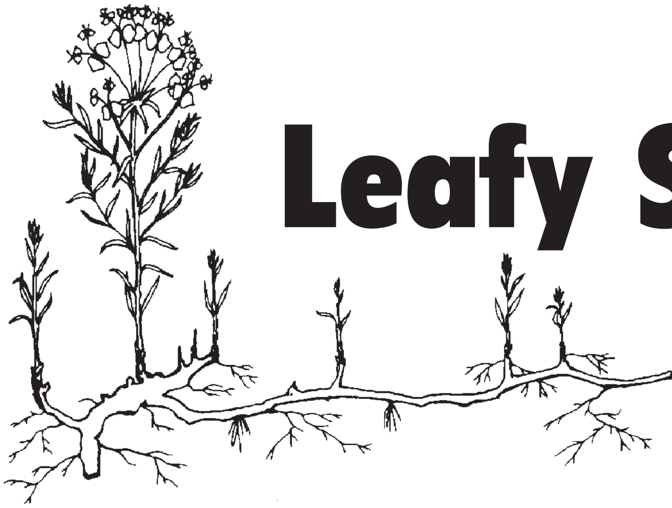

Leafy Spurge *News*

Agricultural Experiment Station
NDSU Extension Service
North Dakota State University, Fargo, ND 58105

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From the Editor's Desk

You are in for a treat — a sneak preview of leafy spurge information to be given at the Society for Range Management 2004 meeting in Salt Lake City, Utah. On January 27 and 28 there will be a special TEAM Leafy Spurge Symposium. I was able to get the abstracts of the 29 papers that will be presented. The first 24 abstracts are in this issue — the remainder will be included in the next issue. To give you an idea of what will be covered I have included the program schedule. In this issue I have also included one research item from the Bioscience Laboratory of the USDA in Fargo.

On January 14-15, 2004, I will be attending a meeting of the North Dakota County Weed Officers in Minot, ND. I will provide you with feedback on items that relate to leafy spurge in the next issue.

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Competitive Grant Awarded for Bud Dormancy Research

In the January, 2001 issue of Leafy Spurge News, I outlined the role of gene expression in relation to leafy spurge root bud dormancy and described a powerful new technology called microarray analysis. Microarray analysis allows scientists to determine the expression of hundreds to thousands of genes simultaneously in response to a particular treatment or condition, instead of one gene at a time. Given that plants have 25,000 to 50,000 individual genes controlling their growth and development, you can see the advantages of this new technology. Our unit is working with USDA-ARS leaders to gather resources to develop a large leafy spurge expressed sequence tag (EST) database, which is a prerequisite for microarray analyses. Meanwhile, we are using some other approaches to investigate the genetic control of bud dormancy. Here, I will introduce another technology called subtractive hybridization that is used to investigate differential gene expression in many organisms, and now in dormant and non-dormant buds of leafy spurge. While subtractive hybridization deals with only tens to hundreds of genes, the cost is much less than to generate an EST-database of around 50,000 leafy spurge genes. In any event, the differentially-expressed genes discovered through subtractive hybridization will complement and be added to our growing EST database. You might say this project will give us a sneak preview of differences in gene expression between dormant and non-

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NDSU Extension Service, North Dakota State University of Agriculture and Applied Science, and U.S. Department of Agriculture cooperating. Sharon D. Anderson, Director, Fargo, North Dakota. Distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914. We offer our programs and facilities to all persons regardless of race, color, national origin, religion, sex, disability, age, Vietnam era veterans status, or sexual orientation; and are an equal opportunity employer.
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Grant continued from page 1

dormant buds, but on a much smaller scale than with microarrays.

Subtractive hybridization works on the principle that cDNAs, which in our case are copies of DNA-containing genes from leafy spurge buds, will find and bind to the cDNAs of matching sequence when you mix two different cDNA sets together. In our subtractive hybridization research, we prepared two sets of cDNAs; one from the growing root buds and one from the dormant root buds. The two cDNA sets were mixed together, which allowed any matching cDNAs to bind together or "hybridize". We removed these unwanted hybrids from the mixture using a biological hooking technique. Thus, we eliminated genes that were equally-expressed in both growing and dormant buds and retained genes that were differentially- or preferentially-expressed in only one of these two bud types. We have taken these two sets of cDNAs and made what are call a "forward" and a "reverse" subtracted cDNA library. Our "forward" library contains copies of genes preferentially-expressed in growing root buds, whereas the "reverse" library contains genes preferentially-expressed in dormant buds. At this time we are collaborating with Dr. Yong-Qiang Gu in the USDA-ARS lab in Albany, CA to eliminate redundant clones (multiple copies of the same clone) from these two cDNA libraries.

In September, 2003, I was awarded $190,000 from the USDA-National Research Initiative Competitive Grants Program to pursue this project. In cooperation with Dr. Rod Lym at North Dakota State University, a postdoctoral research fellow will be hired to identify developmentally-, environmentally-, and temporally-regulated genes associated with growth and development of leafy spurge buds.

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Abstracts

TEAM Leafy Spurgy Symposium at the Society for Range Management 2004 meeting

Assessing area-wide biological control of leafy spurge in Montana and South Dakota

John T. Murphy, Matthew S. Parker and Jack L. Butler*

The objective of this study was to evaluate the micro-scale distribution and dynamics of two species of biological control agents commonly used to control leafy spurge in the Northern Great Plains. Ninety-three permanently located sample sites were established during the 1998 field season within the Mill Iron (Montana) and South Fork of the Moreau River (South Dakota) study areas. The selected sites represent the wide range of topographic, soil, vegetation, and landform situations typical of the region. Approximately 6,000 beetles (3,000 *Aphthona lacertosa* and 3,000 *Aphthona. nigriscutis*) were released in June 1998 at each of the 62 permanently located release sites. Beetle abundance on all sites was estimated using insect sweeps from 1999 through 2003. Species composition and foliar cover of the extant vegetation and leafy spurge cover and density were estimated through six consecutive field seasons.

