AERIAL ASSESSMENT OF LEAFY SPURGE (*Euphorbia esula* L.) ON IDAHO'S DEEP FIRE BURN

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ABSTRACT

High-resolution aerial surveys are a highly effective means for monitoring new and dispersed invasive-species infestations across extensive areas of wildland. Invasive species constitute a leading threat to native vegetation in wildland settings. Monitoring and controlling these species are essential actions to preserving native-plant community integrity and historic wildland character. Infestations continue to increase. Monitoring with conventional ground or lower-resolution aerial data may be problematic as these tools are of questionable value for detecting small or dispersed weed populations. In July 2006, we conducted a dual-camera aerial survey acquiring 1- and 10-mm ground sample distance (GSD) imagery in the Medicine Lodge watershed in eastern Idaho. The survey included most of the 2003 Deep Fire Burn. Survey data were used to determine leafy spurge (*Euphorbia esula* L. [Euphorbiaceae]) distribution on burned and unburned lands and to relate spurge distribution to ecosystem structure, associated vegetation, and control efforts. Leafy spurge was detected in 10% of 10-mm GSD samples versus 8% of 1-mm GSD samples. We conclude that 10-mm GSD is best for detecting leafy spurge because it optimizes the balance between resolution and field-of-view. Litter was about 4% greater where spurge was present than where it was not, and spurge occurrence was associated with significant decreases in cover of native grasses, forbs, and sagebrush (*Artemisia* spp. L. [Asteraceae]). Leafy spurge proximity to water was higher than a random distribution would predict.

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KEY WORDS
digital images, invasive species, light sport airplane, sampling, weed control, Euphorbiaceae

NOMENCLATURE

Plants: USDA NRCS (2009)
Animals: ITIS (2009)

Invasive species, taken together, are one of the most pressing challenges of managing the vast landscapes of the western US. DiTomaso (2000) reported the presence of more than 300 rangeland weeds in the US, and listed 21 as invasive alien species that cause significant problems. He cites cheatgrass (*Bromus tectorum* L. [Poaceae]), leafy spurge (*Euphorbia esula* L. [Euphorbiaceae]), and knapweed (*Centaurea* spp. [Asteraceae]—particularly *C. diffusa* Lam. and *C. stoebe* L. ssp. *micranthos* (Gugler) Hayek) as among the especially noxious weeds that infest more than 1 million ha (2 470 000 ac) across the western US. Public wilderness areas and national parks have been judged at particular risk for new invasions and most lower-elevation public lands have established weed populations (see Parks and others 2005). Land managers of many public and private organizations are faced with more invasive species producing more infestations but they are also often seeing declining monitoring budgets. Yet, the importance of monitoring as part of an effective invasive-species management program is well established. This was further emphasized by the recent report that *unmanaged* weed populations can be expected to increase exponentially within management units (Maxwell and others 2009). Efficiency of invasive-species monitoring for wildlands needs improvement but conventional ground, and lower-resolution (>1 m [3.28 ft] ground sample distance or GSD, a measure of image pixel coverage) aerial monitoring, are of questionable value for detecting small or dispersed weed populations in the interior of large areas. Here we report the utility of very-large scale aerial (VLSA) imagery for detecting small, dispersed populations of leafy spurge across the breadth of a large wildland area. The specific objectives were to assess the information gained from the aerial survey relative to ground information and to relate leafy spurge distribution to the ecosystem structure, native vegetation, and human activities, including weed-control efforts (see Hobbs and Humphries 1995).

METHODS

Study Site

Our survey area, which we refer to as the Medicine Lodge Project Area (MLPA), was centered at lat 44°20'52"N, long 112°33'45"W, northwest of Dubois, Idaho, over 22 130 ha (54 683 ac) of public land extending north from Idaho's Upper Snake River Plain to the Continental Divide on the Montana-Idaho border (Figure 1). The area is administered by the Upper Snake Field Office, Idaho Falls District, US Bureau of Land Management (BLM). It has an elevation mean of 2030 m (6660 ft), ranging from 1710 to 2650 m (5610 to 8695 ft) and a mean, generally south-facing slope, of 10.9 ± 8.1%. Nine perennial streams run through the survey area, making the area especially productive relative to the adjacent plains. Major land uses are livestock grazing, recreation, and wildlife habitat. The native Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri* [Salmonidae]) is present within the watershed (IDEQ 2003) and is classified as a type-2 sensitive species (high likelihood of being listed under the Endangered Species Act in the foreseeable future) by the BLM and the Idaho Department of Fish and Game. In August 2003, a wildfire known as the Deep Fire Burn (DFB) consumed 15 378 ha (38 000 ac) of mountain big sagebrush / Idaho fescue (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle [Asteraceae] / *Festuca idahoensis* Elmer [Poaceae]) with dispersed infestations of leafy spurge (Figures 1 and 2). Average annual precipitation ranges from 305 to 508 mm (12 to 20 in) and was 112% and 136% of normal in 2004 and 2005, respectively (Hankins 2006a).

Leafy-Spurge Control Efforts

Chemical (2,4-D; picloram) and biological (black dot spurge flea beetle [*Aphthona nigriscutis* (Chrysomelidae)], brown legged spurge flea beetle [*A. lacertosa* (Chrysomelidae)], red-headed spurge stem borer [*Oberea erythrocephala* (Cerambycidae)]), control agents were used pre- and post-burn. Some pre-burn control was sporadic and poorly documented; but, beginning five years before the burn (1998), control efforts were documented using geographic information systems (GIS)—the GIS information is presented here. Approximately 297 000 beneficial insects were released at 32 sites prior to the DFB. The fire's effect on the introduced insect population was not assessed. Post-burn, approximately 30 ha (74 ac) were treated annually with herbicide within the burn, yet leafy spurge expanded in drainages and up canyon slopes (Hankins 2006b). Biological-control agents were released in batches of 10 000 insects at 29 and 20 sites in 2004 and 2005, respectively, for a total release of approximately 490 000 insects. Aerial sagebrush seeding occurred in 2004 across 2816 ha (6958 ac). These independent but overlapping treatments resulted in the following management conditions (Figure 1): 1) no spurge-control treatments (untreated); 2) sagebrush seeded; 3) picloram 0.56 kg/ha (0.5 lb/ac) + 2,4-D 0.8 kg/ ha; 4) picloram + 2,4-D + sagebrush seeded. A surfactant was added to both picloram and 2,4-D at a rate of 1:400 solution (1 qt/100 gal). All treatments overlapped with biological-control releases, but the specific area of potential influence by the released populations is not known. Control treatments were targeted at known leafy spurge infestation areas (Figure 1) and were not replicated; therefore, we used GIS analysis to identify covariant environmental factors that differed among the 4 management conditions. The management conditions will be referenced throughout this report.

