Reprinted with permission from: Proceedings: Leafy Spurge Strategic Planning Workshop[1], Dickinson, North Dakota. March 29-30, 1994. pp. 42-56.

Sponsored by: U.S. Department of the Interior; U.S. Department of Agriculture, Forest Service; Rocky Mountain Elk Foundation; and DowElanco.

Mapping leafy spurge (*Euphorbia esula*) infestations within Theodore Roosevelt National Park using large format aerial photography and geographic information system technology

G. L. ANDERSON[1], J. H. EVERITT[1], D. E. ESCOBAR[1], N. R. SPENCER[2], and R. J. ANDRASCIK[3]

[1]Ecologist, Range Scientist, and Remote Sensing Specialist; USDA-ARS, Remote Sensing Research Unit, Weslaco, TX; [2]Entomologist, USDA-ARS, Northern Plains Soil and Water Research Laboratory, Sidney, MT; [3]Resource Management Specialist, USDI, Theodore Roosevelt National Park, Medora, ND

Abstract:

Leafy spurge is a troublesome weed on the northern Great Plains of the United States that chemicals and grazing management have not controlled. Remote sensing and geographic information system (GIS) technology have been used to detect and monitor numerous grassland related problems. The objectives of this study were to use both technologies jointly to map and quantify the extent of leafy spurge within Theodore Roosevelt National Park and to provide information for managing the infestation. Analysis of the data indicated that 550 ha of the 18,680 ha park were infested by leafy spurge. The densest infestations were in the northwest and southeast portions of the park. Most infestations were restricted to drainage channels, creek bottoms, and river bottoms. Leafy spurge infestations decreased exponentially as distance from stream channels increased (r^2=0.989). The significant association of leafy spurge with drainage channels suggests that the weed might be affectively managed on a watershed sub-basin level. The joint use of GIS and remote sensing technology proved to be a powerful combination of tools which provided previously unavailable information about the extent and spatial dynamics of leafy spurge within the park. The results of this study should contribute to the

---

[1] Workshop Coordinator: Roger J. Andrascik, Resource Management Specialist, Theodore Roosevelt National Park, Medora, ND. Compiler: Nancy S. Ohlsen, Natural Resource Specialist, Theodore Roosevelt National Park, Medora, ND. Editor: Claude H. Schmidt, Agric. Exp. Stn., NSDU Extension Svc., NDSU, Fargo, ND.

development of a comprehensive leafy spurge management plan for Theodore Roosevelt National Park.

Introduction

Leafy spurge (*Euphorbia esula* L.) is a deep rooted, perennial weed with erect stems 40 to 80 cm tall (Stevens, 1963). The weed reproduces by both vegetative buds and the production of large quantities of seeds. A native of Eurasia, leafy spurge was first reported in the state of Massachusetts in 1827 (Noble *et al*. 1979). Leafy spurge now occurs abundantly on the Northern Great Plains of the United States and the Prairie Provinces of Canada where it often forms stands dense enough to displace native plants and restrict cattle grazing (Rees and Spencer, 1991).

Various control methods have been tried. Long term chemical control of leafy spurge has generally proven ineffective and expensive because of the extensive area infested (Lym and Messersmith, 1983; Gylling and Arnold, 1985; Lym and Messersmith, 1985; Messersmith, 1979; Alley and Messersmith, 1985; Harvey *et al*., 1988). Grazing by sheep has reduced the density and limited the spread of leafy spurge, but does not eradicate the weed (Landgraf *et al*., 1984; Fay, 1991). Control with pathogens (Quimby *et al*., 1991) and insects (Anonymous, 1989; Rees and Spencer, 1991) is currently being evaluated.

Determining the extent and distribution of weed populations on rangelands is often difficult because of the expanse and inaccessibility of these areas. The value of remote sensing techniques for rangeland assessment is well established (Tueller 1982; Carneggie *et al*., 1983). Remote sensing technology offers rapid acquisition of data at costs lower than for ground surveys (Tueller; 1982; Everitt *et al*., 1992). Both aerial photography and videography have proven useful for detecting many rangeland plants (Driscoll and Coleman, 1974; Gausman *et al*., 1977; Carneggie *et al*., 1983; Everitt *et al*., 1987, 1992, 1993). Advantage is often taken of specific phenological stages to distinguish plant species of interest from others present (Driscoll and Coleman, 1974; Everitt and Villarreal, 1987; Everitt and Deloach, 1990). Leafy spurge produces yellow bracts in late May or early June that give the plant a conspicuous yellow-green appearance (Lacey *et al*., 1985). We hypothesized that leafy spurge might be distinguishable on aerial imagery in this phenological stage.

