation. By 1993, many insects released in field insectary sites (FIS) had reached populations that were ready to be harvested or collected and moved to other spurge locations in a continued redistribution effort.

Knowing that redistribution of natural enemies by man will increase the amount of dispersal of the insects and subsequent control of leafy spurge, APHIS has developed a plan to facilitate these efforts by State Departments of Agriculture and Cooperators. The plan is a three-phase activity which allows for a transfer of technology and management of leafy spurge field insectaries from APHIS to State Departments of Agriculture and cooperators.

Phase 1 (Introduction and establishment)

Objective: Introduction, release and establishment of exotic natural enemies in the United States.

Approach: After sufficient research abroad and locally, including host specificity testing, and consulting or planning with the States, exotic natural enemies of a specific weed will be imported and properly screened in quarantine and approved by USDA for field release, or acquired from USDA, Agricultural Research Service, personnel or other State Cooperators. These natural enemies will initially be released in small numbers at selected sites (Field Insectary Sites – FIS). The release sites would be well-defined and protected areas that are free of any pesticide applications and grazing. These sites will be limited in number depending on the availability of specimens collected and approved for release through the appropriate importation and permit procedures as required. These sites may be in several states or only one state; possibly they could be confined to only one county in any given state.

Roles: APHIS is responsible for importing or locally acquiring available natural enemies, clearing the organisms through quarantine when appropriate, and acquiring necessary permits. The initial release sites would be carefully selected by APHIS with the assistance of various State cooperators. APHIS has the main responsibility in Phase 1 and will track, protect, and maintain these critical sites for several years in order to promote natural population increases of a particular species. The natural enemies produced at such a location then become available for release into additional Phase 1 FIS for additional increase of population, or the natural enemies are made available for redistribution to all infested States, which activity constitutes Phase 2.

Timeline: The time required for Phase 1 between the initial introduction of a natural enemy and its increase in population density to levels considered sufficient for redistribution may be from 2 to 5 years, depending upon the species, the initial number of individuals released, reproductive potential, and other factors affecting population development.

Phase 2 (Collection and redistribution "to" states)

Objective: Establish "state" FIS in all weed-infested states collected from Phase 1 FIS.

Approach: Collect and redistribute the exotic natural enemies from Phase 1 into new FIS in all weed-infested States. Phase 2 releases would occur in each State that expressed interest and approved the establishment of each specific natural enemy. APHIS and the State will cooperatively determine the optimal number and location of the FIS for that State. The release sites will serve: (1) as the source of field-propagated natural enemies to be made available in 2 to 5 years for continued redistribution in Phase 3, and (2) as demonstration plots, showing the potential impact of the natural enemies on the targeted weed in that particular State.

Roles: The establishment of a Phase 2 FIS is a joint cooperative effort by APHIS and State Departments of Agriculture and/or other Cooperators. During Phase 2, APHIS will provide resources for the collection of the natural enemy out of Phase 1 FIS, and (working cooperatively with the State) select sites within each State for the release and establishment of those same natural enemies within "State" FIS. APHIS will be responsible for developing imited numbers of educational materials for landowners and the general public. These materials will be available for reproduction and distribution as necessary by the State cooperators, including the extension service. APHIS will provide technical information to the State and other cooperators in the form of actual training and training manuals for each specific weed program as needed.

Timeline: The time required from the initial releases in Phase 2 to the collection and redistribution will vary with the species of natural enemy, but it will be at least 2 years before any sizable numbers of individuals could be collected for redistribution purposes. These sites could be available indefinitely if host plant material prevails, or depending on how heavily the "State" FIS is used for collection purposes from year to year.

Phase 3 (Collection and redistribution "by" states)

Objective: Collect and redistribute natural enemies within the state from Phase 2 FIS.

Approach: Natural enemies collected from Phase 2 FIS will be redistributed within each state by the state or their authorized parties. These releases may be directed at the state, county, or landowner level for establishment throughout the state.

Roles: The state will be responsible for further collection and redistribution from Phase 2 FIS throughout the state. The establishment of additional FIS within each county and/or at individual landowner sites will be determined by the state Department of Agriculture and/or other cooperators. The actual collection and redistribution of natural enemies from the FIS developed in Phase 2 is the sole responsibility of the State Department of Agriculture and/or other cooperators. At this time, commercial insectary operations and the general public could approach the state for approval to collect and redistribute at their own expense, or commercial groups could ask for starter culture material for their own private FIS establishment for further distribution for profit. Commercial groups be given the authority by the states to the sole manager of collection and redistribution efforts within that state. The redistribution efforts could be: (1) supported within internal state or county resources, or (2) be based on a "user fee" charged by the state, or (3) be turned over to commercial biological control specialist, who could be afforded the opportunity to collect and sell within that state to county weed board or private landowners.

Timeline: Phase 3 could be continued until all counties have established adequate number of FIS with further occurring under natural dispersal, or through wide redistribution efforts by the county personnel, commercial groups, or landowners themselves.

The subsequent success of *Aphthona* spp. populations buildup and spurge suppression have caused all of us involved in the biological control aspects to immediately develop plants to maximize the benefits of these biological control agents. In 1994, development of Phase II insectaries and broad redistribution from state field insectaries has occurred in CO, MN, MT, ND, and WY. In 1994, APHIS has augmented Phase I FIS with redistribution of U.S. collected *Aphthonas* to 15 states.

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The influence of leafy spurge genetic diversity on the reproductive success of leafy spurge gall midge (*Spurgia esulae*)

MARTHA L. ROWE, SCOTT J. NISSEN, DONALD J. LEE, ROBERT A. MASTERS, and RODNEY G. LYM

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The leafy spurge gall midge, *Spurgia esulae*, was introduced into the U.S. in 1986 and has increased significantly in number since that time. Field cage studies with seven leafy spurge biotypes indicated that the number of galled stems and larvae per gall varied with biotype. These data suggest that biotypic differences can have a significant influence on the reproductive success of the gall midge. Restriction fragment length polymorphism (RFLP) analysis of chloroplast DNA (cpDNA) has been used to assess genetic diversity among the seven biotypes. Twelve restriction enzymes and six mung bean cpDNA probes were used to detect variation in the chloroplast genome. Twenty-seven of the probe/enzyme combinations revealed polymorphisms that were used to distinguish the biotypes. Six of the seven biotypes could be separated from each other by their unique combination of polymorphisms. The two biotypes with the fewest number of larvae per gall in the field study were found to have identical cpDNA patterns. These data suggest that genetic variation in leafy spurge can influence the reproductive success of biocontrol agents and that neutral DNA markers could facilitate biocontrol of non-endemic weedy species by providing a means to match agents with acceptable target genotypes.

