Biological Control of Leafy Spurge: Utilization and Implementation

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Abstract

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 Agricultural Research Service and Animal and Plant Health Inspection Service, US Department of Agriculture, initiated a major Integrated Pest Management (IPM) research and demonstration project, The Ecological Area-wide Management (TEAM) Leafy Spurge (TLS), to develop and demonstrate ecologically based IPM strategies that can produce effective, affordable leafy spurge control. A key component of the TLS project was expanding the use of biological control agents. To assess the level of insect utilization and implementation and the level of current and perceived future control of leafy spurge as a result of biological control agents, a mail survey of 468 individuals that obtained biological control agents (insects) at TLS-sponsored events and of all the county weed boards in North Dakota, South Dakota, Montana, and Wyoming was conducted. Forty-six percent of the landowner/land managers and 70% of the county weed boards responded to the questionnaire. Respondents reported basic information about the number and characteristics of release sites, and characteristics of the leafy spurge stands, as well as the level of control to date and perceived level of eventual control.

Resumen

"Leafy spurge" es una maleza perenne, exótica y nociva la cual esta ampliamente establecida en la parte norte-centro de Estados Unidos de América, y es un problema especialmente serio en las Grandes Planicies del Norte. En 1977, el Servicio de Investigación Agrícola y el Servicio de Inspección Sanitaria de Animales y Plantas del Departamento de Agricultura de Estados Unidos inicio un proyecto de investigación y demostración sobre Manejo Integrado de Plagas (IPM), el proyecto TEAM "Leafy Spurge" (TLS), para desarrollar y demostrar estrategias de IPM con bases ecológicas que puedan producir un control efectivo y económicamente viable del "Leafy spurge." Un componente clave del proyecto TLS fue ampliar el uso de agentes de control biológico. Para evaluar el nivel de implementación y utilización de insectos y el nivel actual y la percepción futura del control de "Leafy Spurge" como resultado de agentes de control biológico se condujo una entrevista a través del correo a 468 personas que obtuvieron agentes de control biológico (insectos) en eventos financiados por el TLS y a todos los comités de control de maleza municipales en North Dakota, South Dakota, Montana, y Wyoming. El 46% de los propietarios de tierras/manejadores de tierras y el 70% de los comités de control de maleza respondieron el cuestionario. Los que respondieron reportaron información básica acerca número y características de los sitios de liberación, las características de las poblaciones de "Leafy Spurge," así como del nivel de control a la fecha y el nivel percibido de un control eventual.

Key Words: *Aphthona* spp., flea beetle, noxious weeds, weed management

INTRODUCTION

Leafy spurge (*Euphorbia esula* L.), a noxious perennial weed native to Europe and Asia, has become widely established in North America and is now reported in 35 states and all but one Canadian province (Anderson et al. 2003). The weed has become a serious problem for ranchers and public land managers in the northern Great Plains states of Montana, North Dakota, South Dakota, and Wyoming, where an estimated 1.6 million acres (657 000 ha) are infested, resulting in an annual economic loss of $130 million (Leitch et al. 1996; Leistritz et al. 2004). Leafy spurge has proven particularly difficult to control on untilled land because of its ability to spread rapidly, displace native vegetation, and sustain itself despite repeated chemical treatments. Although extensive research has been devoted to developing more efficacious herbicide treatments, analyses to date indicate that chemicals offer, at best, only short-term control (Bangsund et al. 1996; Anderson et al. 2003) and the costs of repeated herbicide treatments limits their use (Sell et al. 1999; Hodur et al. 2002a, 2002b). As a result, alternative control methods have generated substantial interest, with biological control using introduced insect predators being increasingly viewed as a promising approach (Bangsund et al. 1999; Hodur et al. 2002a, 2002b; Lym 2005).