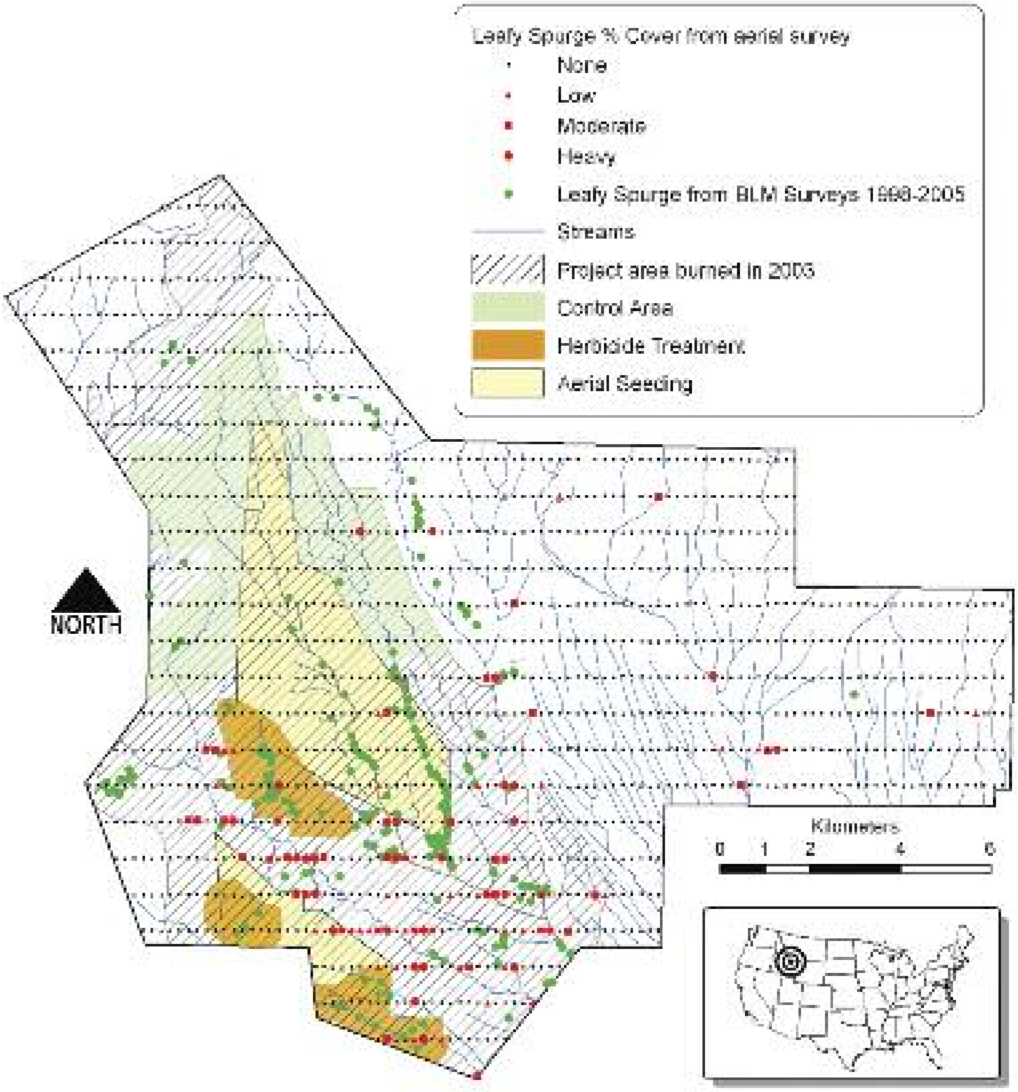


Figure 1. Medicine Lodge study area in Idaho, near the Montana border, showing burned area, streams, and areas of no leafy spurge treatment (control), aerial seeding, and herbicide application. Leafy spurge occurrence was qualitatively assessed from 1378 11-megapixel VLSA samples as none (0%), low (< 30%), moderate (31–60%), or high (> 60%). Leafy spurge occurrence from 1998–2005 BLM ground surveys is shown.

Aerial Imagery

We conducted the VLSA survey in 2006 as a general resource inventory for management purposes to determine the feasibility of using VLSA imagery for assessing ecological condition and for extrapolating the acquired information over the geographic area of interest. Given known infestations of leafy spurge, the survey was scheduled and executed in mid-July when leafy spurge flower bracts aided identification of the plant in the imagery (Everitt and others 1995; Hunt and others 2004). The methods for conducting a VLSA survey have been previously described, including the 2-camera system as used here (Booth and Cox 2006, 2008, 2009). Briefly, we acquired color digital aerial images from a light sport airplane equipped with: 1) a navigation system interfaced with a Wide Area Augmentation System-enabled Global Positioning System (GPS) device; 2) 11- and 16-megapixel, single lens reflex digital cameras (RGB) fitted with 100 mm f/2.0 and 840 mm f/5.6 lenses, respectively; 3) a laser rangefinder used as an altimeter in conjunction with LaserLOG software (Booth and others 2006a) to continuously read and record the airplane's altitude above ground level (AGL) below 300 m; and 4) associated laptop computers and power supply. For our general survey, the navigation system was programmed to automatically trigger the camera at 804-m intervals along 25 flight lines, resulting in images for 1383 locations. We also acquired images for 110 stations over 23 BLM permanent transects.