Geographic information system (GIS) and remote sensing technology have been integrated for a variety of natural resource applications (Graetz *et al*., 1983; Eidenshink *et al*., 1988; Myhre, 1992; Richardson *et al*., 1993; Anderson *et al*., 1993b), including mapping the distribution of noxious weeds (Dewey *et al*., 1991; Anderson *et al*., 1993a; Everitt *et al*., 1994). Remote observations in georeferenced formats help to assess the extent of infestations, develop management strategies, and evaluate control measures on noxious plant populations.

Leafy spurge was first reported in Theodore Roosevelt National Park in the late 1960's. In 1970 an estimated 13 ha of the park were infested. The infestation increased to

162 ha between 1975 and 1983, and was conservatively estimated as 283 ha in 1986. The objectives of this study were (1) to map and quantify the extent and distribution of leafy spurge within Theodore Roosevelt National Park during the summer of 1993, and (2) to provide information for managing the infestation.

Materials and methods

This study was conducted on the south unit of Theodore Roosevelt National Park, near Medora, North Dakota. The park encompasses over 18,680 ha of native mid-grass prairie. Geologically, the park is comprised of clay and sandstone layers deposited in the Williston basin during the late Paleozoic period (Levin, 1978). The entire area was uplifted by the formation of the Black Hills and subsequently highly eroded by glacial meltwaters released at the end of the last ice age. These geologic events produced the rugged clay buttes, limited top soil, and sandstone outcroppings that characterize the North Dakota Badlands.

Aerial photography was chosen for this project because the resolution of film is much better than imagery obtained from satellite or video imaging systems. Imagery was acquired using a large format camera (23 by 23 cm) with a 305-mm lens. Conventional color film was used and the aperture setting of the camera was f11 at 1/250 s. Photographs were taken from 0900 to 1100 hours on June 19, 1993, at a scale of 1:10,000. Over 140 photographs were taken at regular intervals, based on coordinates from a non-differential global positioning system (GPS) mounted in the cabin of the aircraft. Each photo had approximately a 40% endlap and a 30% sidelap to ensure complete coverage.

Mapping leafy spurge within the park was a multi-step procedure. First, all aerial photographs were examined to determine if leafy spurge was visible within the scene. Photographs containing spurge were covered with a clear vellum to protect the original print, and the perimeters of the leafy spurge populations were drawn on the overlay. Tie points that georeferenced features on the photograph with coordinates from USGS 7.5 minute base maps were also identified and marked on each photograph. Terrain features such as butte tops, clay outcroppings, and stream intersections were used as tie points because each photograph contained few identifiable standard map features. The USGS 7.5 minute orthophoto quadrangle maps that were available for the park enabled this procedure. Coordinates for the tie points were obtained from the orthophoto maps by digitizing each position and recording it in a GIS. The corresponding tie points on the photographs and the perimeter of each leafy spurge population were also digitized and recorded in the GIS. The registration procedure used the common tie points on the photographs and orthophoto quadrangle maps to register the leafy spurge polygons to a standard North American Datum (NAD), 1983, Universal Transverse Mercator (UTM), Zone 13, coordinate system. A minimum of 10 tie points, scattered across the image, were selected on each aerial photograph.

Map features such as roads, trails, hydrography, and the park boundary were digitized from a USGS, 1:24,000 scale topographic map converted to a NAD-1983 coordinate base and combined with the leafy spurge polygons in a raster GIS. Each cell on the GIS database was 5 m by 5 m. Digital elevation data (USGS-DEM, 30 m by 30 m horizontal and 5 m vertical resolution) were acquired for the five-7.5 minute quadrangle maps that cover the park and joined together. The DEM data were used to develop slope, aspect, stream channel, and watershed basin maps.

Stream channel data were used to develop a proximity to channel map for the entire park. A stream channel proximity map indicates the distance of all points in the park from the closest stream channel. These data were subsequently divided into 10 m intervals and the total land area, and area covered by leafy spurge within each band determined. Digital map products and statistics presented in this report were produced using software subroutines contained in the Geographical Resources Analysis Support System (GRASS)[2] GIS.