Leafy spurge was identified as a candidate for biological control when observations in the plant's native habitat (Europe and Asia) indicated that a variety of natural enemies appeared to keep the plant's density below the economic threshold (Carlson and Littlefield 1983). By the mid-1980s, several *Aphthona* flea beetle species had been identified as potential biological control agents and were approved for release by APHIS (US Animal and Plant Health Inspection Service). The first of these, *Aphthona flava*, was initially released in

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1985, followed by *A. nigriscutis* in 1989 and *A. lacertosa* in 1993 (Anderson et al. 2003). Efforts to collect biological control agents from the initial release sites and transplant them to other locations intensified during the 1990s (Kirby et al. 2000; Lym and Nelson 2002; Larson and Grace 2004). Numerous local and state government entities, federal and state land management agencies, and individual landowners were active partners in this effort (Hansen et al. 1997; Lym 2005).

In 1997, the US Department of Agriculture, Agricultural Research Service (USDA–ARS) and APHIS initiated a major Integrated Pest Management (IPM) research and demonstration project, The Ecological Area-wide Management of Leafy Spurge, TEAM Leafy Spurge (TLS). The project's mission was to develop, integrate, and communicate ecological, economical, and sustainable leafy spurge management techniques to private landowners and public land managers, as well as federal and state decision makers. The TLS project focused on a multicounty area in southwestern North Dakota, southeastern Montana, northeastern Wyoming, and northwestern South Dakota. TLS programs and activities included six demonstration sites in four states, presentations at numerous state and local weed control meetings, the creation of a variety of educational publications, and sponsorship of several field days. One component of the TLS project was to encourage and facilitate the use of integrated pest management control practices utilizing biological control agents through education and outreach programs. Numerous publications (USDA–ARS 1999) were created to communicate the proper use of biological control agents, and TLS program members gave many presentations throughout the study area on the proper utilization of biological controls. To further facilitate the use of biological control agents, TLS field day events were used to distribute insects (*Apthona* spp.) to landowners and land managers and to provide instruction on the proper use and release of the insects.

The degree with which landowners and landmanagers had utilized biological control was of interest to TLS. A number of authors have examined ranchers' adoption of various management innovations and/or evaluated the effectiveness of extension/outreach programs. Many of the papers focused on characteristics of adopters rather than program evaluation. Didier and Brunson (2004) interviewed Utah ranchers who had been identified as innovators. They found that these ranchers were generally ranching full-time, were primarily dependent on ranch income, and indicated a strong, long-term commitment to ranching. Rowan and White (1994) found that Texas ranchers who treated their pastures for weeds and brush also received higher than average percentages of their family income from livestock sales and lower percentages from off-ranch employment. Coppock and Birkenfeld (1999) found the use of 26 different range and livestock management practices differed substantially among Utah ranch operators, with larger ranch size and higher levels of operator education and income being associated with using more practices. Alston and Reding (1998) also examined farm characteristics in order to determine which characteristics influence adoption of integrated pest management systems. They found various farm characteristics, such as percent of household income from farm income and farm size, do influence adoption and suggested that farm characteristics should be considered when crafting education and outreach programs. Peterson and Coppock (2001) also surveyed Utah ranchers to determine their management approach. About 80% of respondents were passive (i.e., not active) managers; the most common reasons for a passive management style were imminent retirement and economic constraints (e.g., low cattle prices, low returns on ranch investments).

Other research has focused on evaluation of extension/outreach programs. Kreuter et al. (2001) surveyed Texas county extension agents to evaluate the success of a research–extension program on brush management. The agents reported that the new program had generated a high level of producer interest and felt that the main reasons for this interest were its relatively low cost, ease of application, safety/selectivity, and effectiveness/predictability. Fernandez-Gimenez et al. (2005) evaluated Arizona Cooperative Extension Service's Rangeland Monitoring Program, using focus groups and a mail survey of grazing permittees and natural resource agency employees. They found that the extension program has been effective in reaching a large part of its target audience, although overall monitoring rates remain low. Drost et al. examined barriers to adoption of sustainable agriculture practices in Utah (Drost et al. 1996). Hodur et al. (2002a, 2002b) reported landowners' and land managers' perceptions regarding leafy spurge control and an assessment of the effect of the TLS project on respondents' weed control practices.