We simultaneously acquired images having a 3.5 × 5-m field-of-view (FOV) and 1.04-mm (0.04 in) GSD (designated 1-mm GSD) centered within an image having a 29 × 43-m FOV, and 10.7-mm GSD (designated 10-mm GSD). Images were acquired from a flight altitude of 121 m AGL and were initially saved as raw files and later converted to 24-bit Tagged Image File Format (TIFF) files for analysis.

Flight altitude was displayed for the pilot on the screen of one of the laptops storing the images, while stored data were saved for later time-correlation with images. The flight plan was created by extracting coordinates of user-defined points drawn on a digital raster graphic in ArcView 3.3 (Economic and Social Research Institute [ESRI], Redlands, California), then using Track'Air SnapXYZ flight planning software to create the flight plan utilized in flight by Track'Air SnapShot software.

Occurrence and Cover Measurements

Both 10- and 1-mm GSD images were examined for the presence of weeds, riparian areas with and without leafy spurge, disturbance, or other special circumstances. For our purpose, image samples were classified as riparian leafy spurge if a stream channel was in the image FOV. Leafy spurge abundance was visually assessed from images as low (< 30%), moderate (31 to 60%), and high (> 60%) and, by measuring ground cover for every 1-mm-GSD sample from each of the 4 management conditions identified under the Methods subsection Leafy-Spurge Control Efforts (Figure 1). Canopy cover was measured using SamplePoint software with a 100-point grid (Booth and others 2006b). SamplePoint facilitates digital-image point sampling by using single pixels as sample points and by allowing dynamic image magnification ("zoom") on up to 3 monitors to help users understand the context of the sample-point pixel. Where the image GSD is equal-to-or-less than 1 mm, the analysis has a potential accuracy of 92% (Booth and others 2006b).

Here, cover was measured using 535, 1-mm GSD images from the general survey (black dots in Figure 1, cumulatively covering about 0.003% of the management unit area [0.67 ha]) for 22 ground-cover categories: bare ground, litter, gravel, rock, brown grass, brown shrub, brown forb, snakeweed (*Gutierrezia sarothrae* (Pursh) Britton & Rusby [Asteraceae]), sagebrush, rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt. [Asteraceae]), bitterbrush (*Purshia tridentata* (Pursh) DC. [Rosaceae]), unknown shrub, forb, leafy spurge, knapweed, cheatgrass, pricklypear cacti (*Opuntia polyacantha* Haw. [Cactaceae]), unknown herbaceous species, water, willows (*Salix* spp. L. [Salicaceae]), and (other) deciduous or coniferous trees.

Additionally, cover was measured with SamplePoint using 1-mm GSD images over nineteen 30.5-m fire-rehabilitation-plot transects and three 402-m step-point "trend" transects. All transects were established within the DFB perimeter in 2004 by BLM ground crews for vegetation-recovery monitoring. Each transect was covered by one to 8 VLSA images, with each image analyzed by 2 to 4 users. Multiple SamplePoint users allowed us to assess user precision through coefficients of variation (CV). A similar measure of ground-work variation was not done because of the high cost of repeating that effort.

Spatial Analysis

ArcGIS (ESRI, Redlands, California) was used with a digital-elevation model and other spatial data layers to describe image FOV by elevation, aspect, slope, plant community, distance to road, distance to open water, and fires of record. To assess the influence of water on spurge infestations and on treatment efficacy, 2 random points per ha (that is, > 1000 random points for the 4 management conditions; Figure 1) were generated within the burned untreated area and distance to water measured from each random point. Mean random-point distance to water was then compared to the mean distance-to-water of leafy spurge-containing aerial samples within the untreated area to determine if leafy spurge exhibited a preference for invasion of areas close to water.

Leafy spurge cover from 535 1-mm GSD general-survey images (all management conditions plus burned untreated) was compared with distance to water, slope, elevation, and aspect to assess the relationship between leafy spurge infestations and physiography. Leafy spurge cover was measured quantitatively using SamplePoint software and qualitatively using a 0 (no infestation) to 3 (completely infested) rating system. Relationships were assessed using correlation coefficients (r; Microsoft Excel, Redmond, Washing-ton) and multivariate analysis to determine the quadratic response surface (proc rsreg; SAS v. 9, SAS Institute, Nashville, Tennessee)

A second spatial analysis was conducted specifically to assess the effect of distance from water on cover of grass, forbs (except leafy spurge), leafy

TABLE 1

Image count by ground feature for both 10-mm ground sample distance (10-mm GSD) and 1-mm GSD image resolutions. There were 1359 1-mm and 1378 10-mm GSD images examined for this analsyis. Feature counts may overlap.

Image resolution	Road	Fire scar	Stock trail	Gravel pit	Riparian	Leafy spurge	Riparian leafy spurge
10-mm GSD	136	11	86	3	91	139	18
1-mm GSD	10	0	6	0	51	105	—

spurge, and shrubs. Cover data from the 535 general-survey images analyzed with SamplePoint were stratified into bins of 80- or 160-m increments from water and the values were compared using one-way analysis of variance (proc glm, SAS). T-tests comparing upland-vegetation cover means with and without leafy spurge were run using Prism 5.0 (GraphPad, San Diego, California).

A third spatial analysis was conducted to investigate the relationship between biological control and leafy spurge. We used COSTools (Chasen 2005) in ArcMap to calculate the distance from each of the 535 general-survey images analyzed to the closest biological-control point, and then used this distance as an indicator of biocontrol influence for selected aerial samples. Correlation coefficients between distance to closest biological-control point × leafy spurge cover were calculated.

RESULTS AND DISCUSSION

Ocurrence Measurements

We obtained VLSA samples (aerial images) at 2 resolutions (10-mm and 1-mm GSD) from 1383 general-survey sample locations. Leafy spurge was detected in 139 upland and 18 riparian 10-mm GSD samples (10%) and 105 of the 1-mm GSD samples (8%) (Table 1). From 1998 to 2005, BLM field crews detected 214 separate infestations. Though leafy spurge plants showed up more clearly in the 1-mm-GSD imagery (Figure 3), detection capability was lower owing to its smaller FOV ($P = 0.03$, n = 1383), and was poorly correlated with the 10-mm GSD imagery (r = 0.55). The lack of correlation in physical-feature detection between resolutions was also true for roads, fire scars, stock trails, gravel pits, and riparian areas (r < 0.25; Table 1). Thus, we conclude that a qualitative assessment of physical features or leafy spurge presence/absence is best carried out using 10-mm GSD (wide-FOV) imagery. Eighteen 10-mm GSD images were classified as riparian with leafy spurge. Less-conspicuous weeds like spotted knapweed may require the higher resolution for positive identification. Spotted knapweed and cheatgrass were not detected from either image resolution, although they are known to be present within the survey area.