Results

Analysis of the digital park data derived from the 1:24,000 scale map indicated that the south unit of Theodore Roosevelt National Park covered approximately 18,676 ha of the North Dakota Badlands. This estimate compares favorably with the official 18,680 ha extent of the park. Leafy spurge area estimates, derived from the aerial photography, accounted for 550 ha (or 3%) of the park (Fig. 1). The densest infestations of leafy spurge within the park occurred in the Petrified Forest Plateau region, Knutson Creek, and the floodplain of the Little Missouri River. Small scattered populations of spurge were evident throughout the area south and east of the Little Missouri River and another large population of spurge occurred on the upper end of the Paddock Creek drainage basin. Most of the infestation appeared to be restricted to drainage channels, creek bottoms, and river bottoms.

Figure 2 emphasizes the non-random distribution of leafy spurge within the park. The curvilinear relationship:

$$\text{Area} = 64.322e^{-0.01267498d}, \tag{1}$$

where d = the distance from a drainage channel in meters, accounts for almost 100 percent (r^2=0.989) of the variance found in the data. Leafy spurge was not closely associated with other topographic features. Spurge seemed to have a slight affinity for south easterly aspects and gentler slopes, however, substantial spurge populations existed over all conditions (Tables 1 and 2).

Sixteen major watershed sub-basins were developed for the park from USGS-DEM data (Fig 3). The GIS watershed routine delineated watershed boundaries well in the steeper portions of the park. The procedure did more poorly along the Little Missouri River floodplain where the slope values were low. Several sub-basins were combined into four large floodplain basins (Basins 13, 14, 15, 16) to compensate for this problem. Leafy spurge was found in 14 of the 16 watershed basins (Table 3). Sub-basins 9 and 10, in the northwest portion of the park, contained 329 ha of leafy spurge and sub-basins 1 and 12, in the southeast portion of the park, appeared to be free of leafy spurge.

---

[2] GRASS is a product of the U.S. Army Corps of Engineers Construction Engineering Research Laboratories (USACERL) in Champaign, IL.

Figure 4 groups the data from Table 3 into areas of heavy, moderate, light, and no leafy spurge coverage. Heavy infestations included basins with greater then 5 percent of the land area covered by leafy spurge. Moderate, light, and no leafy spurge categories were assigned to basins with greater than one but less than five, greater then zero but less then one, and zero percent coverage respectively (Table 3). Figure 4 illustrates the heavy infestation of the three major drainages of the park (Knutson Creek, Paddock Creek, and the Little Missouri River), the large portion of the park that is being threatened by leafy spurge, and, conversely the small amount of land that has not yet been infested.

Table 1. The association of slope and leafy spurge in Theodore Roosevelt National Park.

Slope	Area (ha
0 - 2	25.3
3 - 5	147.8
6 - 10	96.6
11 - 15	91.7
16 -20	78.7
21 -25	54.8
> 26	59.3

Table 2. The association of aspect and leafy spurge in Theodore Roosevelt National Park.

Aspect	Area (ha)
ESE	115.5
SSE	84.3
SSW	64.1
WSW	3.5
WNW	48.9
NNW	60.7
NNE	53.8
ENE	63.5

Discussion

Normal color aerial photography was useful in mapping leafy spurge infestations on Theodore Roosevelt National Park. The yellow-green signature of well developed stands of leafy spurge were readily identifiable, but small isolated spurge stands with minimal bract formation were difficult to identify. Research in 1994 will seek to determine how much leafy spurge was missed by this procedure.

The non-random distribution of leafy spurge indicates that some factor(s) increase the likelihood of stand establishment near drainage channels. One contributing factor could be that leafy spurge populations are distributed in direct proportion to the amount of total land area present at varying distances from drainage channels. An analysis of the total surface area of the park demonstrates that for distances between 0 and 320 m from a drainage channel, the amount of surface area decreases linearly (Fig 5). Therefore, the distribution of the weed is not merely a reflection of the amount of available land area.