While previous research offered insight into the characteristics of and impediments to adoption of new management practices, TLS was interested in the level of adoption and adopters' perceptions of current and future leafy spurge control. To gauge the level of implementation of biological controls and assess respondent's perceptions of the level of control as a result of biological control agents, a survey of landowners and county weed boards was conducted in 2002. Study objectives were to assess utilization and implementation of biological control agents by landowners in the TLS study area and in the larger four-state area. The survey sought to identify to what degree biological control agents had been used and in what type of conditions. The survey also sought to gauge respondent's perceptions of current and future level of control as a result of biological control agents.

METHODS

A mail survey was delivered to landowners who received *Aphthona* beetles at TLS field days and other TLS events and to all county weed boards in the four-state TLS study area. Surveys were mailed to 202 county weed boards and 468 landowners/land managers in April 2002. After a second mailing, a total of 144 county weed board questionnaires were received for a response rate of 71.3%. The landowner group returned 217 usable questionnaires for a response rate of 46.9%. Duplicate mailings or questionnaires returned "undeliverable" were not included in the effective response rate. The approach was similar to that described in Dillman (1978). Given the high response rate, no investigation of nonresponse bias was deemed necessary.

Both weed board and landowner surveys elicited information regarding the use of biological control agents, including the number of release sites, month agents were released, attributes of the release sites, evidence of leafy spurge stand reduction, and

Table 1. Respondent demographics: landowners, 2002.

Item	Landowners
Acres farmed/ranched	percent
< 1 500 acres	36.2
1 500–2 500 acres	19.0
2 501–5 000 acres	14.7
5 001–10 000 acres	16.6
> 10 000 acres	13.5
(No.)	(163)
Gross farm income, 2001	
less than $50 000	51.1
$50 000–100 000	15.1
$100 001–200 000	20.8
> $200 000	13.0
(No.)	(139)

perceptions regarding future control levels. The questionnaire also attempted to gauge the relative effectiveness of TLS education and outreach efforts by asking questions related to when and under what conditions insects were released. Research has indicated that biological control agents have varying levels of success, depending on various conditions such as time of release, soil type, and shade or full sun. The questions were designed to gauge whether or not TLS was able to effectively communicate the proper timing and release of biological control agents.

RESULTS

Characteristics of Landowner Respondents

Most landowner respondents were North Dakota residents (61%), likely because two major TLS events were held in North Dakota. Most landowner respondents (nearly two-thirds) were either full- or part-time farmers or ranchers, whereas most weed board respondents' occupations were government/public sector. Respondents to the county weed board survey were also most frequently from North Dakota (29%), but the distribution among states was more balanced than the landowner survey (data not shown).

The amount of land owned or operated by the landowners varied, with 36% reporting less than 1 500 acres, and 13% reported over 10 000 acres. Gross farm/ranch income also varied substantially, with 51% reporting less than $50 000 in gross farm income, and 13% had gross farm incomes greater than $200 000 (Table 1). About 63% of respondents reported that more than half of their gross farm income was from livestock grazing (data not shown). Average age of respondents was nearly the same, 52 years for the landowners and 50 years for the county weed board group.

County Weed Infestations and Biological Control Implementation

County weed board representatives were asked to estimate the acreage of leafy spurge in their county and reported average infestations of 10 192 acres of leafy spurge. The mean value should be viewed with caution as a few extreme observations make the mean value somewhat misleading. Three percent reported no leafy spurge, and 28% reported 10 000 acres or more (Table 2). Median acres were 6 650 and the mode was 1 000. Total acres of leafy spurge reported by the county weed board respondents was nearly 1.4 million acres (Table 2).

Table 2. Evaluation of leafy spurge infestations and biological control: county weed boards, 2002.