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Evaluation of season-long mechanical and low herbicide input treatments for leafy spurge suppression

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Conventional management of leafy spurge may be inappropriate in certain situations. Other control options are needed for spurge patches in trees or along waterways. Four alternative control strategies were studied for leafy spurge suppression effectiveness. The methods tested were continuous black plastic smother, mowing at 2 and 4 week intervals, and 0.11 kg/ha^{-1} of 2,4-D (0.1 X rate) applied at 2 week intervals 10 times during the season. These control methods were compared to control (no treatment) and a 1 X rate (1.12 kg/ ha^{-1}) of 2,4-D. In 1992 treatments were applied to 12m x 12m plots. In 1993 plots were split so that half were treated and half were untreated. Plots were sampled at least once every 4 weeks and treatments were applied after each sampling date, as appropriate. Sampling occurred from late May to early October and included determination of leafy spurge stem density, leafy spurge biomass, and associated vegetation biomass.

Table 1. Leafy spurge density and biomass, and associated plant biomass on three sampling dates in 1992.

	EPHES Density (stems m^{-2})			EPHES Biomass (g m^{-2})			Associated Plant Biomass (g m^{-2})**		
Treatment	5-28*	7-23	9-17	5-28*	7-23	9-17	5-28*	7-23	9-17
Control	227	318	203	96	136	122	49	118	173
2,4-D 1X	232	223	150	101	31	41	56	104	192
Smother	230	138	88	87	40	27	62	51	tr
Mow 2wk	315	225	62	104	19	13	66	36	34
Mow 4wk	241	341	73	96	31	5	43	34	52
2,4-D 2wk	140	71	43	78	25	6	67	238	206
Isd (0.05)	ns	153	99	ns	38	42	ns	58	47

*Sampling prior to treatment
**predominantly *Bromus inermis* and *Poa pratensis*

In 1992, all treatments reduced leafy spurge density and biomass (Table 1). Smother and mowing treatments decreased associated plant biomass while the 2,4-D 2-week treatment had increased associated plant biomass production. No treatment had an affect on stem density that carried over into 1993. However, all treatments had less leafy spurge biomass that the control when evaluated in May 1993. All treatments prevented seed production the year of treatment. The best treatment was 2,4-D 2-week because of good leafy spurge suppression and grass production.

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A microcage method for studying *Aphthona* spp. flea beetles in the field

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Aphthona flea beetles are used to facilitate suppression and control of leafy spurge. The root-feeding larvae are the most destructive stage in the life cycle. Often, sweeps for adults are conducted in the release area after one or more years to determine if the insects have established. Unfortunately, this technique does not provide information about the number of larvae present and their impact on leafy spurge. A microcage technique was developed to help answer questions about establishment and overwintering of the *Aphthona* larvae in natural field conditions.

A microcage consists of a 15 cm dia. × 15 cm length segment of PVC pipe that was centered over a leafy spurge stem and hammered into the soil to a depth of 13 cm. A fine-mesh screen is fastened to the top of the pipe segment and supported by a wire flag. Microcages were located on a southeast-facing slope in northeastern South Dakota at three topographic sites: hilltop, midslope, and toeslope. Fifty adult *A. cyparissiae* or *A. nigriscutis* flea beetles were released in each of 60 cages (40 *A. cyparissiae* and 20 *A. nigriscutis*) in 1992 and 35 (30 *A. cyparissiae* and 5 *A. nigriscutis*) cages in 1993. Soil from the microcages was harvested by unearthing the pipe with the soil core intact. In 1992-1993, four cages were harvested in the fall and 10 were harvested in the spring. In 1993-1994, number of cages harvested was dependent on species and topographic site. Larvae were recovered from the soil by sieving and using the Berlese method. In late May screens were replaced over the cages to be monitored for adult emergence.

The use of the microcage technique allowed for the successful recovery of *Aphthona larvae* and adults. Larvae were recovered in late fall, 1992 with numbers ranging from 0 to 44 per cage. The larvae were small (2 mm length) and head capsule measurements indicated that the larvae were first or second instar. The April 1993 sampling also was a success with numbers ranging form 0 to 62 larvae per cage. Larvae in spring-harvested cages were predominantly third instar. Analysis of number of larvae recovered in the fall versus spring indicated that there was little or no overwinter mortality in 1992. No adults were recovered in microcages in 1993. In 1994 adult *A. cyparissiae* were recovered in two cages in late June. Monitoring will continue through the 1994 summer. This microcage technique may be an extremely useful research tool to answer questions about *Aphthona* and other root-feeding insects in natural conditions.

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Potential biological control agents for leafy spurge found in southern France

R. SOBHIAN

Numerous natural enemies have been found in southern France on *Euphorbia* spp., during 1992 and 1993. Among them, the following six species seem to be promising for biological control of leafy spurge in the USA:

1. A gall midge, *Spurgia capitigena* found on *Euphorbia esula*, in under study in Bozeman, MT. Its host specificity also is under study by M. Cristofaro in Rome and by myself in France. So far, there have been no surprises and the first weed insect from France may be released in the USA during 1995.

2. A gall mite, *Phyllocoptes nevadensis*, found on *E. cyparissias*. Preliminary host specificity tests showed that *E. esula* from USA is a susceptible host for the mite, while poinsetia, croton, and *E. corollata* were not attacked.

3. A leaf beetle, *Aphthona occitana*, found on *E. segetalis* and *E. characias*. According to Dr. M. Biondi, the taxonomist in this group, this species has been reported on *Euphorbia* spp. in Europe, and should be specific to the genus *Euphorbia*.

4. and 5. Two new species of Agromyzidae, *Liriomyza* n. sp. and *Ophiomya* n. sp. According to K.A. Spencer, only 4% of the known Agromyzidae are polyphagous. Thus the possibility that the host range of these species is restricted to the genus Euphorbia is very high. *Liriomyza* is a leaf miner; *Ophiomya* is a stem miner.