The observed distribution of leafy spurge could be a function of time, given the primary mode of seed introduction into an area is by surface water movement (accounting for the majority of the stands existing close to a drainage channel) and lateral movement away from a drainage channel is by seedpod dispersal (which requires time for stand establishment, seed production, and dissemination). If the distribution is a function of time, the curvilinear distribution should begin to flatten and approach the total land surface distribution (Fig. 5) as the spurge populations advance further from the drainage channels. This hypothesis needs further investigation. However, the large isolated stands of leafy spurge found on the upper end of the Paddock Creek drainage basin indicate that other modes of seed introduction (wind, man, wildlife, or domestic animals) are important. Seed deposition by modes of movement other than water and pod dispersal could be selective for drainage channel areas, however, the expectation is that the distribution would be much more random. In the park, where the distribution is so significantly associated with the drainage channels, it appears that factors such as soil moisture could be important influences on the success of leafy spurge establishment. In any case, the data indicate a predictable pattern of stand establishment that park managers may be able to use to combat the spread of leafy spurge.

Table 3. The extent of leafy spurge populations in each of 16 watershed sub-basins.

Basin	Total Area (ha)	Spurge (ha)	%
1	2101	0.0	0.0
2	3170	48.6	1.5
3	1919	14.0	0.7
4	1259	2.9	0.2
5	297	5.2	1.7
6	1008	5.2	0.5
7	1504	8.6	0.5
8	1271	4.6	0.3
9	1703	150.1	8.8
10	1143	179.1	15.7
11	31	4.0	13.1
12	231	0.0	0.0
13	475	28.3	6.0
14	622	24.0	3.8
15	1595	68.5	4.3
16	336	6.5	1.9

The significant association of leafy spurge populations with drainage channels suggests that the weed might be affectively managed on a watershed basin or sub-basin level. That is, the limited resources of the park could be partitioned to prevent the spread of the weed to uncontaminated areas, reducing the infestation in areas with small populations, and retarding the advance of the larger more established leafy spurge populations.

Conclusions

The GIS was a good base for incorporating the polygons of leafy spurge identified on aerial photographs. Distortions in the photography that were removed by using the GIS to register the data to the USGS orthophoto maps aided in accurately estimating the size of the spurge infestations. The GIS also made it possible to combine the leafy spurge data with other existing data (map features or digital elevation data) and create new information (watershed basin, stream, slope, and aspect maps) for a more in-depth analysis of the problem. The joint use of GIS and remote sensing technology proved to be a powerful combination of tools which provided previously unavailable information about the extent and spatial dynamics of leafy spurge within the park. The results of this study should contribute to the development of a comprehensive leafy spurge management plan for Theodore Roosevelt National Park.

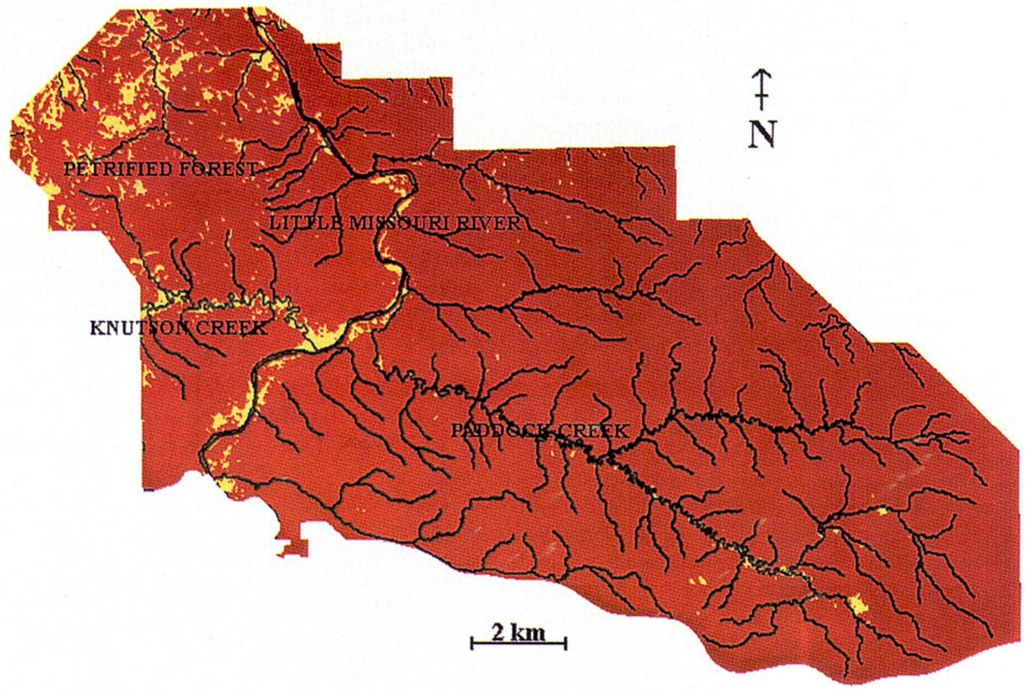

Figure 1. Map of leafy spurge infestations, shown in yellow, within Theodore Roosevelt National Park.