Item	Percent
Acres of leafy spurge	
zero acres	2.9
1–100 acres	13.9
101–500 acres	7.3
501–2 000 acres	20.4
2 001–5 000 acres	13.1
5 001–10 000 acres	14.6
> 10 000 acres	27.7
(No.)	(137)
Acres of leafy spurge per county	
Average	10 192
(SE)	(1 455)
Median	6 650
Mode	1 000
(No.)	(137)
Total acres of leafy spurge reported	1.4 million
(No.)	(137)
Extent of flea beetle implementation	
Not at all	11.1
Very little	21.5
Somewhat	34.8
Extensively	20.7
Very extensively	11.9
(No.)	(135)

Across the study area, a substantial number (89%) of county weed boards have utilized biological control agents as part of their leafy spurge control efforts (Table 2). In contrast, 61% of county weeds boards in the same four-state area utilized a biocontrol agent in 1997 (Bangsund et al. 1997). When asked how extensively biological control using *Aphthona* flea beetles had been implemented in their county, responses varied; 11% of county weed boards indicated biological control has not been implemented at all, and 12% indicated very extensive implementation of biological controls (Table 2). A contingency table revealed a relationship between the extent of leafy spurge infestations and biological control implementation. Among counties reporting less than 1 000 acres of leafy spurge, 58% indicated biological control had been implemented very little or not at all. Those counties reporting 1 001 to 5 000 acres of leafy spurge were fairly evenly divided between little or no utilization (31%), some utilization (38%), and extensive or very extensive utilization (31%). In counties that reported infestations of 5 000 acres or more reported greater utilization, 44% reported utilizing flea beetles extensively or very extensively, with 39% reporting utilizing biological controls somewhat, and only 17% indicating little or no utilization (Table 3).

Table 3. Extent of flea beetle utilization by acres of leafy spurge: county weed board representatives, 2002.

Acres of leafy spurge reported in county	Little or no utilization	Utilized somewhat	Extensive or very extensive utilization
	---------- percent ----------		
< 1 000	57.9	26.3	15.8
1 001–5 000	31.2	37.5	31.2
> 5 000	17.5	38.6	43.9
(No.)		(127)	

Table 4. Number of *Aphthona* release sites in the last four years: landowners, county weed boards, 2002.

	County weed boards	Landowners
Distribution of the number of sites	---------- percent ----------	
zero	15.0	0.0
1–10	31.9	57.6
11–25	16.8	23.3
26–50	12.4	10.5
51–150	13.3	6.4
≥ 151	10.6	2.3
(No.)	(133)	(172)
Number of release sites		
Total	9 534	10 227
Average	84	59
(SE)	(23)	(27)
Mode	10[1]	4
Median	20[1]	8
(No.)	(113)	(172)
Sources of flea beetles[2]		-- percent --
TLS field days	n/a	62.0
County weed board	n/a	52.0
County extension agent	n/a	25.7
Sites on own land	n/a	28.5
Sites on others land	n/a	33.5
State dept. agric.	n/a	7.8
Other	n/a	8.4
(No.)		(179)

[1]Respondents indicating zero releases not calculated in the mode or median. Mode is 0 and median is 12 when zero releases are included in the calculation.
[2]Does not sum to total due to multiple responses.

The number of release sites in the last four years reported by county weed boards varied considerably. (Respondents were asked about the number of releases in the last four years to coincide with the TLS project.) The county weed boards reported a total of 9 534 release sites, for an average of 84 release sites per county. The average, however, does not reveal the large range in the number of releases made by county weed boards and should not be used as a single indicator. Fifteen percent of county weed boards reported no release sites in the last four years and almost 50% indicated 10 or fewer release sites. Alternately, 11% had 151 or more release sites (Table 4). The mode was 10 release sites and the median, 20 release sites. Using the average alone as an indicator would overstate the number of release sites in most counties. Even though the average number of release sites tends to overstate utilization per county, the fact that 85% of county weed board respondents had at least one release site suggests high adoption rates across the four-state area.