6. A Tortricide moth, *Acroclita subsequana*, found on *E. characias*. The species has been reported only from *Euphorbia* spp. and has a very wide distribution, from England through Europe to the former USSR (it is under study by L. Fornasari).

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Insects for leafy spurge control

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Leafy spurge is a noxious long-lived weed on the Great Plains of the United States and the Prairie Provinces of Canada. New infestations are continuously occurring throughout the United States with the major economic impact in the northern Great Plains. A recent study by North Dakota State University estimated the cost of leafy spurge to the economics of Montana, North Dakota, South Dakota, and Wyoming will be $144,350,000 per year by 1995. Chemical control, which is only partially effective, is expensive and not suitable for many leafy spurge infestation sites (i.e. shelter belts, land with high water tables, and near open water). Cattle cannot use leafy spurge infested rangeland.

In its native habitat of Europe and Asia, naturally occurring enemies prevent leafy spurge from becoming a problem. Importation and use of highly host specific Eurasian insects on the northern Great Plains offers considerable potential for leafy spurge control without risk to wildlife, endangered plants, or water resources.

Twelve species of Eurasian insect biocontrol agents which selectively attack leafy spurge have been cleared by federal, state and Canadian agencies for release to control leafy spurge in the United States. These insects have dramatically reduced weed numbers at several experimental research sites in the United States and Canada.

The USDA/ARS Biocontrol of Weeds Research Unit in Sidney, Montana, has established research sites in Montana and North Dakota to study the establishment and population dynamics of introduced flea beetles in the genus *Aphthona*. The comparatively fast developing flea beetles have stimulated interest in the biocontrol of leafy spurge and shown biological control's capabilities. Other introduced species such as *Oberea erythrocephala* and *Chamaesphecia spp.* may have an important impact on the control program, but it is still too early to make that judgment. All insect introductions are of species whose lives are linked to their host, leafy spurge, and will never become a problem.

Hyles euphorbiae. The leafy spurge hawk moth species was first introduced into the United States in 1964. The hawk moth larvae feed on leafy spurge foliage, however an insect virus associated with the species has prevented it from reaching high population levels. It is not known whether the moth was introduced with the virus or was infected in North America. The impact on the plant from the larval foliage feeding appears to be minimal. Adult hawk moths are strong flyers and are known to cover long distances.

Hyles euphorbiae may become widely distributed and over a period of years may impact leafy spurge in conjunction with other biocontrol agents.

Chamaesphecia tenthrediniformis. The larvae of this clear-wing moth bore into the roots of leafy spurge. This species was introduced in 1975 and is not thought to have established due to its high degree of specificity and the lack of the host biotype in North America (at least at sites where *C. tenthrediniformis* were released).

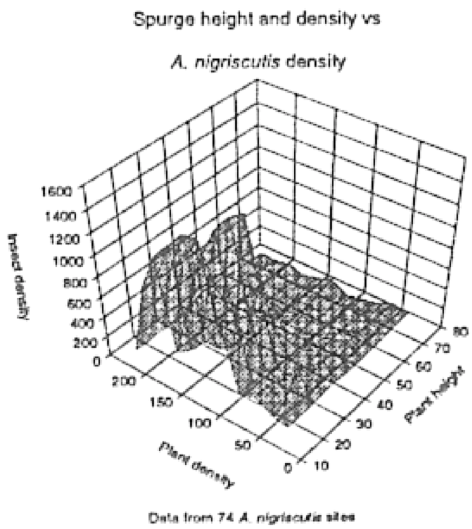
Oberea erythrocephala. This leafy spurge long horned beetle is well established in Montana. First released in 1980, it has taken approximately 10 years to develop a damaging population. The best known release site is along a river in Stillwater Co., Montana. This species is thought to require a leafy spurge stem diameter of 2.5 mm or more to successfully invade a plant. Many of the leafy spurge plants in the area of the *Oberea* infestation fit this stem diameter restriction. I believe habitats producing spurge of this stem diameter are limited, but the beetle fits into an important niche for wide area leafy spurge control by a variety of introduced biocontrol agents.

Spurgia esula. This leafy spurge gall fly is well established in North Dakota and to a lesser extent in Montana. It is effective in reducing seed production; however, a native parasite in North Dakota builds up after the first generation in the spring and reduces the effectiveness of the biocontrol agent. Reduction in the production of leafy spurge seeds will assist the overall control program and reduce the competitive advantage of the plant. Vegetative reproduction will continue to spread the weed at a somewhat reduced rate where *S. esula* is active.

Aphthona flava. First released in the United States in 1985, populations in the US and Canada have multiplied at numerous sites. We are only now beginning to understand the niche requirements of this species. Where it has developed high populations, *A. flava* is a good control agent, reducing spurge to a few short stems. Many thousands of the beetles have been collected from Canada and a site near Bozeman, Montana for redistribution.

Aphthona cyparissiae. Released in the United States in 1986, this species has established at many sites in several states. The premier site is in Saskatchewan, Canada, located about 70 miles north and east of Plentywood, Montana. Here, *A. cyparissiae* has reduced leafy spurge from a large area and has increased in numbers and spread to all neighboring leafy spurge infestations. The figure below shows the data gathered on characteristics of sites where *A. cyparissiae* has developed good colonies. Place new sites where leafy spurge average height is 50 cm or more.

Aphthona czwalinae. Released in 1987, it is now established in Montana and North Dakota. Because of a mix-up in identifications, a mixed population of *A. czwalinae* and *A. lacertosa* exists in eastern North Dakota. I have not seen the release sites in North Dakota and, thus, do not know the degree to which the two species are mixed. In the future, *A. czwalinae* and *A. lacertosa* may well occupy an extensive area of leafy spurge infestations as the plant moves eastern into the higher in fall areas in Minnesota and Wisconsin. It is still too early to predict the best habitat for *A. czwalinae*. We may not have yet placed *A. czwalinae* where it will do best. *A. lacertosa* appears to be the more abundant species where the two occur together.



Aphthona nigriscutis. This flea beetle has increased in numbers and controls leafy spurge at limited sites in Canada and the United States. It is well adapted to the dryer portions on the northern Great Plains. *A. nigriscutis* has been established on sites with a variety of soil types in Montana and North Dakota (see figure below). This species prefers sites where leafy spurge plants are 30-45 cm tall and with a density in the range of 150 - 200 plants per square meter. These preferences are restrictive; however, many sites with these conditions occur on the northern Great Plains. Multiple biocontrol agents will probably be required to gain leafy spurge control from the top of the hill to bottoms of ravines.