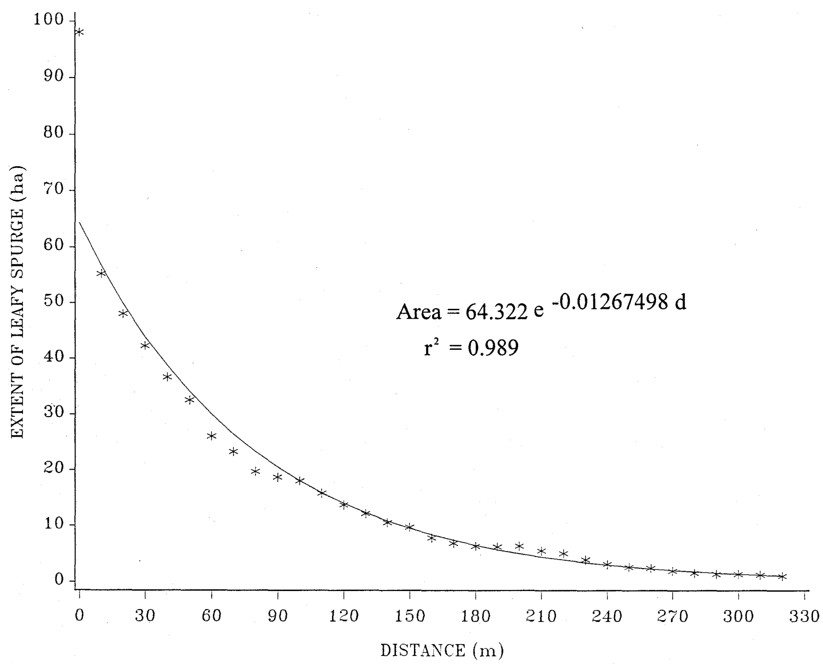

Figure 2. Relation between area inhabited by leafy spurge and the distance of stands from a drainage channel.

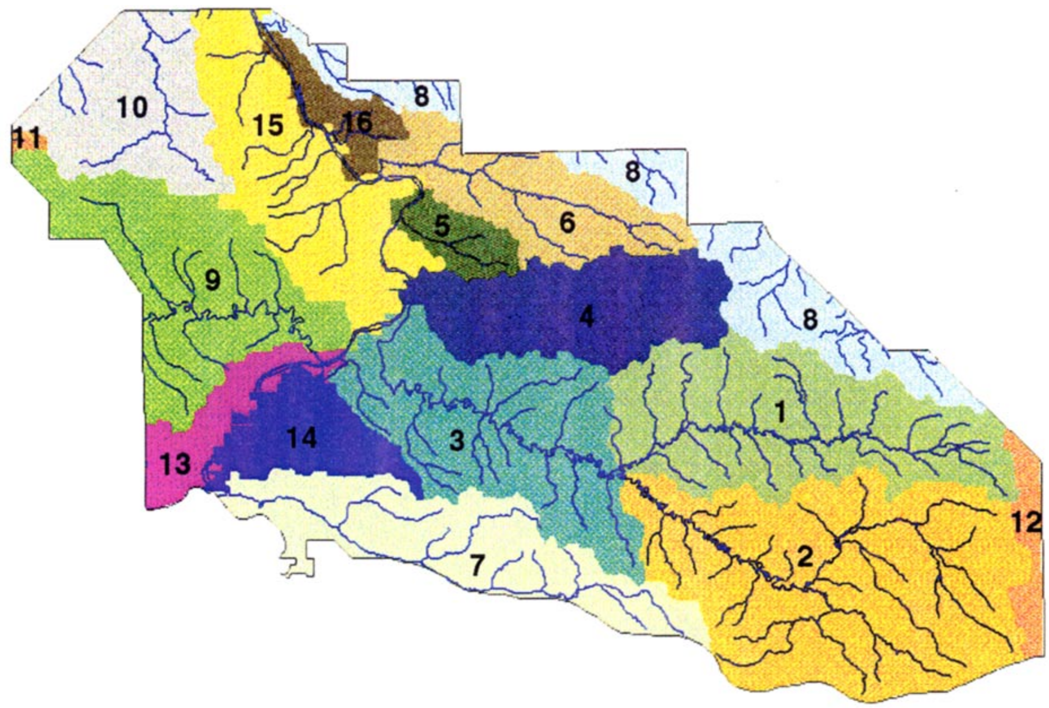

Figure 3. Watershed sub-basin map developed from the USGS Digital Elevation Model (DEM) data.