Distribution of landowner releases also varied considerably but not as extremely as for the weed boards. The average number of releases was 59 even though most landowner respondents (58%) reported 1 to 10 release sites. Although only 2.3% had 151 or more release sites, the outliers distorted the mean. The median number of releases was 8 and the mode 4 (Table 4).

TLS Field Days were most frequently reported by the landowners (62%) as the source of *Aphthona* flea beetles (Table 4). Considering that the survey population was individuals who received flea beetles at a TLS event or attended a TLS event where flea beetles were distributed, that result is not surprising. Half of the landowners indicated county weed boards were their source. It is likely that many or at least some of the flea beetles distributed by weed boards were also from TLS. TLS made concerted efforts to distribute *Aphthona* flea beetles to county weed boards for further redistribution. Most releases in the past four years (1998–2001) were in the month of June (50%), with most of the remaining releases made in July (approximately one-third), with less than 5% of releases in August. The high percentage of release sites in June and July is a positive indicator for TLS outreach and education efforts. TLS publications directed readers to make sure insect releases were made before the insects laid their eggs and that releases later than mid-July would generally be considered too late (USDA–ARS 1999).

Release Site Attributes

Landowners and county weed boards reported site attributes on over 8 000 release sites each. The most common land use at the release sites was rangeland, accounting for 91% of landowner release sites and 81% of weed board sites. Considering that leafy spurge primarily infests rangeland, a high percentage of rangeland sites would be expected. Riparian areas were a very distant second (6% and 10%, respectively) (Table 5). Most often releases were made on sunny, well-drained sites (61% of landowner and 66% of weed board sites) with loamy soil (37% of releases for landowners and 56% for weed boards). Shaded sites accounted for only 23% of landowner releases and 21% of weed board releases, and poorly drained sites accounted for only 8% of landowner and 6% of weed board releases. The fact that most of the release sites were on sandy or loamy soils on sunny, well-drained sites, also provides a good indicator of the outreach and education efforts of TLS. TLS publications described sunny dry locations with some slope (for drainage) as site characteristics that increase the chances of successfully establishing flea beetles (USDA–ARS 1999).

Both groups most often made releases in heavy stands (>120 plants · m^{-2}) of leafy spurge—61% for landowners and 44% for weed boards, but the two groups targeted different-sized infestations. Landowners most often released flea beetles in leafy spurge infestations covering 1 acre or less (48%), whereas weed boards more frequently targeted leafy spurge patches of more than 10 acres (45%). Black flea beetles (*A. lacertosal czswalinae*) were more frequently released by both landowners

Table 5. Release site attributes: landowners and county weed boards, 2002.

Site attribute	County weed boards	Landowners
Land use	-------- percent of release sites--------	
Rangeland	81.1	90.7
Hayland	3.3	1.4
Conservation Reserve Program	1.8	1.1
Road ditch	1.6	0.2
Fence line	2.0	0.9
Riparian area	10.2	5.7
(No.)	(8 602)	(8 365)
Soil type		
Sandy	28.5	31.7
Loamy	55.6	36.8
Clay	15.8	31.4
(No.)	(13 389)	(6 300)
Drainage/topography		
Sunny sites, well-drained	66.2	61.2
Sunny sites, poorly drained	13.7	15.5
Shaded sites, well-drained	14.5	15.1
Shaded sites, poorly drained	6.1	8.2
(No.)	(13 496)	(8 951)
Stand density		
Light (< 25 plants/sq. yard.)	15.7	10.6
Moderate (25–100 plants/sq. yard)	39.9	28.6
Heavy (> 100 plants/sq. yard)	44.4	60.8
(No.)	(13 425)	(9 039)
Spurge height		
Short (< 2 feet)	34.1	55.9
Medium (2–3 feet)	53.7	35.6
Tall (> 3 feet)	12.2	8.5
(No.)	(13 374)	(8 940)
Infestation area		
< 1 acre	27.6	47.6
1–10 acres	27.8	19.2
> 10 acres	44.6	33.2
(No.)	(10 965)	(8 213)
Flea beetle type		
Black (*A. lacertosa*/*czswalinae*)	36.4	57.9
Brown (*A. nigriscutis*)	33.3	21.2
Mixed (black and brown)	30.4	20.9
(No.)	(13 791)	(9 848)
Number of beetles per site		
< 3 000	66.0	81.3
3 000–9 999	24.7	15.1
10 000–50 000	9.1	3.0
> 50 000	0.9	0.6
(No.)	(13 582)	(9 608)