Aphthona lacertosa. This black flea beetle cleared in 1993 is already well established in North Dakota and in Canada. This species seems to prefer sites where the grass can grow taller than the spurge. It may act as an important control agent where the rainfall is >400 mm.

Dasineura* nr. *capitigena. Gall fly cleared for release in the United States in 1991, this species has not been released. It is expected to reduce leafy spurge seed production in a manner similar to *S. esula*.

Aphthona abdominalis. Small multi-voltine flea beetles first released in 1993. It will take several years to determine if it will establish in the United States and impact leafy spurge abundance.

Chamaesphecia hungarica. Clear-winged moth cleared and released in 1993. It will be some years before establishment can be confirmed and impact accessed.

The biological control of leafy spurge research program has provided the foundation on which wide area control will occur in both the United States and Canada. This research program has been conducted by The **Agricultural Research Service** of the U.S. Department of Agriculture and **Agriculture Canada**. The introduced biocontrol agents, coupled with new potential agents being tested by the ARS in France and the IIBC in Switzerland will have a major impact on leafy spurge abundance in North America. Dr. Peter Harris and I believe many of the concerns about the weediness of leafy spurge will be reduced in the next 10-15 years. We will not have eliminated leafy spurge within the period, but the impact of biocontrol and the resultant reduction in the plant's weediness will turn weed concerns to other plant problems. It would be worthwhile at this time in the research program to look in Eurasia for additional *Aphthona* species occurring in a wide range of habitats (from xeric to mesic sites and shady area). The momentum of foreign exploration and testing should be continued now with the interest in the United States and Canada. Farmers and ranchers see the potential of biological control. The support for the program has been gratifying from this group and from federal and state land managers.

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Effect of imazapyr, glyphosate, and naphthalene acetic acid (NAA) on leafy spurge adventitious shoot bud growth and development

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Leafy spurge maintains established stands through vegetative reproduction from adventitious shoots buds located on the crown and roots. The ability to manipulate these buds is essential to the development of long-term management strategies. Glyphosate can induce release of adventitious shoot buds from dormancy. Imazapyr has been observed under field conditions to have a similar effect. This study was conducted to evaluate the effects of Imazapyr and glyphosate on leafy spurge adventitious shoot bud growth and determine if they can overcome the effect of naphthalene acetic acid (NAA). NAA, a synthetic auxin, is an excellent inhibitor of leafy spurge adventitious shoot bud elongation and is not metabolized as easily as its endogenous counterpart, indole acetic acid (IAA). Six month old flowering plants growing in 6" diameter by 30" tall tubes were sprayed wither either 1.12 kg ha^{-1} glyphosate/X-77, 0.84 kg ha^{-1} Imazapyr/X-77, or 0.25% v/v X-77 alone. Plants were allowed to grow in the greenhouse for 8 DAT. Top growth was removed and root systems were chilled for 14 d at 5°C to simulate overwintering. The roots were then dissected into 10 cm segments, each containing five buds. Secondary treatments (water or NAA) were applied through solutions in microfuge tubes placed on the proximal end of the segment. Mean bud growth after 12 d was 0.6, 3.3, and 14.2 mm for Imazapyr, glyphosate, and control segments treated with water. Treatment with NAA reduced average bud growth to 0.5, 1.0, and 3.5 mm, respectively. Differences were seen in the distribution of growth along the segments. The first bud closest to the proximal end of the segments from control plants averaged 61.0 mm growth at 12 d, while the other four buds averaged 6.2, 1.7, 0.8, and 1.2 mm bud growth at 12 d. Bud growth for glyphosate treated plants was 7.6, 3.1, 2.7, 2.0, and 1.2 mm at 12 d for buds 1 to 5 respectively. Glyphosate reduced total bud growth and evenly distributed growth among the five buds. Buds originating from plants treated with Imazapyr did not elongate, regardless of secondary treatment. Glyphosate delays or reduces total bud elongation, but also released more buds from their quiescent state.

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The establishment, increase, and impact of *Aphthona* spp. (Chrysomelidae) on their host, leafy spurge (*Euphorbia esula*), in Fremont County, Wyoming

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Flea beetles have been released at over 100 locations in Fremont county, Wyoming, from 1990 through 1994 for the biological control of leafy spurge. One site in particular has been the focus of the research. The site of emphasis is referred to as site 3.

In 1990, approximately 2,750 *Aphthona nigriscutis* beetles were released in site 3. Feeding of *Aphthona nigriscustis* in site 3 had eliminated 5,281 square feet of leafy spurge in 1993 and 56,410 square feet in 1994. Elimination of leafy spurge increased ten fold over the two-year period. A degree day model was set up for the emergence of *Aphthona nigriis* based on 1993 and 1994 data. Also, a sweep net population graph was developed for beetles collected in a 36-foot-square sampling area from 1993 to 1994.

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The role of livestock in integrated leafy spurge management

JOHN W. WALKER, SCOTT L. KRONBERG, SAUD L. AL-ROWAILY and NEIL E. WEST

The concept of shifting paradigms is presently a hot topic for improving management and human effectiveness. We believe this idea of examining and critically evaluating our paradigms can result in major improvements in our dealing with noxious weeds such as leafy spurge. Steven Covey a current guru in management theory and author of "Seven Habits of Highly Effective People" depicts paradigms as being analogous to maps. Maps represent our understanding of the spatial relationship of different locations just as paradigms represent our understanding of the relationships that determine how nature works. Our effectiveness or ability to reach our goals is dependent upon the accuracy of our paradigms or maps. If your paradigm is inaccurate then better technologies will simply move you in the wrong direction faster just as having a faster car will only move you away from your intended destination faster if the map is wrong.

In science significant breakthroughs have always been breaks with old ways of thinking. This line of reasoning is self evident, but the hard question is how do we recognize when it is time to change paradigms?

Covey suggests two tests:

First, is your present way of thinking solving your problem? That the area infested with leafy spurge is doubling every the 7-10 years in spite of significant control efforts would suggest the answer is no.