Within one year following introduction, *A. lacertosa* greatly outnumbered *A. nigriscutis* on all sites. Beetle numbers increased rapidly within one year, peaked in 2001, and then decreased 70% the following year. Beetles did not appear to demonstrate any particular affinity for site differences related to slope and aspect. Insects were first recorded on many of the non-release sites in 2000 and beetles appear to be increasing exponentially on these sites. Concomitantly with the increases recorded in beetle abundance, foliar cover of leafy spurge was reduced an average of 75% (range 50% to 100%) by 2002. The diversity, frequency, and abundance of the native vegetation increased significantly within two years following flea beetle release.

Evaluation of biological control of leafy spurge in northeastern Wyoming

*Amy P. Williams and David J. Kazmer**

In 1998, 3,000 *Aphthona nigriscutis* and 3,000 *A. lacertosa* were released for biological control of leafy spurge on 76 of 101 monitoring sites in northeastern Wyoming. Flea beetle abundance, leafy spurge canopy cover, and flea beetle impact area were measured in 1999 and 2000. After two years, *Aphthona* releases

Abstracts continued on page 4

Program Schedule and Abstracts

January 27, 2004

Regional Findings

8:00 a.m. Assessing area-wide biological control of leafy spurge in Montana and South Dakota
John T. Murphy, Matthew S. Parker, Jack L. Butler*

8:30 a.m. Evaluation of biological control of leafy spurge in northeastern Wyoming
*Amy P. Williams, David J. Kazmer**

9:00 a.m. Soil seedbank and secondary succession relationship following control of leafy spurge using flea beetles
Donald R. Kirby, John A. Kava, Dean A. Cline, Gerald L. Anderson*

9:30 a.m. Evaluating leafy spurge change over a ten-year period in Theodore Roosevelt National Park using multiple aerial imaging platforms
Gerald L. Anderson, Raymond F. Kokaly, Steve N. Hager, Ralph R. Root*

10:00 a.m. Break *(Moderator: Bob Richard)*

10:30 a.m. Effects of biological control on leafy spurge-infested rangeland
Luke W. Samuel, Donald R. Kirby, Gerald L. Anderson*

11:00 a.m. Assessment of the extent and success of biological control agents for control of leafy spurge
Nancy M. Hodur, F. Larry Leistritz, Dean A. Bangsund*

11:30 a.m. Perceptions of leafy spurge and evaluation of the TEAM Leafy Spurge project by public land managers, local decision makers, and ranch operators
Nancy M. Hodur, F. Larry Leistritz, Dean A. Bangsund*

Ecology and Control

1:00 p.m. Effects of integrated chemical and biological methods for leafy spurge control on the western prairie fringed orchid
Ann M. Erickson, Rodney G. Lym, Donald R. Kirby*

1:20 p.m. Ecological impacts of natural enemies of leafy spurge in four plant communities
Nik G. Wiman, Robert M. Nowierski, David K. Weaver*

1:40 p.m. Impacts of grasshopper treatments on leafy spurge biological control agents
R. Nelson Foster, K. Chris Reuter, L. Keith Winks, Terry E. Reule, Robert D. Richard*

2:00 p.m. A field evaluation of potential impact of leafy spurge biological controls on a non-target, native species
Stefanie D. Wacker, Jack L. Butler*

2:20 p.m. Patterns of vegetation recovery following biological control of leafy spurge
*Julie A. Laufmann, Jack L. Butler**

2:40 p.m. Leafy Spurge: The search for new natural enemies
Gaetano Campobasso, Neal R. Spencer, Gianni Terragitti and Margarita Yu. Dolgovskaya*

3:00 p.m. Break *(Moderator: Chad Prosser)*

3:20 p.m. Effects of multi-species grazing and biocontrol on leafy spurge-infested rangeland using rotational grazing
Luke W. Samuel, Kevin K. Sedivec, Jack D. Dahl, Lyndon L. Johnson, Timothy C. Faller*

3:40 p.m. Effects of herbicides on plant richness and biomass on leafy spurge infested rangeland
Chad W. Prosser, Kevin K. Sedivek*

4:00 p.m. Integrated management of leafy spurge
James S. Jacobs, Roger L. Sheley*

4:20 p.m. Nutritional composition of leafy spurge in North Dakota and Montana
Kevin K. Sedivek and Chad W. Prosser*

4:40 p.m. Toward a decision support system for leafy spurge-infested plant communities
Matt J. Rinella, Roger L. Sheley, Daniel Goodman*

January 28, 2004

Remote Sensing

8:00 a.m. Application of advanced remote sensing and modeling techniques for the detection and management of leafy spurge: Challenges and opportunities
Ralph R. Root, Gerald L. Anderson, Steve N. Hager, Karl E. Brown, Kathleen B. Dudek, Raymond F. Kokaly, Carol S. Mladinich, Susan F. Stitt, Monica Ruiz-Bustos*

8:20 a.m. Landscape assessment of leafy spurge at Theodore Roosevelt National Park, North Dakota: Modeling and mapping approach
Karl E. Brown, Mohammed A. Kalkhan*

8:40 a.m. Mapping leafy spurge by identifying signatures of vegetation field spectra in Compact Airborne Spectrographic Imager (CASI) data
Raymond F. Kokaly, Gerald L. Anderson, Ralph R. Root, Karl E. Brown, Carol S. Mladinich, Steve N. Hager, Kathleen B. Dudek*

9:00 a.m. The use of Earth Observing-1 Hyperion data for mapping of leafy spurge
Ralph R. Root, Pablo Zanco-Tejada, Carlos Pinilla, Susan Ustin, Raymond F. Kokaly, Gerald L. Anderson, Steve N. Hager*