and weed boards, and the bulk of releases by both groups consisted of less than 3 000 insects (Table 5). There were, however, a few respondents who reported very large releases of more than 50 000 insects.

Table 6. Distribution of sites, number of sites used for collection, and extent of control: landowners, county weed boards, 2002.

Item	Weed boards	Landowners
	---- percentage of respondents----	
Respondents that monitored sites	82.3	87.3
(No.)	(113)	(173)
Monitored sites		
Total	3 447	5 653
Average	42	4042
(SE)	(14)	(21)
Median	10	6
Mode	10	2
(No.)	(81)	(141)
Distribution of monitored sites	---- percentage of respondents----	
< 5	29.6	41.1
5–15	30.9	36.2
16–30	19.7	9.9
31–75	7.4	7.8
> 75	12.4	4.9
(No.)	(81)	(141)
Extent of stand reduction on monitored sites	--------- percentage of sites --------	
No evidence	20.1	9.6
Small reduction	16.6	23.6
Moderate reduction	23.6	36.2
Substantial reduction	39.7	30.6
(No.)	(5 665)	(857)
	---- percentage of respondents----	
Collections and redistribution		
Collected beetles from release sites	61.3	44.0
(No.)	(93)	(150)
Number of collection sites	---------- number of sites ----------	
Total	682	477
Mean	12.2	7.1
(SE)	(2.9)	(1.8)
Median	3	3
Mode	1	2
(No.)	(56)	(64)
Distribution of collection sites	---- percentage of respondents----	
< 5 sites	64.3	75.0
6–15 sites	16.1	14.1
> 15 sites	10.7	10.9
(No.)	(56)	(64)
Biological control has met expectations		
Yes	67.6	70.1
(No.)	(105)	(164)

Collection and Redistribution and Extent of Stand Reduction

Most of the landowners (87%) and weed boards (82%) had monitored some or all of the sites where flea beetles had been released (Table 6). Landowners reported monitoring over 5 000 sites and county weed boards reported monitoring over 3 000

Table 7. Evaluation of effectiveness of leafy spurge control practices: landowners and weed boards, 2002.

Item	Landowners		County weed boards	
	Very effective	Pays	Very effective	Pays
	--------- percent --------		--------- percent --------	
Biological control with insects	34.7	63.9	24.4	66.9
(No.)	(167)	(166)	(127)	(133)
Integrated Pest Management (IPM) using two or more practices	41.1*	43.6**	53.8*	67.4**
(No.)	(141)	(133)	(119)	(129)

*Significantly different between study groups ($P \leq 0.05$, Fisher's Exact test).
**Significantly different between study groups ($P \leq 0.10$, Fisher's Exact test).

sites. On average, landowners monitored 40 release sites whereas weed boards monitored 42 sites. Again, the average does not accurately represent respondent actions because a few extreme observations distorted the average. For landowners, median release sites monitored was 6, and the mode was 2. For county weed boards, both the median and mode were 10 sites. That so many respondents monitored release sites is a very positive indicator. By monitoring release sites, landowners and land managers are better able to gauge the relative success of biological controls on various sites under various conditions, which should enable the land manager to better manage leafy spurge infestations.