Second, does your present paradigm result in dilemmas? By this question, Covey means are the solutions suggested by your current paradigm incompatible with your long-term goals. While there are many goals or desired conditions for rangeland, its use for profitable livestock production is a predominant one. Because the cost of controlling leafy spurge on rangelands is often greater than the value of the land, there is an obvious dilemma. Furthermore, in a society that is increasingly suspicious of agri-chemicals, the broadcast use of herbicides on the hundreds of thousands of infested acres will not be acceptable particularly if that land is in the public domain.

Thus, it appears that according to these two tests it is time to change paradigms. We suggest that it is time to stop considering leafy spurge as a noxious weed and instead consider it as a plant that is extremely competitive and can displace other species in many plant communities. It may appear that we are taking the easy out by denying that a problem exists; however, this is not what is being suggested. The competitiveness of leafy spurge has often been attributed to its extensive root system and prolific seed production. However, the real advantage of this plant is that in North America there are few pathogens or herbivores (invertebrate or vertebrate) that feed on it. It has been shown that when herbivores are found that feed on leafy spurge, it quickly loses its competitive advantage. We have shown that goats display a preference for leafy spurge compared to other herbaceous species in the community and that sheep, although they show a relative avoidance, will consume leafy spurge. We suggest that it is time to shift paradigms and rather than try to change the landscape to adapt to our management we should adapt our management to suit the landscape. We are not suggesting that herbicides should not be used in certain situations; however, we are suggesting that the areas where they are appropriate is limited. We believe there are currently ample herbivores available to make use of leafy spurge converting it to food and fiber products and that such an approach should not be viewed as a last resort when all other options are exhausted. We believe that ranchers should realize they are land managers and livestock are a tool for harvesting solar energy stored in the form of plant biomass. As with any job, it is important to pick the appropriate tool for the job.

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Factors affecting leafy spurge preference by livestock

JOHN W. WALKER, SCOTT L. KRONBERG, SAUD L. AL-ROWAILY and NEIL E. WEST

Consumption of leafy spurge by ruminants appears to be primarily the result of post-ingestive consequences received by the animal. We hypothesize that phyto-chemicals in the plant cause varying degrees of gastrointestinal distress in animals and thus regulate consumption.

Post-ingestive consequences vary according to the level of aversive phyto-chemicals and the ability of the animal to denature these phyto-chemicals. Management of leafy spurge using small ruminants will be most effective if these animals can be induced to show a preference for leafy spurge relative to other plants in the community. Studies using sheep and goats have been conducted at the U.S. Sheep Experiment Station since 1989 to determine factors that regulate post-ingestive consequences and thus preference for leafy spurge. These studies have involved small pasture grazing trials, pen feeding trials, and aversion studies. The goal of our research is to discover ways to manipulate either the grazing animal or the leafy spurge plant and cause leafy spurge to become a preferred forage. Plant factors that effect preference for leafy spurge include location and nitrogen fertilization. Sheep preferred leafy spurge in North Dakota compared to Idaho and fertilized compared to unfertilized. Animal factors that affect preference include species, physiological condition and experience. Goats consume spurge more readily than sheep demonstrating a positive relative preference while sheep although they will consume leafy spurge generally show a relative avoidance. Lactating compared to dry ewes consume more spurge. We hypothesize this is caused by higher levels of prolactin in lactating ewes, which may partially relieve the aversive response. Finally, experienced sheep show a higher preference for spurge than native sheep.

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Recovery of leafy spurge seed from sheep manure

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Sheep are used to control several noxious weeds. However, if sheep graze noxious weeds when seeds are maturing they may help disperse seed. We recovered leafy spurge (*Euphorbia esula*) seed from manure of sheep grazing an Idaho fescue (*Festuca idahoensis*) rangeland infested with leafy spurge. Manure from four yearling Targhee ewes grazing three separate pastures was collected from late June until mid-August 1993. After air-drying, washing, and weighing, we estimated the number of spurge seeds (g^{-1}dry weight) in manure. We also estimated the number of leafy spurge seeds (m-2) before sheep grazed each pasture. In the first pasture, there were 647 spurge seeds m^{-2} on 27 June. We recovered 0.18, 0.40, and 0.14 leafy spurge seeds g^{-1} of manure 3, 11 and 16 days afterward, respectively. On 14 July there were 608 leafy spurge seeds m^{-2} before sheep grazed the second pasture. Three and 11 days later, we recovered 0.52 and 0.41 leafy spurge seeds g^{-1} of manure. On 29 July, the third pasture had 226 spurge seeds m^{-2}. Two and ten days later we recovered 0.06 and 0.07 seeds g^{-1} of manure. On 14 August, we recovered less than 0.01 seeds g^{-1} of manure. Sheep grazing leafy spurge consumed most of the seed produced in each pasture. Some of that seed passes through the animal, remains viable, and thus enhances the dispersal of the weed.

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Herbicide and fire effects on leafy spurge density and seed germination

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Where dense stands of leafy spurge (*Euphorbia esula*) have become established in Northern Great Plains rangelands, native plant communities have been severely impacted. A spring or fall prescribed burn, a single application of picloram plus 2,4-D, and a combination of fire and herbicides were evaluated as techniques to reduce stands of leafy spurge. A spring burn with or without a fall herbicide application was the most effective treatment for reducing leafy spurge seed germination. Herbicides with or without burning were most effective in reducing leafy spurge stand density. Picloram plus 2,4-D applied in the fall followed by spring burning provided the best control of leafy spurge density and seed germination on the Little Missouri National Grassland.

Leafy spurge (*Euphorbia esula*) is a deep-rooted, Eurasian perennial forb that thrives in a wide variety of habitats throughout the northern United States and southern Canada. In the Northern Great Plains, leafy spurge occupies over 1.1 million ha (Dunn 1979). Leistritz *et al.* (1992) estimated the annual regional net economic impact from leafy spurge infestations to be about $75 million when impacts on ranch incomes and regional economies are considered.

Leafy spurge spreads rapidly from seed and by an extensive underground root system (Watson 1985). A single leafy spurge seed stalk can produce up to 150 seeds per year. At maturity, seeds are expelled up to 4.6 m when the ripe fruit dehisces (Bakke 1936). Most seeds germinate the following spring when air temperatures reach approximately 28°C (Messersmith 1983). However, seeds may remain viable in the soil as long as 8 years

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[1] Headquarters is in Fort Collins in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit in Rapid City, in cooperation with the South Dakota School of Mines and Technology.