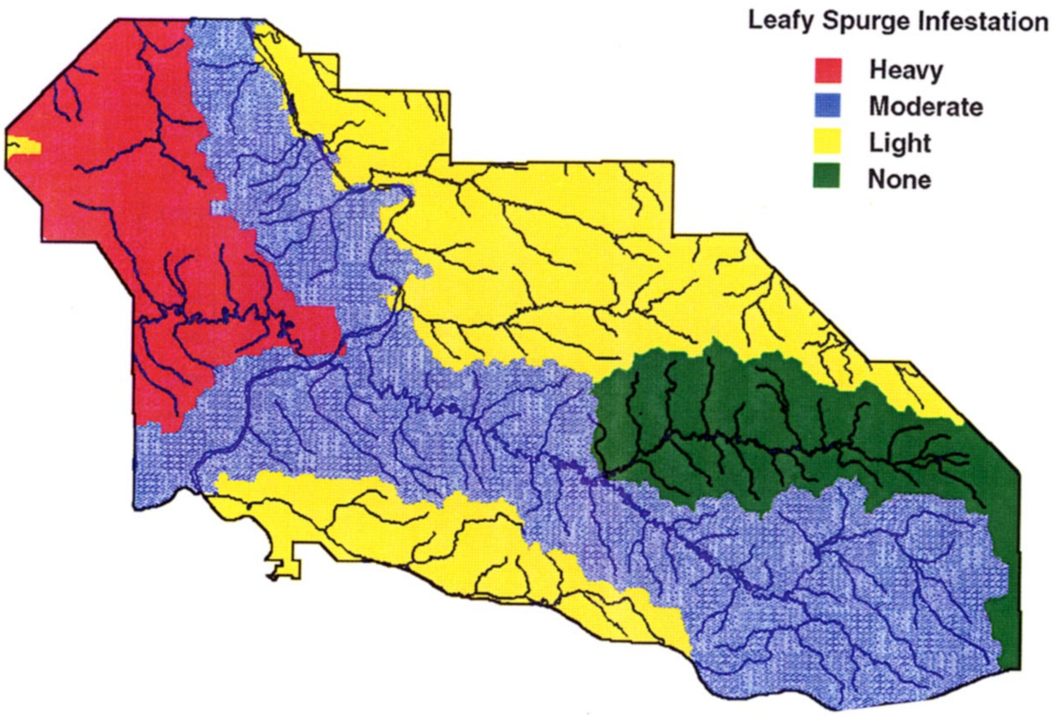

Figure 4. General breakdown of leafy spurge infestation by watershed sub-basin. Heavy (>5%, red), moderate (1-<5%, blue), light (>0 but 1<%, yellow), and none infested areas (green).