Of the monitored sites, moderate or substantial reductions in the leafy spurge stand were reported on 67% of landowner sites and 63% of weed board sites (Table 6). Forty percent of the weed boards reported a substantial reduction in infestation and 24% reported moderate reductions. Landowners reported similar reductions in infestations; 31% reported substantial reductions and 36% reported moderate reductions. Twenty percent of weed boards and only 10% of landowners reported no evidence of stand reduction. In addition to monitoring the release sites, more than 61% of weed board representatives indicated they had collected flea beetles for redistribution from over 600 sites, an average of 12 sites per weed board (Table 6). Again, a few extreme observations distorted the mean. Median number of collection sites for county weed boards was 3 and the mode was 1. Nearly half of the landowners surveyed (44%) indicated they had collected flea beetles for redistribution from over 400 sites, an average of 7 sites per landowner. Again, the median and mode provide better indicators than the mean. Seventy-five percent of landowners had collected flea beetles for redistribution on 5 or fewer sites. Mode and median number of collection sites for landowners was 2 and 3 sites, respectively. Seventy-five percent of landowners and 73% of weed board representatives planned to collect insects in the future for redistribution.

Half of the county weed boards also reported they held, on average, 5 field days or similar events to distribute flea beetles to landowners (data not shown). Seventy-six percent of weed boards held between 1 and 4 events. Almost all (98%) of the weed boards that had previously held field days plan to hold more of these events in the future (data not shown). Two-thirds of respondents in both groups indicated biological control efforts had met their expectations (Table 6).

Expected Future Control

In an attempt to gauge respondents' expectations, both landowners and weed board representatives were asked what percentage of leafy spurge stands on their land or in their county they felt would eventually be controlled with flea beetles. Both groups were generally optimistic; however, landowners were somewhat more optimistic than the weed board representatives. One-third of the landowners felt that more than 75% of the leafy spurge stands on their land would eventually be controlled by flea beetles, compared to only 4% of weed board representatives. Further, a majority of landowners (56%) believed that more than 50% of their leafy spurge stands would eventually be controlled by flea beetles, compared to 23% of the weed board representatives. Weed board members most frequently (32%) indicated they expected 26% to 50% of leafy spurge to be controlled by flea beetles. There is no way to know what factors influenced such a large difference in the two groups' expectations regarding future control, especially considering that on many other issues the two groups' responses were quite similar. It is possible that weed board respondents were more cautiously optimistic or perhaps the infestations managed by the county weed boards were larger and less manageable than those of landowners.

Use of Other Control Practices

Respondents were also asked if they used other leafy spurge control practices in addition to biological control. Most respondents used more than one weed control practice to combat leafy spurge, most frequently herbicides. Almost 84% of landowners and 98% of weed board representatives used herbicides to control leafy spurge (data not shown), whereas 24% of landowners and 31% of weed boards reported grazing with sheep and/or goats. Both groups utilized tillage and reseeding with competing grasses less frequently, 15% and 22%, respectively (data not shown).

Evaluation of Control Practices

Both landowners and weed board representatives rated biological control and IPM systems favorably. Forty-one percent of landowners rated IPM as very effective in controlling leafy spurge, and 35% rated biological control as very effective (Table 7). County weed board representatives more frequently rated IPM as very effective, 54% compared to 41% among landowners. Landowners more frequently rated biological control as very effective, than county weed board representatives, 35% compared to 24% (Table 7).

Landowner and county weed board perspectives on whether or not a practice pays were similar with respect to biological controls, but different with respect to IPM systems. County weed boards viewed IPM practices more optimistically. Approximately two-thirds of respondents in each group indicated biological control "pays," but weed board representatives more frequently indicated that IPM systems "pay." Sixty-seven percent of weed board representatives felt IPM pays, compared to 44% of landowners, a significant difference at $P \leq 0.05$ (Table 7).