9:20 a.m. Temporal monitoring of leafy spurge: An example using 1999 and 2001 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data over Theodore Roosevelt National Park
Kathleen B. Dudek, Ralph R. Root, Raymond F. Kokaly, Gerald L. Anderson, Karl E. Brown, Carol S. ladinich, Susan F. Stitt, Steve N. Hager, Michael A. Lefsky*

9:40 a.m. The use of Landsat 7 ETM+ data for mapping leafy spurge
Carol S. Mladinich, Monica Ruiz-Bustos, Susan F. Stitt, Ralph R. Root, Karl E. Brown, Gerald L. Anderson, Steve N. Hager*

10:00 a.m. Break *(Moderator: Gerry Anderson)*

10:20 a.m. Comparison of hyperspectral and multispectral remote sensing for leafy spurge
Raymond Hunt and Amy P. Williams*

10:40 a.m. Application of eCognition to enhance the classification process for mapping leafy spurge
Monica Ruiz-Bustos, Carol S. Mladinich, Susan F. Stitt, Ralph R. Root, Gerald L. Anderson, Steve N. Hager*

11:00 a.m. The use of Earth Observing-1 Advanced Land Imager (ALI) data for mapping leafy spurge
Susan F. Stitt, Ralph R. Root, Karl E. Brown, Steve N. Hager, Carol S. Mladinich, Gerald L. Anderson, Kathleen B. Dudek, Raymond F. Kokaly*

11:20 a.m. Issues of ortho-rectification of multi-source imagery for the mapping of leafy spurge
Carol S. Mladinich, Thomas Owens, Gerald L. Anderson, Steve N. Hager, Ralph R. Root*

11:40 a.m. The Ecological Areawide Management (TEAM) of Leafy Spurge
Gerald L. Anderson, Chad W. Prosser, Robert D. Richard*

*Presenter of abstract

resulted in significant reductions in leafy spurge canopy cover (from 49% to 6%) with suppression of leafy spurge averaging 285 m^2. Flea beetles were effective in controlling leafy spurge regardless of the site characteristics (vegetation type, topographical position, soil type, and aspect) and initial leafy spurge canopy cover.

Soil seedbank and secondary succession relationship following control of leafy spurge using flea beetles

Donald R. Kirby, John A. Kava, Dean A. Cline and Gerald L. Anderson*

We examined the relationship between the soil seedbank of leafy spurge *(Euphorbia esula L.)*-infested rangeland and the secondary succession of rangeland following leafy spurge control using flea beetles *(Aphthona spp.).* On a xeric, upland site we found a large relative abundance of high seral grasses, *Poa spp*. and *Carex spp*., in both soil seedbank and secondary succession analyses. At the species level, the soil seedbank predicted approximately two-thirds of the high seral grasses found on the leafy spurge-controlled sites. A small percentage of introduced invasive species such *as Bromus japonicus* and *Cirsium arvense* were noted in the soil seedbank with both occurring sparingly in the field evaluations. For the mesic site, *Poa spp*. dominated the soil seedbank as well as in the field evaluations. Lesser amounts of high seral grasses and *Carex* spp. were present in the soil seedbank. High seral grasses were also predominant in field evaluations of the sites; however, on a species level, the soil seedbank again only predicted approximately two-thirds of the high seral grass species present at field sites. The soil seedbank analysis predicted the presence of introduced invasive species on the mesic site but was inaccurate at the species level. In summary, soil seedbank analysis was a good indicator of functional groupings of plant species, seed present, such as combined high seral grasses or total introduced invasive species, but did not predict as well at the plant species level.

Evaluating leafy spurge change over a ten-year period in Theodore Roosevelt National Park using multiple aerial imaging platforms

Gerald L. Anderson, Raymond F. Kokaly, Steve N. Hager and Ralph R. Root*

Leafy spurge is a troublesome weed in the northern Great Plains of the United States that herbicides and grazing management have not consistently controlled. The objectives of this study were to use remote sensing and GIS technologies to map and quantify the extent, distribution, and spatial-temporal dynamics of leafy spurge within Theodore Roosevelt National Park between 1993 and 2002. Data were collected using aerial color photography in 1993 and digital hyperspectral imagery in 2003. Photo-interpretation of the 1993 data indicated that 550 ha of the park's 18,680 ha (3%) were covered by leafy spurge. Since that time, a substantial decrease in leafy spurge infestations has been noted. The hyperspectral data collected in 2002 indicated only a few scattered patches of the weed were identifiable. While leafy spurge will always be a component of the park, the use of biologically based integrated pest management has proven to be an effective and affordable approach to controlling leafy spurge in this rugged and ecologically sensitive area.

Effects of biological control on leafy spurge-infested rangeland

Luke W. Samuel, Donald R. Kirby and Gerald L. Anderson*

TEAM Leafy Spurge began distributing flea beetles (*Aphthona spp*.) to landowners and land managers in Montana, North Dakota, South Dakota, and Wyoming for leafy spurge (*Euphorbia esula L*.) control in 1998. A study to evaluate the long term effects of leafy spurge control by flea beetles was initiated in 2002 on leafy spurge-infested range and pastureland in the Little Missouri River drainage and selected nearby locations. Data was collected at flea beetle release sites in June and July of 2002 during the period of adult activity. In 2002, 115 flea beetle release sites were analyzed for leafy spurge stem density and cover, flea beetle densities, and native vegetation. Flea beetles impacted leafy spurge stem densities at 93% of the release sites. Leafy spurge stem densities were reduced from over 100 stems/m^2 to fewer than 25 stems/m^2 on nearly two-thirds of the sites. Leafy spurge foliar cover was less than 5% on approximately two-thirds of the flea beetle release sites and less than 25% on over 90% of the release sites. Area of flea beetle control ranged from little or no leafy spurge control to areas greater than 30,000 m^2. Approximately 40% of the release sites experienced a control of 1,000 to 5,000 m^2, and 14% of the release sites had greater than 10,000 m^2 of leafy spurge control. Flea beetles effectively reduced leafy spurge stem density and cover across a variety of locations and corresponding environmental conditions throughout both the Little Missouri River drainage and the region.