Leafy spurge was scattered throughout the MLPA, with the heaviest infestation in the southern portion (Figure 1). Of the 1383 VLSA samples collected, 322 samples fell within the 4 management conditions identified under the Methods subsection Leafy-Spurge Control Efforts (Figures 1 and 4). Of these, the untreated and aerial-seeded treatments have >100 samples, while the remaining treatments have < 42 samples and thus are of questionable value for deducing a treatment effect. Leafy spurge occurrence was lowest in the herbicide + seeded area (6.0%) and highest in the herbicide treatment area (21.4%, Figures 1 and 4).

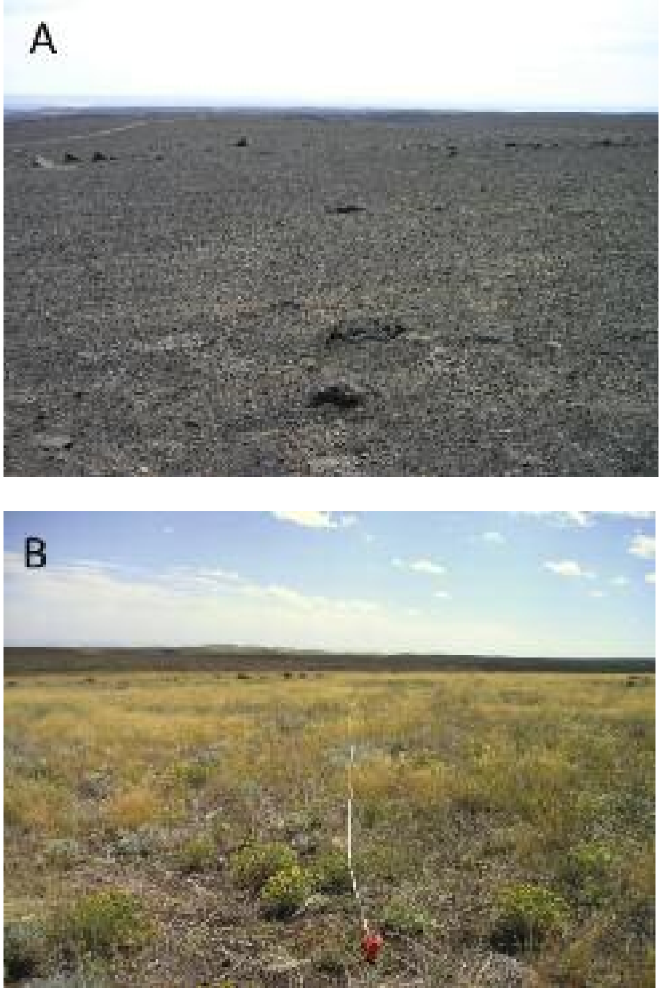
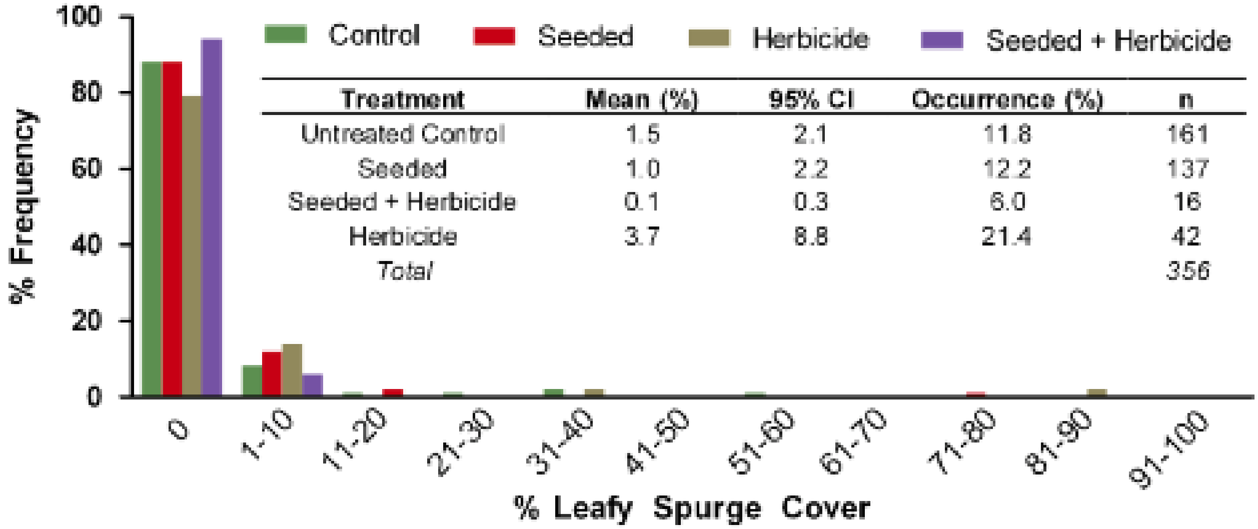


Figure 2. Deep Creek Bench following the Deep Fire Burn, August 2003 (A). Approximately the same area in August 2005 before the June 2006 aerial survey (B). Reprinted from Hankins (2006a,b) with permission.

Figure 3. Leafy spurge captured in 10-mm GSD (*left*) and 1-mm GSD (*right*) images. The teal rectangle shows coverage of the nested 1-mm GSD image.



Treatment	Mean (%)	95% CI	Occurrence (%)	n
Untreated Control	1.5	2.1	11.8	161
Seeded	1.0	2.2	12.2	137
Seeded + Herbicide	0.1	0.3	6.0	16
Herbicide	3.7	8.8	21.4	42
Total				*356*

Figure 4. Frequency plot for percentage of images within each management condition showing leafy spurge cover in 10% cover classes. The inset table details leafy spurge cover and percentage occurrence from 1-mm GSD imagery within each management condition.