(Selleck *et al.* 1962). Thus, for long-term control of leafy spurge: treatments must be repeated annually for at least 8 years to prevent reinfestation from seed and regrowth from crown buds and adventitious buds on the deep root system (Watson 1985).

The depth and longevity of the leafy spurge root system, along with its ability to reproduce vegetatively, make this plant very persistent (Coupland *et al.* 1955). Leafy spurge's long roots grow horizontally and invade new areas; they also produce buds and establish new growth centers (Raju 1985). Further, the production of these buds is enhanced by injury. Root systems have lived up to 6 years (Selleck *et al*. 1962), and they have the capability of producing new shoots from various depths and from root fragments (Messersmith 1983).

Leafy spurge can generally be controlled with herbicides (Chow 1984, Hickman *et al.* 1990, Lym and Messersmith 1985b); however, treatment success can vary from year to year. The cost effectiveness of chemical treatments also varies with time, area treated, and the herbicide used (Lym and Messersmith 1983, 1990). Picloram provides the best long-term control of leafy spurge on grasslands, but the dosage required is often not cost-effective (Bakke 1936, Lym and Whitson 1991). Applying picloram annually at 0.28 kg/ha or picloram at 0.28 kg/ha plus 2,4-D at 1.1 kg/ha are the most effective methods for controlling leafy spurge (Lym and Messersmith 1983). Chemical treatments have to be repeated periodically due to reinfestation from seed reserves in the soil and from crown and root buds. Therefore, a low-cost treatment or series of treatments that control top growth and inhibit seed germination would reduce the spread of this noxious weed.

Limited research has been conducted to determine the effects of herbicides on germination of leafy spurge seed. Bowes and Thomas (1978) reported that soaking leafy spurge seeds in picloram did not inhibit germination. The influence of herbicides combined with burning treatments on leafy spurge density and seed germination has not been documented.

Although little research has been conducted on the effects of prescribed burning on leafy spurge, fall burning in western North Dakota reduced its frequency (Dix 1960). Plant seeds are generally tolerant of heat (Daubenmire 1968), but given higher temperatures associated with heavy fuel loads and longer burn times, some seed mortality can be expected (Wright and Bailey 1982). Fire can also be used as a follow-up treatment to herbicides under the premise that sprouting induced by burning will further deplete carbohydrate reserves of already damaged plants. Thus, the objective of this study was to evaluate the effectiveness of herbicides and fire, applied alone or in combination, in reducing leafy spurge density and seed germination.

Study area

The study was conducted on the Little Missouri National Grassland in southwestern North Dakota, which is administered by the USDA Forest Service. The area is approximately 30 km northeast of the town of Beach. Precipitation at Beach averages 38 cm annually, 77 percent % of which occurs between April and September (National Oceanic and Atmospheric Administration 1990). The dramatic expansion of leafy spurge on the Little Missouri National Grassland is a serious concern (McIntyre 1979).

Two study sites were established: an upland site in the East Twin Butte Allotment, and, approximately 8 km northeast, a floodplain site in the Wannagan Creek Allotment. Plant species present on the East Twin Butte study site in addition to leafy spurge were big bluestem (*Andropogon gerardii*), little bluestem (*A. scoparium*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), and buffalo grass (*Buchloe dactyloides*). Besides leafy spurge, the Wannagan Creek study site had remnants of big sagebrush (*Artemisia tridentata*) and silver sagebrush (*A. cana*), western wheatgrass, needle-and-thread (*Stipa comata*), and green needlegrass (*S. viridula*). (Great Plains Flora Association [1986] is the authority for common and scientific names.)

Methods

Twenty-one 15.2m^2 plots were delineated on each study site in May 1985. The design was a randomized complete block, where plots were arranged in 3 rows of 7 plots each in dense, relatively uniform stands of leafy spurge. Treatments were randomly assigned within rows. Each plot was separated by a 3m border on all sides, and each study site was fenced to prevent livestock grazing during the study. Treatments tested to determine which combination of burning and herbicide best controlled leafy spurge included:

1) herbicide only applied in the spring
2) herbicide only applied in the fall
3) herbicide applied in the spring followed by a fall burn
4) herbicide applied in the fall followed by a spring burn
5) spring burn only
6) fall burn only
7) untreated control.

The herbicide treatment was a mixture of 0.28 kg of picloram and 1.1 kg of 2,4-D, applied in 470 liters of water per hectare. The herbicide mix was applied by a certified applicator using a low pressure (2.9 to 5.8 kPa) pickup-mounted sprayer. Spring and fall herbicide treatments were applied 19 June and 15 September 1985, respectively. Backing fires (where the fire moves against the wind) were used on the burn treatments on 19 September 1985 and 4 May 1986. A combination of mowing and commercial fire retardant was used to contain the fires within designated treatment boundaries.

Leafy spurge seed germination

Germination rates of leafy spurge seed in the upper 10 cm of soil and in the soil surface mulch were compared among treatments. Nine systematically spaced soil samples were collected from each plot with a 30cm^2 bulk-density sampler to a depth of 10 cm. Samples were placed in individual plastic bags for transport and storage. Soil samples were kept moist and in cool storage (<30°c) until the seeds were separated from the soil and surface mulch. Within 5 days of collection, 200 leafy spurge seeds were randomly selected from the 9 composited samples from each plot. The seeds were placed in a germinator programmed to alternate between 20 and 30°C; each temperature period lasted 8 hours. The germination trial was conducted for 30 days. The best leafy spurge germination can be expected with alternating temperatures in the range of 20 to 300 degrees C for at least 14 days (Messersmith *et al*. 1985). Seeds were examined daily for appearance of the hypocotyl an indication of germination.

Leafy spurge density

Density of leafy spurge stems in each of the plots was evaluated in early July 1986. The number of leafy spurge stems was counted in 20 0.1-m^2 quadrats randomly positioned in each plot. Stem counts were summarized and converted to number/m^2.

Statistical analysis

test (Steel and Torrie 1960). Square root transformation was used to control heterogeneous variances. Differences among treatments in number of seeds that germinated and stem densities were evaluated by two-way analyses of variance (Steel and Torrie 1960). Mean differences were considered significant at the 5% probability level according to Tukey's w -procedure (Steel and Torrie 1960). Transformed data were converted to actual percent germination for presentation.