Assessment of the extent and success of biological control agents for control of leafy spurge

Nancy M. Hodur, F. Larry Leistritz and Dean A. Bangsund*

Leafy spurge is an exotic, noxious, perennial weed which is widely established in the north central United States and is an especially serious problem in the northern Great Plains. In 1997, the U.S. Department of Agriculture's Agricultural Research Service and Animal and Plant Health Inspection Service initiated a major Integrated Pest Management (IPM) research and demonstration project to develop and demonstrate ecologically based IPM strategies that can produce effective, affordable leafy spurge control. A key component of the project centered on expanding the use of biological control agents, specifically insects. To assess the level of insect establishment and the level of current and perceived future control of leafy spurge, a mail survey of 468 individuals that obtained biocontrol agents (insects) at TLS-sponsored events and the county weed boards in North Dakota, South Dakota, Montana, and Wyoming was conducted. Forty-six percent of the landowner/land managers and 70 percent of the county weed boards responded to the questionnaire. Respondents reported basic information about the number and characteristics of release sites, characteristics of the leafy spurge stands, as well as the level of control to date and perceived level of eventual control. Respondents were also queried on their perceptions regarding a number of broad-based weed control and leafy spurge control issues. Results from this study represent the most comprehensive assessment to date of the utilization and effectiveness of biological control agents on leafy spurge.

Perceptions of leafy spurge and evaluation of the TEAM Leafy Spurge project by public land managers, local decision makers, and ranch operators

Nancy M. Hodur, F. Larry Leistritz and Dean A. Bangsund*

Leafy spurge is an exotic, noxious, perennial weed which is widely established in the north central United States and is an especially serious problem in the northern Great Plains. In 1997, the U.S. Department of Agriculture's Agricultural Research Service and Animal and Plant Health Inspection Service initiated a major Integrated Pest Management (IPM) research and demonstration project to develop and demonstrate ecologically based IPM strategies that can produce effective, affordable leafy spurge control.

In 1998 and 1999 a survey of ranchers, local decision makers, and public land managers was conducted to evaluate managerial, institutional, and social factors that might affect the rate and extent of implementation of various control strategies. In 2001, a second survey of the same ranchers, local decision makers, and public land managers was conducted to (1) assess any changes in land managers' perceptions of weed problems, control alternatives, and related issues, and (2) evaluate the impact of the TEAM Leafy Spurge project on the respondents' weed control practices. Findings from the first survey identified a number of constraints limiting land managers' ability to utilize available control techniques to manage leafy spurge infestations. The TLS project used a variety of tools and communication strategies, such as presentations at local meetings, demonstration plots, and field days to address the impediments to leafy spurge control identified in the first survey. Findings from the second survey indicated TEAM Leafy Spurge efforts had effectively addressed many of the constraints to leafy spurge control previously reported by landowners and land managers.

Effects of integrated chemical and biological methods for leafy spurge control on the western prairie fringed orchid

Ann M. Erickson, Rodney G. Lym and Donald R. Kirby*

Leafy spurge is a serious threat to the western prairie fringed orchid, a federally-listed threatened species. The purpose of this research was to evaluate leafy spurge control and flea beetle establishment in habitat of the orchid using herbicides in combination with *Aphthona spp*. flea beetles. The effect of imazapic and quinclorac on the survival and fecundity of the western prairie fringed orchid was evaluated. Imazapic at 140 and 210 g ai/ha and quinclorac at 840 and 1120 g ai/ha were applied with an MSO to 1-m^2 plots each containing a single orchid. The number of orchids that regrew was similar between treatments. However, orchids treated with imazapic tended to regrow as vegetative plants 10 months after treatment (MAT), and fewer orchids treated with imazapic at 210 g/ha regrew 34 MAT than untreated orchids. In addition, orchids treated with imazapic at either rate were shorter than untreated orchids 10 MAT, and orchids treated with the higher rate of imazapic had shorter racemes and produced fewer flowers than untreated orchids both at 10 and 34 MAT. Orchids treated with quinclorac regrew similar to untreated orchids. In a separate study, leafy spurge stem density decreased from about 120 to approximately 5 stems/m^2 at 9 months after treatment with herbicides alone and to 0 stems/m^2 at 9 months after treatment with both flea beetles and herbicides. Stem density of leafy spurge treated only with flea beetles decreased from 152 to 40 stems/m^2.

Ecological impacts of natural enemies of leafy spurge in four plant communities

Nik G. Wiman, Robert M. Nowierski and David K. Weaver*

The ecological impacts of host-specific natural enemies introduced for biological weed control are poorly understood in plant communities. The goal of this project was to examine the effect of biological control of leafy spurge (*Euphorbia esula L.)* by *Aphthona spp*. flea beetles (Coleoptera: Chrysomelidae) on plant species richness and exotic plant species abundance. Our four research sites were under various levels of biological control, and represented different environmental types, plant communities, and flea beetle species compositions. Sampling was accomplished with quadrats spaced along transects that radiated outward from flea beetle release points. Data were spatially analyzed using geo-statistical methods, including variogram analysis and kriging. Temporal changes in the plant community variables and *Aphthona spp.* abundances were tested using Monte-Carlo permutations in an exact test to avoid problems from conventional data testing in the presence of auto-correlation. The abundance of leafy spurge increased and decreased over the study period at the different sites. Environmental factors affecting the plants and the insects are discussed as potential explanations for this observation. Plant species richness tended to exhibit a highly heterogeneous spatial pattern at each site, with the highest numbers of plant species occurring in areas where *E. esula* had been successfully controlled. Biological control affected plant species richness in the research site with the highest populations of *Aphthona spp*. Intense herbivory of *E. esula* plants by *Aphthona spp*. was spatially associated with exotic plant species hot spots, although the overall abundance of exotic species never increased over the three-year study period.