Cover Measurements

The cover measurements from the general survey provide an overall characterization of vegetative conditions. Upland sites with leafy spurge had more litter, rock, and bitterbrush with less brown grass, sagebrush, and forbs ($P < 0.01$; Table 2). Other measured cover types did not differ. Green-forb cover represented the largest difference: 24% in samples without leafy spurge, but only 13% in samples with leafy spurge, a finding also reported by Kazmer and Marrs (2005). Lesica and Hanna (2009) reported that a plant-diversity increase after 14 y of leafy spurge control was largely due to increased forb richness. Rock (stones > 13 cm [5.1 in] diameter) accounted for 3% of ground cover where leafy spurge did not occur and 10% where it did occur ($P < 0.001$). This finding is in agreement with the report of Mitchell and Glenn (2009) that leafy spurge in this area is associated with rock outcrops. We suspect this association is due to high soil moisture near rock outcrops as a result of water runoff (Figure 3). The greater litter cover on sites with leafy spurge may reflect a buildup or mulching effect of spurge material; or, it may result from the tendency of leafy

TABLE 2

Cover means (percentage) and standard deviations for select categories measured from upland images taken within the Deep Fire Burn with leafy spurge (LS+) and without leafy spurge (LS–). Welch's (to control for heteroscedasticity) t-test mean comparison p-values are shown. LS+ n = 99; LS– n = 122. Ground cover was obtained by measuring the selected cover categories from every 1-mm GSD sample in each management combination (Figures 1 and 4) using SamplePoint software (Booth and others 2006b).

Cover category	LS+	LS–	p
Bare ground	5.4 ± 6.6	6.6 ± 8.3	0.228
Litter	6.8 ± 7.0	2.4 ± 2.6	<0.001
Brown grass	7.0 ± 8.0	11.4 ± 9.4	<0.001
Brown shrub	1.5 ± 3.4	1.9 ± 2.9	0.402
Brown forb	1.0 ± 5.4	3.2 ± 3.7	<0.001
Green grass	22.8 ± 15.4	23.2 ± 12.4	0.806
Gravel	3.4 ± 5.2	2.4 ± 3.6	0.137
Rock	10.1 ± 11.0	3.1 ± 6.0	<0.001
Snakeweed	0.3 ± 1.0	0.2 ± 0.6	0.108
Sagebrush	5.5 ± 8.3	9.7 ± 12.6	<0.001
Rabbitbrush	0.5 ± 2.6	0.2 ± 1.1	0.275
Bitterbrush	1.2 ± 3.1	0.1 ± 0.3	<0.0001
Green forb	12.9 ± 14.3	24.3 ± 14.0	<0.001
Leafy spurge	16.6 ± 24.6	0 ± 0	na

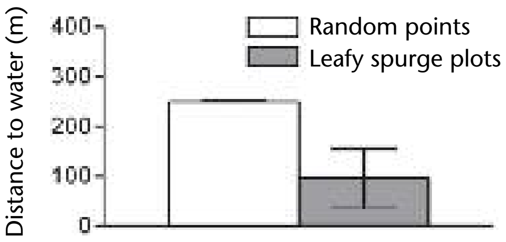


Figure 5. Distance to water (mean ± 95% CI) from a set of random points (2 points/ha; n = 55,390) and from VLSA untreated, burned sample locations showing leafy spurge (Spurge Plots; n = 18).

spurge to occupy wetter, more productive microsites. Sagebrush cover was lower in burned areas with leafy spurge ($P < 0.001$; Table 2), and while we can't establish a cause-and-effect relationship, it may prove important that leafy spurge is associated with reduced sagebrush seedling cover after a fire.

Image analysis of 22 transects by multiple users resulted in CV means of 14 for grass, 27 for forb, 59 for shrub, 20 for litter, 78 for soil, and 63 for rock, indicating that precision across users is not very high for most categories (Table 3). Corresponding precision measurements for field-collected point-intercept data are not available for this project. Data from other non-image-based methods indicate that ground methods have their own precision shortcomings (Booth and others 2005, 2008; Cagney and others, unpublished manuscript); however, these are rarely reported because of the cost of assessing precision when using conventional ground measurements. The CVs suggest historical comparisons would best be made by having evaluators do their own SamplePoint analyses on historical and current imagery so that the same interpretations are used for all years.

Spatial Analysis

Using untreated sample locations within the burned area, we determined that leafy spurge occurrence was significantly closer to water than a set of random points ($P < 0.001$), indicating that the threat of leafy spurge invasion increases in proximity to riparian areas (moist soils; Figure 5). The finding is consistent with Kazmer's and Marrs' (2005) observations from their 6-y study that, generally, leafy spurge cover was highest in riparian areas and that spurge is particularly persistent in riparian areas even when treated with biological-control agents. This finding is also consistent with our hypothesis that water runoff accounts for the association between leafy spurge and rock.

Distance to water, slope, aspect, and elevation had little to no correlation with either leafy spurge cover or level of infestation ($r < 0.51$, $n = 535$). Aspect had a particularly weak relationship ($r < 0.04$, $n = 535$). Results from multiple regressions of physiographic variables differed depending on which leafy spurge metric was compared. Slope and elevation ($P < 0.05$, $n = 535$), as well as distance to water ($P = 0.09$, $n = 535$), were significant factors related to leafy spurge cover, although the correlations indicate that the influence of these factors was weak. The significance of all 3 factors was much higher when compared with the qualitative level of infestation ($P < 0.001$, $n = 535$). Distance from water had no effect on forb or shrub cover ($P = 0.46$ and 0.67); however, grass cover was lower closer to water ($P = 0.025$, $n = 535$; Figure 6). Using unpaired t-tests we found that grass cover was 8.5% lower 0 to 80 m from water compared to > 80 m from water (means = 28.2 [n = 121] as compared with 36.6 [n = 415]; $P < 0.001$). Leafy spurge cover was essentially divided into 3 groups of 0 to 80 m, 80 to 320 m, and > 320 m (means = 9.06 [n = 121], 3.58 [n = 257], and 1.78 [n = 178]; $P = 0.001$]). We strongly suspect that the depression of grass cover in the first increment from water is due to the abundance of leafy spurge within that distance. A similar conclusion was supported by the cover measurements reported by Kazmer and Marrs (2005).