Results and discussion

Leafy spurge seed germination

Germination of leafy spurge seeds collected from both upland and floodplain sites ranged from <1% to nearly 5%. Other researchers have reported germination rates between 51% and 84% (Messersmith *et al*. 1985), although Selleck *et al*. (1962) reported germination rates of < 1% to 44%. The variability in germination could be due to genetic differences in seed dormancy or viability, environmentally induced dormancy, or an after-ripening phenomenon (Messersmith *et al*. 1985). Genetic differences within sites in our study are unlikely, since it is likely the plants all have a similar genetic makeup; however, both dormancy and after ripening may have contributed to low germination rates.

In spite of the low germination rates observed in our study, rates varied among seasons and treatments (table 1). All treatments, except the spring herbicide application, significantly depressed leafy spurge seed germination relative to the untreated plots on both upland and floodplain sites. Fall herbicide + spring burn or a spring burn alone were the most effective treatments in reducing leafy spurge seed germination; both of these treatments reduced leafy spurge seed germination by over 95% compared to untreated plots. Spring herbicide + fall burn was more effective in reducing leafy spurge seed germination than either spring or fall herbicide application without fire. Fall herbicide provided a slight but significant reduction in germination compared to no treatment, as did fall burning alone.

Table 1. Germination (%) of leafy spurge seed collected on two Little Missouri National Grassland study sites following herbicide and burn treatments.[1]

Treatment	Study site: Floodplain	Study site: Upland
	Germination (% ± standard error)	
Fall herbicide2 + spring burn	0.17 ± 0.08[a]	0.80 ± 0. 12[ab]
Spring herbicide + fall burn	0.90 ± 0.20[ab]	1.33 ± 0.32[bc]
Spring burn	0.23 ± 0.08[a]	0.73 ± 0.11[ab]
Fall burn	1.07 ± 0.24[bc]	2.47 ± 0.32[de]
Fall herbicide	1.57 ± 0.37[bc]	1.70 ± 0.32[cd]
Spring herbicide	3.40 ± 0.55[de]	3.33 ± 0.42[ef]
Untreated	4.93 ± 0.67[e]	3.83 ± 0.35[f]

[1]Values followed by different letters are significantly different ($P < 0.05$).
[2]All herbicide treatments were Picloram at 0.28 kg ha^{-1} plus 2, 4-D at 1.1 kg h^{-1}.

All burn treatments substantially reduced the germination of leafy spurge seed compared with no treatment; spring burns were slightly more effective than fall burns. However, natural loss in seed viability may have been greater on spring burn sites than on fall burn sites due to winter mortality. Viability of leafy spurge seed generally diminishes slowly over time (Bowes and Thomas 1978). Our study suggested that a single spring burn is an effective method to reduce leafy spurge seed germination.

Herbicides alone did little to decrease germination of leafy spurge seed (table 1). Similar findings were reported by Bowes and Thomas (1978). The general effectiveness of fall herbicide/spring burn treatment on leafy spurge seeds was attributed to the lethal effects of fire. Prescribed burning has been used in other areas to reduce germination of downy brome (Bromus tectorum) and medusahead (Taeniatherum asperum) seeds (Young *et al*. 1972). More research on lethal temperatures is necessary to fully understand the mechanisms involved in reducing seed germination rates observed in our study.

Leafy spurge density

Leafy spurge density was not influenced by site (upland or floodplain), but was influenced by treatment. All herbicide treatments, with or without a followup burn, reduced the density of leafy spurge compared to untreated plots or burned-only treatments (table 2). Previous field studies also reported excellent control of leafy spurge with picloram plus 2,4-D (Lym and Messersmith 1985a, 1985b).

Burning did not reduce leafy spurge density; to the contrary, fire top-killed the leafy spurge plants and stimulated vigorous sprouting. Picloram plus 2,4-D with or without burning controlled leafy spurge better than burning alone. Although our study did not evaluate long-term effectiveness, Lym and Messersmith (1985a) noted that picloram plus 2,4-D provides excellent control for up to 15 months after treatment, although annual application of the herbicide is necessary for long-term control.

Table 2. -Leafy spurge stem density on Little Missouri National Grassland study sites following herbicide and burn treatments.[1]

Treatment	Density
	number m^2 ± standard error
Spring herbicide2 + fall burn	14 ± 8[a]
Fall herbicide + spring burn	67 ± 22[a]
Spring herbicide	33 + 14[a]
Fall herbicide	41 ± 11[a]
Fall burn	228 ± 107[ab]
Spring burn	364 ± 41[b]
Untreated	239 ± 28[b]

[1]Values followed by different letters are significantly different ($P < 0.05$).
[2]All herbicide treatments were picloram at 0.28 kg ha^{-1} plus 2, 4-D at 1.1 kg ha^{-1}.

These preliminary data indicate that a spring burn with or without a fall herbicide application was the most effective treatment for reducing leafy spurge seed germination. Herbicides with or without burning were most effective in reducing leafy spurge stem density. Therefore, the best all-around treatment for reducing both germination and stem density would be a fall application of picloram plus 2,4-D followed by spring burning. Additional research is needed to verifv these initial results.

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USDA-APHIS-PPQ redistribution of *Aphthona* spp. leafy spurge flea beetles, 1988-1993

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USDA-APHIS-PPQ began its biological control program on leafy spurge in 1988 with the introduction of three species of *Aphthona* flea beetles: *A. cyparissiae*, *A. czwalinae*, and *A. flava*. *A. nigriscutis* was brought into the program in 1989, followed by *A. lacertosa* and *A. abdominalis* in 1993. The following redistribution activity by species has occurred from 1988 through 1993:

A. abdominalis (50 adults in one Montana release)

A. cyparissiae (128,553 adults released at 178 sites in 110 counties in two states)

A. czwalinae (749 adults released at seven sites in three counties in two states)

A. flava (174,590 adults released at 131 sites in 77 counties in fifteen states)

A. lacertosa/*A. czwalinae* mix (25,720 adults released at 21 sites in fifteen counties in eleven states)

A. nigriscutis (336,894 adults released at 389 sites in 149 counties in fourteen states)

The following state have received *Aphthona* species flea beetles in the period from 1988 to 1993: Colorado, Idaho, Iowa, Minnesota, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, Wisconsin, and Wyoming. Thematic maps of the redistribution of *Aphthona* species leafy spurge flea beetles in these states and tables summarizing the releases by species and state were displayed.