Impacts of grasshopper treatments on leafy spurge biological control agents

R. Nelson Foster, K. Chris Reuter, L. Keith Winks, Terry E. Reule and Robert D. Richard*

Established populations of introduced *Aphthona spp*. on leafy spurge may be in jeopardy on western rangelands where populations of grasshoppers require insecticide treatments. Laboratory bioassays and field evaluations were conducted to determine the impacts of grasshopper control treatments. In laboratory bioassays, diflubenzuron spray produced no significant mortality. Malathion and carbaryl sprays produced 17%-67% and 80%-96% significant mortality respectively. In the season of treatment, combined field evaluations showed carbaryl bait, diflubenzuron, malathion and carbaryl sprays resulted in 17%, 0%-18%, 21%-24% and 60%-82% adjusted percentage mortality respectively. *Aphthona spp.* populations in the following year did not decline and year one population decreases did not translate into plant density increases a year after treatment. *Aphthona spp*. field populations exceeded first year pretreatment levels, in 23 of 24 plots one year after treatment. When locations were combined, all treatments except malathion 584 ml/ha and diflubenzuron 73 ml/ha resulted in population increases greater than in untreated plots. Reduced treatments of diflubenzuron and malathion resulted in greater population growth at one year after treatment compared to the traditional doses. *Aphthona spp*. populations increased the most in bran bait plots (4.50X), fol-

lowed by carbaryl 1169 ml/ha plots (4.32X), malathion 292 ml/ha plots (3.28X), carbaryl 584 ml/ha plots (2.83X), diflubenzuron 55ml/ha plots (2.73X), untreated check plots (2.08X), malathion 584 ml/ha plots (2.01X) and diflubenzuron 73 ml/ha plots (1.84X). Timing of grasshopper treatments at third instar and peak adult *Aphthona spp*., allowed for pretreatment oviposition sufficient to insure the survival of the next year's generation of *Aphthona spp.*

A field evaluation of potential impact of leafy spurge biological controls on a non-target, native species

Stefanie D. Wacker and Jack L. Butler*

The brown flea beetle (*Aphthona nigriscutis)* is a biological control agent often used to reduce the cover and density of leafy spurge throughout the Northern Great Plains. However, there is concern that the beetles may use alternative hosts for feeding and development. At risk, non-target, native species include those that are most closely related, ecologically and taxonomically, to leafy spurge. Shrubby spurge (*Euphorbia robusta*) is congeneric and sympatric with leafy spurge throughout the region. The objective of this study was to evaluate the actual and potential ecological overlap among leafy spurge, flea beetles, and shrubby spurge. The physical and biological characteristics of eight sites, four in SD and four in WY, were evaluated during the 2002 field season. To assess the direct impact of beetles on natural populations of shrubby spurge, approximately 3000 black flea beetles were released at each of two sites in SD. Soil cores (10 X 20 cm), containing randomly selected plants, were collected in April 2003, transferred to a greenhouse, and evaluated for beetle emergence. In addition, soil cores with plants were collected and evaluated from a WY site that was immediately adjacent to a population of leafy spurge that had been controlled by flea beetles. Preliminary analysis indicates that shrubby spurge is infrequent throughout the region, and occurs in low densities on sites with a high percentage of bare ground. No beetles emerged from the soil cores and no plant mortality or evidence of use by the beetles either as adults or larvae were observed.

Patterns of vegetation recovery following biological control of leafy spurge

*Julie A. Laufmann and Jack L. Butler**

Flea beetles *(Aphthona lacertosa and Aphthona nigriscutis*) have been aggressively and successfully used in Theodore Roosevelt National Park to help control leafy spurge. The objective of this study was to simultaneously evaluate the extant vegetation, transient seed bank, and persistent seed bank following biocontrol of leafy spurge infested sites. Seed bank samples were collected in 2002 from 52 sites within three plant associations (silver sagebrush shrublands, green-ash draws, and needle-and-thread grasslands) that reflect the chronological and topographic sequence of leafy spurge invasion into the Park. Selected sites included non-infested, infested, and infested/biocontrol stands for each association. Seed bank samples were evaluated using greenhouse germination trials and microscopic examination. The extant vegetation was evaluated using Modified-Whitaker plots. Total species richness of the extant vegetation and persistent seed bank was higher in the non-infested stands compared to infested and infested/biocontrol for all 3 plant associations. Species richness of the extant vegetation and seed bank samples tended to be lowest in the silver sagebrush sites, regardless of leafy spurge infestation or biocontrol. Preliminary results of greenhouse trials indicate that annuals tend to dominate the transient seed bank of all sites. Species richness of the transient seed bank was higher in the infested and infested/biocontrol sites compared to non-infested sites. Results so far suggest that, while seed banks have tremendous potential to serve as a major source of propagules in the re-establishment of native vegetation following bio-control of leafy spurge, recovery of the vegetation to pre-infestation composition may be a complex, and long-term process.

Leafy Spurge: The search for new natural enemies

Gaetano Campobasso, Neal R. Spencer, Gianni Terragitti and Margarita Yu. Dolgovskaya*

Leafy spurge, *Euphorbia esula L. (Euphorbiaceae*), has been a bane to ranchers and land managers in the U.S. and Canada for much of the past 100 years. Fifteen insect species have been imported into the United States for leafy spurge control following extensive research on host specificity and efficacy.