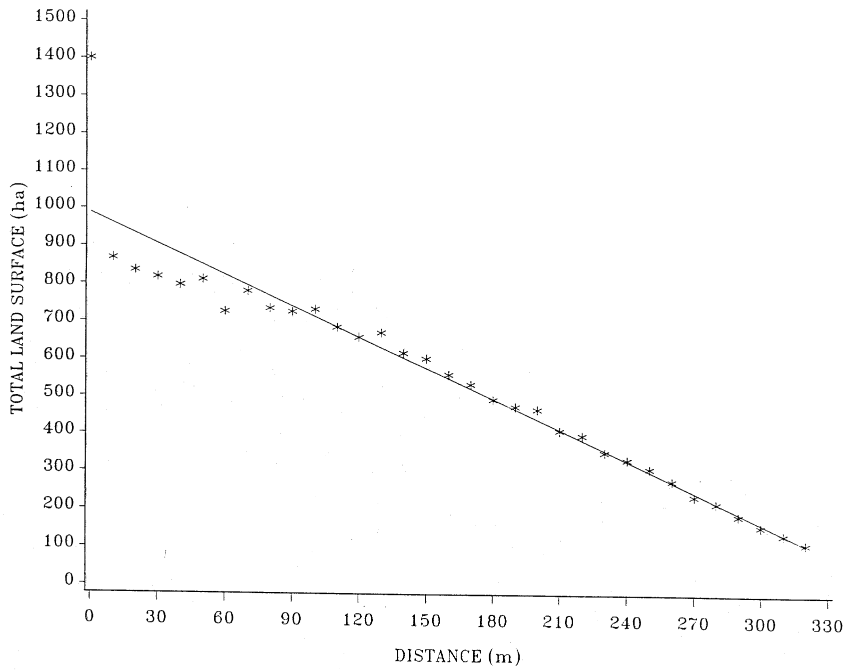

Figure 5. Relation between total area and distance from a drainage channel.

Acknowledgments

The authors thank M. R. Davis, W. Swanson, and I. Cavazos for their time and assistance in obtaining the photography and creating the GIS database.

References

Alley, H. P. and C. G. Messersmith. 1985. Chemical control of leafy spurge. Pages 65-79 *in* A. K. Watson, ed. Leafy Spurge. Weed Sci. Soc. Am., Champaign, IL.

Anderson, G. L., J. H. Everitt, A. J. Richardson, and D. E. Escobar. 1993a. Using Satellite data to map false broomweed (*Ericameria austrotexana*) infestations on South Texas rangelands. Weed Tech. 7:865-871.

Anderson, G. L., J. D. Hanson, and R. H. Haas. 1993b. Evaluating LANDSAT thematic mapper derived vegetation indices for estimating above-ground biomass on semi-arid rangelands. Remote Sensing of Environment 45:165-175.

Anonymous. 1989. Biological control of leafy spurge. United States Department of Agriculture, Animal and Plant Health Inspection Service. Progress Aid No. 1435. 11 p.

Carneggie, D. M., B. J. Schrumpf, and D. M. Mouat. 1983. Rangeland applications. p. 2325-2384 *in* R. N. Colwell, ed. Manual of Remote Sensing. Vol. 2. Am. Soc. Photogrammetry and Remote Sensing, Falls Church, VA.

Dewey, S. A., K. P. Price, and D. Ramsey. 1991. Satellite remote sensing to predict potential distribution of Dyers woad (*Isatis tinctoria*). Weed Tech. 5:479-484.

Driscoll, R. S. and M. D. Coleman. 1974. Color for shrubs. Photogramm. Eng. 40:451-459.

Eidenshink, J. C., R. H. Haas, D. M. Zokaites, D. O. Ohlen, and K. P. Gallo. 1988. Integration of remote sensing and GIS technology to monitor five danger in the Northern Great Plains. U.S. Geological Survey Contract 14-08-0001-22521. 13p.

Everitt, J. H., M. A. Alaniz, D. E. Escobar, and M. R. Davis. 1992. Using remote sensing to distinguish Common (*Isocoma coronopifolia*) and Drummond goldenweed (*Isocoma drummondii*). Weed Sci. 40:621-628.

Everitt, J. H. and C. J. Deloach. 1990. Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. Weed Sci. 38:273-278.

Everitt, J. H., D. E. Escobar, R. Villarreal, M. A. Alaniz, and M. R. Davis. 1993. Canopy light reflectance and remote sensing of shin oak (*Quercus havardii*) and associated vegetation. Weed Sci. 41:291-297.

Everitt, J. H., J. V. Richerson, M. A. Alaniz, D. E. Escobar, R. Villarreal, and M. R. Davis. 1994. Light reflectance characteristics and remote sensing of Big Bend loco (*Astragalus mollissimus* var. *earlei*) and Wooton loco (*Astragalus wootonii*). Weed Sci. 42:(In press).

Everitt, J. H., R. D. Pettit, and M. A. Alaniz. 1987. Remote sensing of broom snakeweed (*Gutierrezia sarothrae*) and spiny aster (*Aster spinosus*). Weed Sci. 35:295-302.

Everitt, J. H. and R. Villarreal. 1987. Detecting huisache (*Acacia farnesiana*) and Mexican palo-verde (*Parkisonia aculeata*) by aerial photography. Weed Sci. 35:427-432.

Fay, P. K. 1991. Controlling leafy spurge with grazing animals. Pages 193-199 *in* L. F. James, J. O. Evans, M. H. Ralphs and R. D. Child, eds. Noxious Range Weeds. Western Press, Boulder, CO.