Leafy spurge cover was highest nearest areas of biological-control release (Figure 7), with leafy spurge cover > 10% within 400 m of a release point, > 5% within 600 m of a release point, and < 1% more than 1400 m from a release point. In the absence of a suitable control, the effectiveness of the biological control cannot be determined. Leafy spurge is high in the vicinity of the biological control, but this is probably more a function of the BLM releasing biological-control agents in areas with established, high-density leafy spurge populations. What is apparent is that leafy spurge populations remain unacceptably high—a finding in agreement with Mitchell and Glenn (2009). This is particularly true near the release sites; however, dramatic reductions in, and in some cases eradication of, leafy spurge is reported to have occurred in some areas of the MLPA as a result of treatment with biocontrol agents (Wright 2009).

Management Implications

Maxwell and others (2009) simulated invasion rates of a hypothetical plant species to make objective comparisons among 4 monitoring/management strategies and a no management (control) treatment, for a hypothetical 20-y period and management area. The management area was created with initial populations (15 or 30) distributed at random in the central portion or along a road of a 100 ×100-cell map of the management area. Simulations resulted in growing the number of populations by spatially expanding from the initial source populations. Short-distance dispersal was assumed. The management strategies were: 1) managing a fixed number of populations at random each year (early detection rapid response [EDRR] random); 2) managing an

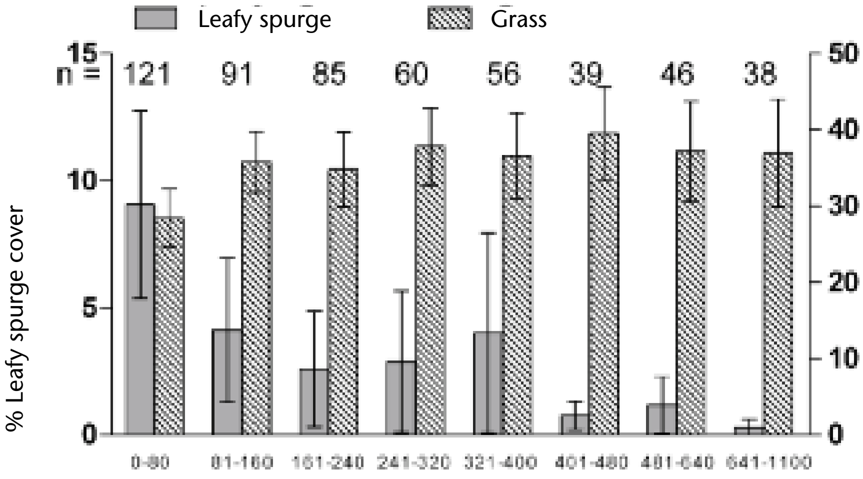


Figure 6. Leafy spurge and grass cover in 80- or 160-m increments up to 1100 m from water source, mean ± 95% confidence interval (n = number of aerial samples and is the same for leafy spurge and grass).

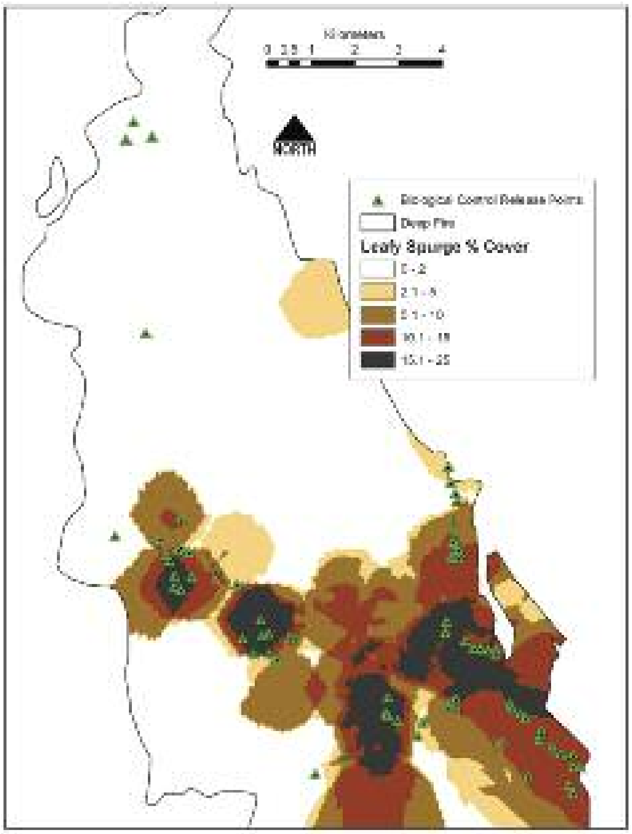


Figure 7. Predictive map of leafy spurge cover based on cover analysis of 500 VLSA image samples within the Deep Fire Burn. Biological-control release points are shown.

equivalent number of populations along a road each year (EDRR road); 3) managing half of the fixed populations that were determined by monitoring to be sources of new populations (monitoring every year); and 4) managing an equivalent set of source populations only on even years, leaving the odd years for monitoring (monitoring every other year). They report that simulated metapopulations with no management increased exponentially from 15 or 30 initial populations in the management area. Given equal financial resources, *devoting funds to annual monitoring* at the expense of management *resulted in greater population **reduction***, long-term, than applying all resources toward management of random populations alone. They write further that:

> When detection was allowed to occur earlier in the invasion . . . , some management strategies could consistently drive the metapopulation to extinction or set it on a trend to extinction. The *EDRR that **restricted** management to roadsides was the least effective management strategy* for reducing the number of populations, regardless of the initial conditions or parameter value changes. This result was disconcerting considering the prevalence of management *restricted* to roadsides (emphasis added).