Presently, nine of the 15 insects have established, however, extensive leafy spurge control has been achieved primarily by the *Aphthona, spp*. flea beetles, *A. nigriscutis*, *A. czwalinae* and *A. lacertosa*. It has become apparent from research conducted in both Canada and the U.S. that these biocontrol agents do not control leafy spurge in all areas where the weed is a problem. The search for new natural enemies was extended to the central Asian portion of Russia and to China with the concept of extending the range of sites for effective biological control. The *Aphthona* species, *A. russica (new* species), *A. pygmaea*, *A. abdominalis*, and *A. nigriscutis* were found on *Euphorbia* species in the Northern Caucasus. *A. nigriscutis was* originally imported from northern Europe for leafy spurge control in both Canada and the U.S. The same species collected from the Northern Caucasus of Russia may exhibit different feeding and habitat preferences. A sawfly, *Arge beckeri* Tournier (Hymenoptera: Tenthredinoidea: Argidae) was found feeding on leafy spurge, in the Krasnodar territory of Russia. Another *Aphthona* species, *A. chinchihi*, was discovered feeding on leafy spurge in China. Host specificity testing reported here indicates the species all have a limited host range.

Effects of multi-species grazing and biocontrol on leafy spurge-infested rangeland using rotational grazing

Luke W. Samuel, Kevin K. Sedivec, Jack D. Dahl, Lyndon L. Johnson and Timothy C. Faller*

A study to evaluate the effects of multi-species grazing and biocontrol (insects) on the control of leafy spurge *(Euphorbia esula L.*) was initiated in 1998. The objectives of this study were to determine if grazing leafy spurge infested rangeland with cattle and sheep using a twice-over rotational grazing treatment (TOR) in combination with biocontrol would: 1) reduce leafy spurge stem density and production compared to season-long (SL) grazing with biocontrol or biocontrol alone (BCE or Biocontrol Exclosure), 2) enhance plant species diversity and richness, and 3) enhance livestock grazing efficiency and performance compared to SL. Leafy spurge stem density reduction was greatest ($P \leq 0.05$) on the TOR compared to the SL and BCE on overflow range sites in 2000; however, all three treatments effectively reduced leafy spurge stem densities after four years on both overflow and silty sites. The grazing treatments reduced ($P \leq 0.05$) leafy spurge production after four years, whereas no change ($P > 0.05$) in leafy spurge production occurred across years on the BCE. Grass production increased ($P \leq 0.05$) on all treatments over the four-year study. Species richness and diversity were similar across treatments and years. Cow, calf, and ewe average daily gains (ADG) were similar ($P > 0.05$) between the TOR and SL during all years of the study. Calf ADG improved yearly, with increases ($P \leq 0.05$) in 2000 and 2001 on the TOR, and 2001 on the SL. Multi-species grazing combined with a biocontrol program is an effective method for leafy spurge control on rangeland, providing greater overall leafy spurge control than biocontrol alone.

Effects of herbicides on plant richness and biomass on leafy spurge infested rangeland

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A 5-year experiment to evaluate herbicide treatments on leafy spurge *(Euphorbia esula L.*) control, plant diversity and biomass production was established in southeastern Montana. Herbicides were applied for three consecutive years and evaluated for two years after the last treatment. Twenty-one treatments were evaluated on a loamy soil with vegetation classified as a crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) plant community. The study design was a randomized complete block design with three replicates. All herbicide treatments reduced leafy spurge density. Picloram for three consecutive years at 0.56 kg ha-1 provided the greatest amount of control among spring applied treatments. Fall applied treatments of picloram plus 2,4-D applied at 0.56 plus 1.1 kg ha-1 and picloram plus 2,4-D applied at 0.28 plus 1.1 kg ha-1 provided the greatest amount of control. These treatments reduced leafy spurge stem density by 90%. In addition, all herbicide treatments reduced plant species richness. Quinclorac and imazapic were the least detrimental, reducing richness by 43 and 50% respectively. Conversely, Landmaster BW and 2,4-D, Dicamba, and picloram plus 2,4-D treatments reduced plant species richness by 80, 73 and 73%

respectively. Dichlobenil and 2,4-D reduced herbage production of graminoid species among spring applied treatments by 51 and 50% respectively while picloram applied in the fall at 0.56 kg ha-1 and 2,4-D reduced herbage production by 33 and 34% respectively. Among spring or fall applied herbicides, picloram plus 2,4-D applied at 0.56 plus 1.1 kg ha-1 resulted in the greatest control of leafy spurge.

Integrated management of leafy spurge

James S. Jacobs and Roger L. Sheley*

Our objective was to determine effects of multi-species grazing combined with *Aphthona* on leafy spurge infested rangeland. On two western North Dakota sites, divided into pastures of 25 to 79 hectares, there were two grazing treatments: season-long with 7-10 cow/calf pairs and 20-25 sheep from late May through mid-September, and rotational with 18-21 cow/calf pairs and 45-50 sheep for three weeks twice per year. Grazing treatments started in 1999 and ended in 2001. Four grazing exclosures were constructed in each pasture in 1998. *Aphthona* were released in 1998. Cover of leafy spurge, grass and forbs, and density of vegetative and flowering leafy spurge stems were measured in July 1998 through 2002. *Aphthona* densities were estimated July 1999 through 2002. Grazing initially increased leafy spurge vegetative stem density, but by 2002, grazing decreased vegetative stem density from 104 in 1999 to 20 stems/m^2. Season-long grazing reduced vegetative stem density by over 30 stems compared to rotational grazing. Leafy spurge flowering stems decreased from 80 stems/m^2 in 1998 to 4 stems/m^2 in 2002 in all plots. The decrease was more rapid when grazing was combined with *Aphthona.* Initially, *Aphthona* densities were greater in the grazed areas than the exclosures, but by 2002, more *Aphthona* were found in the exclosures than the grazed areas. Grass cover was reduced by grazing and forb cover was increased by grazing. Results suggest a synergistic effect of combining multi-species grazing and *Aphthona* when restoring spurge infested grasslands.