Gausman, H. W., R. M. Menges, D. E. Escobar, J. H. Everitt, and R. L. Bowen. 1977. Pubescence affects spectra and imagery of silverleaf sunflower (*Helianthus argophyllus*). Weed Sci. 25:437-440.

Graetz, R. D., R. P. Pech, M. R. Gentle, and J. F. O'Callaghan. 1983. The application of LANDSAT image data to rangeland assessment and monitoring: The development and demonstration of a land image-based resource information system (LIBRIS). J. of Arid Environments 10:53-80.

Gylling, S. R. and W. E. Arnold. 1985. Efficacy and economics of leafy spurge (*Euphorbia esula*) control on pasture. Weed Sci. 33:381-385.

Harvey, S. J., R. M. Nowierski, P. G. Mahlberg, and J. E. Story. 1988. Taxonomic evaluation of leaf and latex variability of leafy spurge (*Euphorbia* spp.) for Montana and European accessions. Weed Sci. 36:726-733.

Lacey, C. A., P. K. Fay, R. G. Lym, C. G. Messersmith, B. Maxwell, and H. P. Alley. 1985. The distribution, biology and control of leafy spurge. Circular 309. Cooperative Extension Service, Montana State University, Bozeman, MT. 15 p.

Landgraf, B. K., P. K. Fay, and K. M. Havstad. 1984. Utilization of leafy spurge (*Euphorbia esula*) by sheep. Weed Sci. 32:348-352.

Levin, H. L. 1978. The Late Paleozoic. *in* The Earth Through Time. W.B. Saunders Company, Philadelphia 530 p. Lym, R. G. and C. G. Messersmith. 1983. Control of leafy spurge with herbicides. North Dakota Farm Res. Bull. 40(5):16-19, 26.

Lym, R. G. and C. G. Messersmith. 1985. Leafy spurge control with herbicides in North Dakota: 20-year summary. J. Range Manage. 38:149-154.

Messersmith, C. G. 1979. Leafy spurge chemical control. Page 78. Proc. Leafy Spurge Symp. North Dakota Coop. Ext. Serv., Fargo. 84 pp.

Myhre, R. J. 1992. Use of color airborne videography in the U. S. Forest Service. Pages 145-152 *in* Proc. Resource Technology 92 Sympos. Amer. Soc. Photogrammetry and Remote Sensing, Bethesda, MD.

Noble, D. L., P. H. Dunn, and L. A. Andres. 1979. The leafy spurge problem. Pages 8-15 *in* Proc. Leafy Spurge Symposium. Bismarck, ND. June 26 and 27.

Quimby, P. C., W. L. Bruckart, C. J. Deloach, L. Knutson, and M. H. Ralphs. 1991. Biological control of rangeland weeds. Pages 85-102 *in* L. F. James, J. O. Evans, M. H. Ralphs, and R. D. Child, eds. Noxious Range Weeds. Western Press, Boulder, CO.

Rees, N. E. and N. R. Spencer. 1991. Biological control of leafy spurge. Page 182-192 *in* L. F. James, J. O. Evans, M. H. Ralphs, and R. D. Child, eds. Noxious Range Weeds. Westview Press, Boulder, CO.

Richardson, A. J., K. R. Summy, M. R. Davis, A. Gomez, and D. W. Williams. 1993. The use of 1990 Tiger/Line Census files for monitoring the Rio Grande Valley cotton stalk destruction program. Proc. Application of Advanced Information Technologies Sympos. pp. 231-239.

Stevens, O. A. 1963. Handbook of North Dakota plants. North Dakota Institute of Regional Studies. Page 197. Cushing-Malloy, Inc. Ann Arbor, MI. 324 p.

Trammell, M. A. 1994. Exotic plants of Theodore Roosevelt National Park: Extent, distribution and ecological impact. M.S. Thesis, University of South Dakota, Vermillion. 174 pp.

Tueller, P. T. 1982. Remote sensing for range management. Pages 125-140 *in* C. J. Johannsen and J. L. Sanders, eds. Remote Sensing for Resource Management. Soil Conserv. Soc. Am., Ankeny, IO.

Wallace, N. M., J. A. Leithch, and F. L. Leistritz. 1992. Economic impact of leafy spurge on North Dakota. North Dakota Farm Research Vol. 49, No. 5.