We stress that Maxwell and others (2009) are not arguing against roadside monitoring—roads are known corridors of invasion. Rather they, and we, emphasize that roadside monitoring must be accompanied by methods that address the whole area of concern. They note that early detection means finding the species while it occurs with low frequency—but that the lower the frequency, the more costly it is to detect.

TABLE 3

Coefficients of variation among users for manual image analysis (SamplePoint) of VLSA images acquired over permanent transects.

Transect	Number images	Users	Grass	Forb	Shrub	Litter	Soil	Rock
R08	3	4	20	48	9	31	99	48
R11	2	3	6	17	28	24	43	22
R14	3	4	14	46	49	36	49	41
R17	2	3	18	53	39	22	35	31
R24	2	3	11	29	87	9	26	60
R25	3	3	12	14	135	5	158	115
R26	2	4	9	14	98	26	100	108
R27	3	3	27	14	173	18	80	53
R29	2	3	9	19	88	24	89	65
R31	3	3	8	10	46	16	107	87
R33	3	2	11	7	34	1	—	141
R35	3	2	9	3	35	15	8	20
R38	3	2	22	2	141	4	20	10
R39	2	3	9	17	22	38	160	125
R40	3	2	14	10	35	15	141	141
R42	2	2	36	62	33	16	47	52
R43	1	2	2	24	11	14	—	0
R45	3	2	19	30	96	25	47	80
R46	3	2	3	71	47	35	49	28
T7	8	3	24	23	51	29	173	87
T8	8	3	17	21	11	27	62	25
T9	7	3	12	50	20	20	68	57
Mean			14	27	59	20	78	63

Systematic sampling of wildland vegetation is recognized as usually superior to random sampling (Mueller-Dombois and Ellenberg 1974, 39), but it may require greater sampling intensity for equal accuracy (Wei and Chen 2004). A comparison of leafy spurge detection points for 8 y of BLM ground monitoring with our 1-time aerial survey (Figure 1) illustrates both the advantage of a systematic aerial survey (≥ 30 new populations identified) and a need for greater aerial-sampling intensity (aerial detection was 73% of the number detected by the 8-y ground effort). Although an unknown number of ground-detected populations may have been eliminated before the aerial survey, we doubt that number is great enough for us to change our recommendation for higher VLSA sample density in future aerial surveys. Blumenthal and others (2007) recommended that for toadflax in the mixed-grass prairie of Wyoming, a VLSA sampling intensity capturing 0.5% of the area of interest in image fields-of-view would be appropriate. The MLPA survey, conducted a year before the Blumenthal recommendation, had an order of magnitude lower sampling rate, capturing only 0.05% of the area of interest (10-mm GSD images).

A further point for consideration can be deduced from other leafy spurge data collected in 2006 along Medicine Lodge Creek (Mitchell and Glenn 2009). A ground survey of leafy spurge was conducted in late July and early August 2006, using fifty-six, 168.25-m^2 (1716-ft^2) plots, with some upland overlap of the MLPA. Leafy spurge was detected in 96% of their ground samples. Our VLSA survey detected leafy spurge in only 21% of samples. The difference is most likely due to differences in survey designs and location since their survey concentrated on high spurge infestations and covered only 16% of the area of our larger, predominantly upland (less spurge) survey. We concede the possibility that we may have

TABLE 4

List of costs (2006 US dollars) associated with aerial and ground monitoring. These costs are not comparable and are presented here only to provide some cost information for each method. USDI Bureau of Land Management (BLM) costs are from Hankins (2006a,b).

BLM costs for 3 y monitoring	
Internal resource specialists and technicians	$85 200
Temporary employee for weed inventory and follow-up control	28 000
Vehicle for temporary employee	5 600
USDA Agricultural Research Service costs	
Aerial-image acquisition costs	
CloudStreet	$3 344
Associated costs (flight planning, ground support, travel, data management)	2 015
Analysis	4 420

missed some vegetative-stage (no showy bracts) plants. That possibility serves to emphasize our position that, as much as possible, people analyzing VLSA images should have substantial ground experience in the survey areas.

The findings of Maxwell and others (2009), particularly the failure of road-only based monitoring and the demonstrated capability of the systematic VLSA sampling used for the MLPA and in Wyoming (Blumenthal and others 2007), combine to suggest the importance of VLSA-type surveys for detecting low-frequency or dispersed populations in wildland settings. The importance of developing aerial methods for rangeland surveys has long been recognized. West (1999) observed, in a context of ground-cover measurements, that:

> I see no hope that traditional methods of monitoring . . . *on the ground*, will be able to accomplish those (monitoring) needs . . . especially when landscape and regional perspectives are required. There are simply not enough adequately trained people and that approach would not be affordable, even if the necessary professionals existed (emphasis added).

West's observation is true whether the monitoring objective is ground cover or weeds. We are unable to provide a side-by-side comparison of on-the-ground and VLSA survey monitoring costs; however, available cost information for each method is presented in Table 4. (Note that BLM costs may lump monitoring and control efforts.)

The aerial survey methods used here provide information about the resource and about management results; however, great care must be exercised in drawing conclusions, as is evident in this work where pre-existing differences in the management conditions prevented conclusions about weed-control treatments. For example, biological-control agents were released primarily in areas of highest spurge density near the riparian areas (Figure 7), so even after treatment, the biological-control area had the highest spurge presence. Untreated ground in dryer areas had less spurge. A careless consideration of the data, and a lack of knowledge of the resistance of riparian leafy spurge to biological control (Kazmer and Marrs 2005), could be interpreted to indicate biological control *increased* spurge. (Similarly, the herbicide management condition had the greatest spurge cover [Figure 4].) Those attempting to glean knowledge from uncontrolled comparisons must be fully aware of the area's land-management history and adapt to this reality by recognizing confounding situations and the extent to which valid conclusions can be drawn. In this study, we attempted to normalize the physiographic characteristics between management conditions to permit direct comparisons, but we were unable to do so to our satisfaction. Where agencies wish to enhance the potential to gain knowledge while implementing treatments, they should plan for valid comparisons (Boyd and Svejcar 2009) and recognize that the best way to test treatment effect is with before-and-after measurements to show trend. Although trend data are most desirable, there are some conclusions that can be drawn using one-time-only monitoring data.