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Biological control of leafy spurge with the use of pathogens

TONY CAESAR

Pathogenic soilborne fungi have been isolated from insects (or plants which have been injured by insects) which are biological control agents of rangeland weeds. *Rhizoctonia*, *Pythium* and *Fusarium* spp. have been isolated from *Aphthona nigriscutis* or *A. flava* and leafy spurge. Similar results have been obtained in Europe on *Euphorbia spp.* Several bacteria are also associated with insect-injured leafy spurge. Plants of *Centaurea maculosa* and *C. diffusa* in Russian with injuries to the roots and crowns, caused by larvae of three different insects, are also infected by *Fusarium*, *Pythiyum*, *Rhizoctonia* and other species. The possible implications of these results for biological control will be discussed.

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Insect association on *Euphorbia characias* L. in Western Europe, a plant closely related to leafy spurge

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Euphorbia characias is a perennial weed wide distributed in all the European countries of the Mediterranean basin. The plant is perennial and its habitat is dry and rocky soil (generally limestone) from 0 to 1,000 m a.s.l. The plant is in the subgenus *Esula* the same subgenus of *E. esula* and *E. virgata*, the most common spurge weed species in USA. Insects associated to leafy spurge in Europe, and released in North America as *Hyles euphorbiae*, *Oberea erythrocephala*, *Aphthona spp.*, also occurred on *E. characias*. The list of these promising candidate agents for biologial control of leafy spurge in the U.S. includes seven insect species. Within them, there are leaf feeders (the pyralid moth *N. divisella* and the tortricid moths *Acoclita subseguana* and *Lobesia sp.*), three stem borers (the scolitid beetle *Tamnurgus euphorbiae*, the agromyzid fly *Opheomya sp.*, and the pyralid moth *Nephopterix divisella*), one gall midge (*Spurgia* sp. nr. *esulae*), and one agromyzid fly leaf miner (*Liriomyza sp.*). Some of these insects (*N. divisella* and *T. euphorbiae*) shows in preliminary host range tests the capability to complete their larval development on leafy spurge U.S. biotypes and are mentioned in the literature closely related to the family Euphorbiaceae, feeding on plants in the genus Euphorbia. At the present time, biology notes and host suitability tests are in progress at the USDA ARS European Biological Control Laboratory, Montpellier, France; at the USDA ARS EBCL Field Station, Rome Italy, at the ENEA CRE Casaccia, Rome, Italy; and at the Laboratorio di Acqualcoltura e Ecologia Animale of the II University of Rome.

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Status of biocontrol research projects in North Dakota with special reference to *Aphthona* spp. and the gall midge, *Spurgia esula*

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The gall midge project has demonstrated the capability of this insect to undergo four generations per year with the fourth generation showing very little evidence of pupation. It would appear that the majority of the larvae move out of the galls and to the soil for overwintering. For 3342 adults emerging from falls in the laboratory, the sex ratio was 1.59:1 (female:male). The endemic predator, *Zatropis nigroaenus*, was prevalent in galls collected from the second through fourth generations. The collection site near shelterbelt type plantings showed a lower incidence of predator occurrence (max. 43%) than an "open prairie" site (max. 75%) in 1993.

Aphthona spp. research is focusing on release strategies in two types of spurge infestations; "patch" treatments, where insects have been released on small, well defined areas of spurge and large scale treatments, where insects have been released in patterned grids or at uniform intervals along transects through large scale spurge infestations. The patterned grid study is also designed to obtain information on establishment success in relation to the time of collection of the insects which were released. Insects collected at approximately weekly intervals were released at different points on the grid and each point will be monitored for population increase and impact on the spurge. Each collection date is represented by five points on the grid. Impacts of larval feeding on roots will continue to be monitored and studies of the interactions of *A. lacertosa* and *A. czwalinae* within mixed populations will continue.

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Herbicides and grass competition for leafy spurge control

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A series of experiments were established to compare cost and efficacy of a glyphosate plus 2,4-D application followed by herbicide retreatments of picloram, dicamba, or picloram plus 2,4-D to each herbicide retreatment alone. The initial treatments were applied late June of 1993 and evaluation taken in 1993 and 1994. Glyphosate plus 2,4-D provided 90% leafy spurge control 3 months after treatment (MAT) compared to 65% for all other treatments. When reevaluated 12 MAT the glyphosate plus 2,4-D treatment sustained >70% control compared to 35% for all other treatments. There was no significant grass injury for any treatment.

A regional research experiment was established by scientists in Colorado, Minnesota, Montana, Nebraska, Wyoming, and North Dakota to evaluate leafy spurge control with quinclorac. Leafy spurge control was >90% regardless of rate at all locations except North Dakota and Wyoming. In those states the level of control was >55% with quinclorac, which was comparable to picloram plus 2,4-D at 0.5 plus 1 lb/A.

Grass competition is one means of controlling the rate of spread of leafy spurge based on data from an experiment established in 1990 at Fargo. The three grass species that provided >70% control were 'Rebound' smooth brome, 'Rodan' western wheatgrass, and 'Bozoisky' Russian wildrye. 'Arthur' Dahurian wildrye and 'Hycrest' crested wheatgrass averaged 50% control.

A second experiment was established near Jamestown to evaluate competitive grass species on a soil type more typical of North Dakota than found at Fargo. Glyphosate plus 2,4-D at 0.4 + 0.6 lb/A was applied to all plots except the untreated control when leafy spurge was in the flowering growth stage in June and again in July. The seedbed was prepared and grass species planted August 24, 1994 except in the untreated control and glyphosate plus 2,4-D plots. Six grass species were selected from the 1990 study along with three new grass species to include: 'Rebound' smooth brome, 'Rodan' western wheatgrass, 'Bozoisky' and 'Mankota' Russian wildrye, 'Arthur' Dahurian wildrye, 'Reliant' intermediate wheatgrass, 'Hycrest' crested wheatgrass, 'Pryor' slender wheatgrass, 'Lodorm' green needlegrass, and 'Manska' pubescent wheatgrass. For evaluations taken May 1994 the three most competitive species were 'Manska' pubescent wheatgrass, 'Arthur' Dahurian wildrye, and 'Reliant' intermediate wheatgrass which provided >55% control.