KEY FINDINGS AND IMPLICATIONS

Although much previous research has focused on identification of the characteristics of adopters and/or impediments to

adoption of biological control practices, this study population consisted primarily of adopters. Further leafy spurge biological control agents lack many of the commonly identified impediments to adoption of new management practices. The landowner group was comprised of known adopters (individuals that received insects at TLS events) with characteristics consistent with previous research findings that suggested individuals that farm/ranch larger acreages and whose primary income is from farming and ranching are more likely to adopt new management practices. Although not every county weed board in the four-state area were known adopters, it would seem reasonable that an organization whose primary purpose is to control weeds would be considered adopters, or at least likely adopters. Frequently cited impediments to adoption also were not a factor in this study. In fact, leafy spurge biological control's low cost compared to alternatives and relative ease of application are two characteristics that typically favor adoption (Kreuger et al. 2001). Accordingly, the main focus in this study was not the characteristics of the adopters, or why the practice was or was not adopted, but rather what have the adopters done and what they perceive the results of their actions to be.

The level of implementation varied widely. Most respondents utilized biological control on a relatively small scale. Even though most respondents used biological control on a small scale, the use of biological control agents to manage leafy spurge infestation is definitely on the rise. The increase in the number of county weed boards using biological control since 1997 (Bangsund et al. 1999) would certainly seem to be a positive indicator in terms of area-wide adoption of the practice.

Private landowners and public land managers that used biological control agents appeared to appropriately time the release and to release insects on sites with conditions most conducive for effective control. Flea beetles were most frequently released on sunny, well-drained rangeland sites, consistent with TLS's message. Although it is not possible to definitively conclude that TLS was solely responsible for the increase in release sites or the timeliness of a release, considering that one of the goals of TLS was to encourage and facilitate the appropriate use of biological control agents, the program's influence should not be discounted.

Landowners and land managers that utilize biological control are also utilizing other control practices in conjunction with biological control. Again, this is a positive indicator because integrating more than one control practice generally yields better results than using a single treatment (Lym 2005). Nearly all the respondents in both groups use herbicides in addition to biological control and a quarter of landowners and nearly a third of county weed boards reported grazing with sheep or goats. It would seem reasonable that TLS had some role in communicating that message as most landowner respondents indicated TLS was their source for flea beetles and TLS strived to work closely with county weed boards.

Another positive indicator for ongoing efforts to control leafy spurge is the level of control reported by respondents. That two-thirds of respondents indicated moderate to substantial reductions in infestations is very positive especially when considering the substantial economic losses as a result of leafy spurge infestations (Leitch et al. 1996, Leistritz et al. 2004). Even though a majority of respondents in both study groups monitored biological control release sites (also consistent with TLS's message), further research documenting the level of control is needed. Documentation of successful control efforts surely would act to facilitate expanded use of biological controls.

Perhaps one of the most encouraging insights from this survey was the apparent change in private landowners' and public land managers' perceptions regarding future control of leafy spurge. In addition to reporting reductions in infestations, most respondents indicated that biological control efforts had met their expectations. Their perceptions on future levels of leafy spurge control were also optimistic. In the not too distant past, control efforts were at best short term (Bangsund et al. 1996) and often cost-prohibitive (Sell et al. 1999). Landowners and land managers were frustrated with their inability to manage leafy spurge infestations (Hodur et al. 2002a, 2002b). Respondents' generally positive perceptions regarding future levels of control would suggest that private landowners and public land managers are optimistic about future control efforts, something that historically was not the case.

Although this study is not a definitive examination of the utilization and implementation of biological control agents, it does provide some insight into the number of release sites in the TLS study area, the characteristics of release sites, and the perceived level of control on those release sites. These results would also seem to suggest that TLS's education and outreach efforts at a minimum were effective in communicating the appropriate use of biological control agents to county weed board representatives and public and private landowners who obtained flea beetles from a TLS event. The level of control reported by respondents and the level of optimism expressed by respondents should be useful to extension and outreach professionals as they work to expand the use of biological control agents throughout the upper Great Plains where leafy spurge has been and continues to be a serious problem.

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