CONCLUSIONS

From this study, we conclude:

- Ten-mm GSD imagery is better than 1-mm GSD for detecting the presence of leafy spurge because it optimizes the balance between resolution and field-of-view.
- Our sampling intensity resulted in 0.05% of the MLPA being captured within the field of view of the 10-mm GSD imagery. That was too low a sampling intensity and we believe repeat surveys should obtain an order-of-magnitude greater sample density.
- Our data support those of Kazmer and Marrs (2005) that leafy spurge generally supplants other forbs, and to a lesser extent grasses, when it invades.

- Sagebrush cover in the area of the DFB was lower where leafy spurge was present. We believe this is the first evidence that leafy spurge is associated with a reduction in sagebrush seedling cover.
- Currently, the leafy spurge infestation (cover) on the DFB is highest in the biological-control area and lowest in the untreated area. We draw no conclusion about the efficacy of the biological-control treatment for the reasons discussed above. However, the survey data are evidence that leafy spurge has supplanted native plants on 10% of the 22 130-ha MLPA and that it has significantly reduced forage where it occurs; thus, it remains a significant threat to the affected native-plant communities. The survey is a basis for future comparisons of leafy spurge cover and occurrence to determine whether control efforts are effective.
- Leafy spurge proximity to water is higher than random distribution would predict. We believe this explains the frequency of leafy spurge supplanting native plants around rock outcrops away from riparian areas.
- Slope, aspect, elevation, and distance-to-water, taken individually or together, appear to influence cover and distribution of leafy spurge in the MLPA, but there is not a close association (r) between these variables.
- VLSA sampling is an effective means for systematically acquiring high-density sampling over extensive wildland areas. We recommend it be used with ground-based methods for early detection of invasive species that might threaten wildland native-plant populations.

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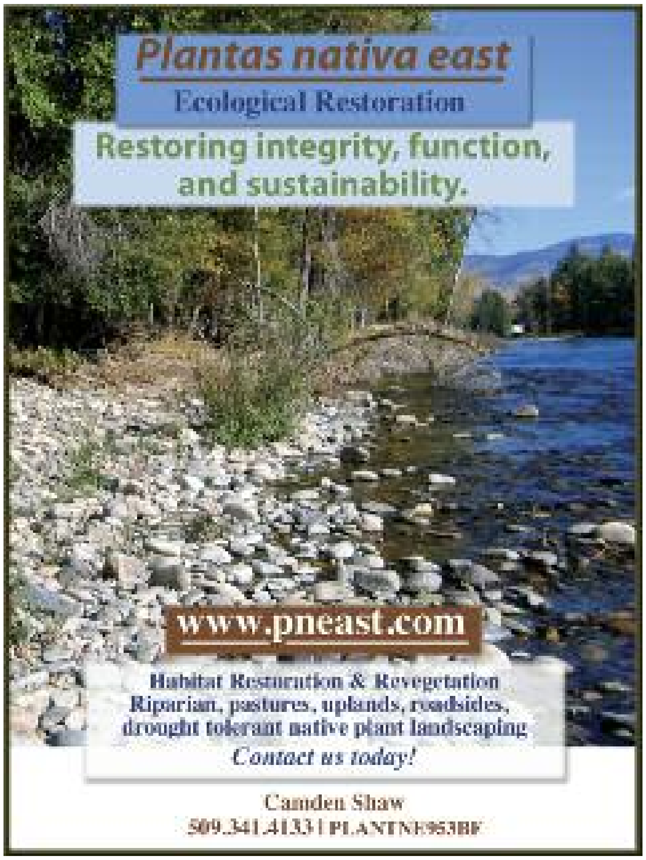

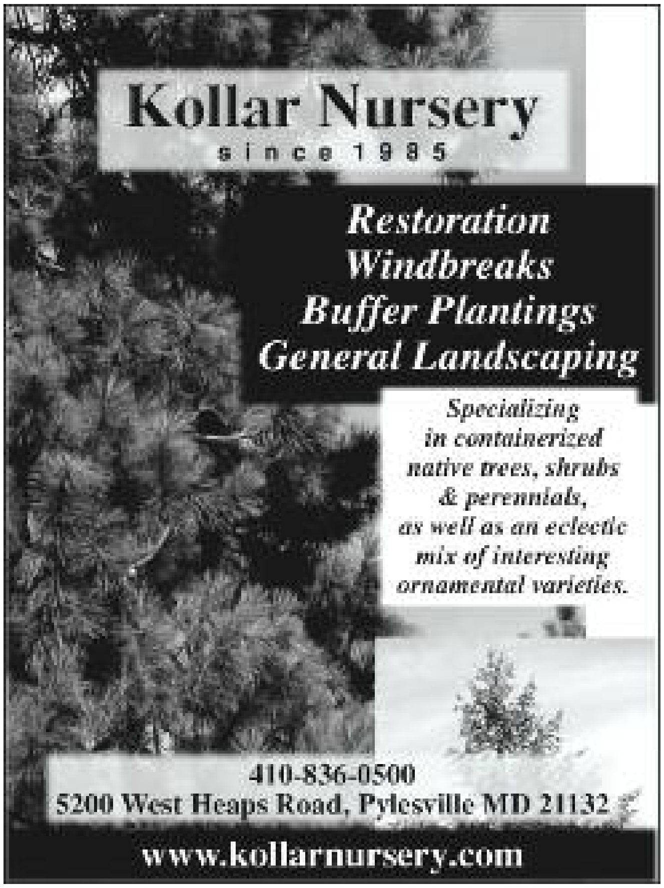

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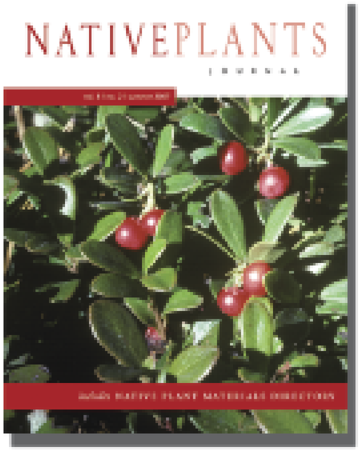
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