Nutritional composition of leafy spurge in North Dakota and Montana

Kevin K. Sedivek and Chad W. Prosser*

Leafy spurge is an introduced perennial plant that is highly competitive and displaces native vegetation. Although herbicides have been the tool of choice for controlling small infestations, grazing with sheep and goats has been successful for large infestations and environmentally sensitive areas. Since sheep graze leafy spurge, the plant's nutritional composition was evaluated. The study objective included evaluating the nutritional composition of leafy spurge in North Dakota and Montana. A location effect ($P<0.05$) occurred between study sites. Crude protein (CP) was similar ($P>0.05$) between years; however, reduced ($P<0.05$) throughout the season in North Dakota, ranging from 18.1 percent in May, 12.1 percent in late June, and 6.2 percent in October. A year effect ($P<0.05$) for CP occurred at the Montana site, ranging from 10.4 and 14.3 percent in late June to 4.8 and 8.1 percent in October of 2000 and 2001 respectively. CP content was different ($P<0.05$) between plant parts. CP ranged from 18.1 and 16.1 percent in leaves in North Dakota and Montana respectively. In comparison, CP of stems was 4.8 and 5.2 percent at North Dakota and Montana; respectively. *In vitro* dry matter digestibility (IVDMD) followed similar trends with year and seasonal effects ($P<0.05$) occurring in Montana, and, only seasonal effects occurring in North Dakota. IVDMD was higher in leaf tissue (74 and 72 percent) than stem tissue (36 and 40 percent) in Montana and North Dakota respectively. CP and IVDMD were highest, early in the growing season, with leaf tissue having the highest value among plant parts.

Toward a decision support system for leafy spurge-infested plant communities

Matt J. Rinella, Roger L. Sheley and Daniel Goodman*

Technology estimating the probability that various species or functional group compositions will result from different management options, would enable invasive plant managers to make well-informed decisions. In ongoing efforts to develop that technology we used competition experiments to develop/select deterministic time series models that predict grass and leafy spurge response to management. The predictive capability of these models were evaluated using data from herbicide, revegetation and selective plant removal experiments. Predicted lines were centered on observed values for most accuracy assessments indicating that there are no consistent differences between the system used to develop the models and the system used to assess them. Bayesian parameter estimation techniques were used to develop stochastic versions of the deterministic models. Prior probability distributions on competition parameters were developed from herbicide, revegetation and selective plant removal experiments. These prior distributions and non-informative prior probability distributions describing intrinsic rates of population increase, carrying capacities and standard deviations of error terms were updated with competition experiment data using likelihood functions. Because the response variables from the stochastic models are probability distributions, probabilities that particular shifts in leafy spurge and grass production will result from management actions are estimated.

Application of advanced remote sensing and modeling techniques for the detection and management of leafy spurge: Challenges and opportunities

Ralph R. Root, Gerald L. Anderson, Steve N. Hager, Karl E. Brown, Kathleen B. Dudek, Raymond F. Kokaly, Carol S. Mladinich, Susan F. Stitt and Monica Ruiz-Bustos*

From 1998 through 2003 an interdisciplinary team of research scientists examined the capabilities of multiple types of hyperspectral and multispectral remote sensing systems with varying spatial resolutions for detecting and mapping *Euphorbia esula* L. (leafy spurge) infestations in and adjacent to Theodore Roosevelt National Park in southwestern North Dakota. Some members of the team also used existing geospatial information to develop a predictive spread model of leafy spurge for the same study area. This paper summarizes the leafy spurge classification results from each of the sensors and the predictive model with cost comparisons to determine the most cost efficient way of mapping leafy spurge in larger regions. Verification of leafy spurge classifications was accomplished by GPS field crews and biologists who described vegetation cover and estimated density and biomass of leafy spurge and associated vegetation at over 500 plots throughout the study area. Cost/benefit analyses of each of the sensors and the modeling approach indicates that use of existing and future satellite-based, multispectral sensors (MSS), possibly combined with broad-scale modeling, offers the most cost efficient path for regional mapping of leafy spurge infestations, with classification accuracies ranging from 60%-70%. Hyperspectral sensors yielded slightly better overall classification results (63%-78% accuracy) at all spatial scales, but analyses were more costly because of additional spatial and spectral preprocessing requirements. Hyperspectral sensors are also limited by narrow swath width, geo-referencing issues, and aircraft platforms.

Landscape assessment of leafy spurge at Theodore Roosevelt National Park, North Dakota: Modeling and mapping approach

Karl E. Brown and Mohammed A. Kalkhan*

Leafy spurge is a durable, troublesome invasive weed with significant economic and social costs. The economic results in the northern Great Plains have made the study and control of leafy spurge a current and important research topic. Leafy spurge was first reported in Theodore Roose-velt National Park (THRO) in the late 1960's. The latest 1998 estimate was 1,198 ha of the 18,680 ha 'South (Management) Unit.' The primary study objectives were to define the relationships between various physical factors of slope and slope position, aspect, elevation, and soil type as they contribute to aggregate soil moisture on the landscape where leafy spurge exists. Spatial statistical analysis was used to develop a thematic mapping classification for leafy spurge, to evaluate spatial auto-correlation and cross-correlation statistics between leafy spurge and physical environmental variables, and to develop the Ordinary Least Squares (OLS) based on stepwise regression analysis and examining residual characteristics using kriging based on semi-variogram models. The lowest values of standard errors, Akaike's Information Criteria (AIC) statistics, and high R^2 served as the selection criteria for all models. Additionally, semi-variogram analysis and kriging of the residuals for the combined model (OLS and trend surface) improved the R^2 over the OLS procedure alone. This study concluded that the OLS and kriged model of leafy spurge probability was superior over the OLS alone in performance, and that the slope, aspect, and zone (slope position) exhibited significant cross-correlation with elevation in the presence of spurge on the landscape.

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Mapping leafy spurge by identifying signatures of vegetation field spectra in Compact Airborne Spectrographic Imager (CASI) data

Raymond F. Kokaly, Gerald L. Anderson, Ralph R. Root, Karl E. Brown, Carol S. Mladinich, Steve N. Hager and Kathleen B. Dudek*

The invasive species leafy spurge *(Euphorbia esula)* is a major management problem in the western United States. This paper describes the results of using field-based measurements of leafy spurge and other vegetation, spectral feature analysis methods, and data from the Compact Airborne Spectrographic Imager (CASI) to map the distribution of leafy spurge in Theodore Roosevelt National Park, North Dakota, USA. CASI data were collected in July 2000 and July 2001. Concurrent field measurements of vegetation reflectance were made on the day of each flight and several days before and after. Areas infested by leafy spurge (density from 20 to 90% cover) and areas of non-infested, native vegetation (grasses, forbs and shrubs) were measured.

Results from spectral feature comparisons showed that leafy spurge spectra from field measurements made in 2000 matched field measurements of leafy spurge in 2001 at 82% accuracy. The USGS Tetracorder system, a spectral feature comparison algorithm, was used to compare each pixel of CASI data to the 2001 field spectra. The resulting leafy spurge map, comprised of pixels which most closely matched leafy spurge, was compared to field surveys. The results show an overall accuracy of 74%. Error of omission was considerably larger than error of commission. A comparison of CASI data from 2000 and 2001, shows an overall decrease in leafy spurge cover. This method for mapping leafy spurge is a useful tool for investigating the temporal changes of leafy spurge cover in relation to climatic, edaphic, and anthropogenic controls on leafy spurge population dynamics.

The use of Earth Observing-1 Hyperion data for mapping of leafy spurge

Ralph R. Root, Pablo Zanco-Tejada, Carlos Pinilla, Susan Ustin, Raymond F. Kokaly, Gerald L. Anderson, Steve N. Hager*

In a series of research studies sponsored by the The Ecological Area-wide Management (TEAM) Leafy Spurge program, a variety of sensors have been tested for their ability to map leafy spurge. This study focuses on the Earth Observing-1 (EO-1) Hyperion, the first, earth orbiting, imaging spectrometer. This research was undertaken within a NASA sponsored science validation team that sought to validate several types of new remote sensing technologies implemented on the EO-1 satellite, which was launched in November 2000. Three different analysis approaches applied to data collected in July, 2001 over the western part of Theodore Roosevelt National Park yielded classification accuracies ranging from 63% to 78%. Leafy spurge stands mixed with as much as 65% of other grass and shrub species were detectable. Even though Hyperion had the coarsest spatial resolution of all the sensors tested, the tendency for leafy spurge to grow in spatially extensive stands makes it feasible to map at a 30 m ground sampling size. Orbiting imaging spectrometers are of limited use at the present time for collecting data over large areas, however, future sensor designs with improved signal to noise ratios and wider swath width may eventually enable more widespread use of this technology.

Temporal monitoring of leafy spurge: An example using 1999 and 2001 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data over Theodore Roosevelt National Park

Kathleen B. Dudek, Ralph R. Root, Raymond F. Kokaly, Gerald L. Anderson, Karl E. Brown, Carol S. Mladinich, Susan F. Stitt, Steve N. Hager and Michael A. Lefsky*

From 1827 when leafy spurge (*Euphorbia esula* L.) was introduced into North America, it has spread throughout the northern Great Plains where it is currently a significant management concern. Accurate, rapid location of the weed is critical for economical control, while repeatable measurements are necessary for temporal monitoring of its response to control methods. Leafy spurge has been located using remote sensing in the past, but development of standardized mapping procedures has been problematic. Using commercially available software and algorithms, Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data, collected in 1999 and 2001 over Theodore Roosevelt National Park, N.D., were used to locate leafy spurge and document the effectiveness of biological and chemical controls. Published image-processing methods were tested, with best results obtained using a modified mixture-tuned matched filtering (MTMF) algorithm. The image-processing protocol appears to be temporally and spatially portable. Map accuracies were analyzed with two independent data sets. Accuracy varied from 35 to 70%, demonstrating that some validation data were

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more appropriate for assessing detailed maps of small, fragmented patches of leafy spurge. Confusion matrices were misleading due to sensitivity to: 1) registration offsets between field and image locations; 2) modifications of the analysis procedure; and 3) the method used to acquire field data. Qualitative evaluation indicated that the maps realistically represent actual cover. A 40% decrease in leafy spurge was estimated between 1999 and 2001. Pixel-by-pixel change detection was difficult due to misalignment between multi-temporal images, but yielded general change patterns that should prove valuable for monitoring leafy spurge.

The use of Landsat 7 ETM+ data for mapping leafy spurge

Carol S. Mladinich, Monica Ruiz-Bustos, Susan F. Stitt, Ralph R. Root, Karl E. Brown, Gerald L. Anderson and Steve N. Hager

Euphorbia esula L. or leafy spurge, an invasive weed, is a major problem in much of the Upper Great Plains region, which includes parts of Montana, South Dakota, North Dakota, Nebraska, and Wyoming. Leafy spurge displaces native grasses and forbs in prairie habitats and fields resulting in the degradation of the badlands and prairie ecosystems and is a major threat in many national parks in the region. This study explores the use of Landsat 7 ETM+ imagery as a management tool to map leafy spurge in Theodore Roosevelt National Park (TRNP) in southwestern North Dakota. An unsupervised clustering algorithm was used to map potential leafy spurge classes. An overall accuracy assessment of 63% was achieved with this technique. While this sensor does not provide the accuracy required for detailed mapping of the weed, it may be sufficient as a broad scale, regional indicator of potential leafy spurge occurrences. This paper offers recommendations to the suitability of Landsat 7 ETM+ imagery as a key tool for use by resource managers to monitor leafy spurge control measures in the park.