Proc. VII. Int. Symp. Biol. Contr. Weeds, 6-11 March 1988, Rome, Italy.
Delfosse, E.S. (ed.). Ist. Sper. Patol. Veg. (MAF), pp. 585 - 93 (1989).

Using Remote Sensing for Detecting Brush and Weeds on Rangelands in the Southwestern United States

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Abstract

Remote sensing is used to distinguish and measure infestations of several woody and herbaceous plant species on rangelands of the southwestern United States. Color-infrared and conventional color aerial photographs and ground reflectance measurements are used to distinguish the plant species; phenological stage of the plants is important in this process. Computer-based image analysis is used to measure the percent of photographs infested by several species, which can be directly converted to hectares infested. Noxious weed species distinguished and in some cases measured by these techniques include false broomweed (*Ericameria austrotexana*), broom snakeweed (*Gutierrezia sarothrae*), and spiny aster (*Aster spinosus*) (all Compositae); blackbrush (*Acacia rigidula*), huisache (*Acacia farnesiana*), and Mexican palo-verde (*Parkinsonia aculeata*) (all Leguminosae); and saltcedar (*Tamarix* sp.; Tamaricaceae).

Introduction

The invasion and spread of undesirable plant species on rangelands and the vegetative composition of wildland areas present serious problems to range managers and wildland ecologists. Because these areas are often extensive and inaccessible, determining the extent of infestations or the botanical characteristics by ground surveys is difficult (Driscoll 1974). Remote sensing techniques offer rapid and cost-effective means of obtaining reliable data for these areas (Tueller 1982).

Aerial photography has been used successfully to identify weed, shrub, and tree species on rangelands (Tueller and Swanson 1973, Driscoll and Colemen 1974; Gausman *et al.* 1977; Carneggie *et al.* 1983, Strong *et al.* 1985, Everitt *et al.* 1987). In this paper, we present an overview of the use of aerial photography for detecting and measuring the cover of several troublesome weed and woody plant species on rangeland and other wildland areas of the southwestern United States.

Experimental Techniques

The steps in developing a technique for identifying a plant species by remote sensing are: 1) determine the reflectance spectrum of the target plant at close range; 2) make aerial photographs with appropriate film, at an appropriate scale, and at the appropriate phenological stage; 3) perform ground verification of the plants identified in the photograph, and 4) develop methods to determine the area infested in a photograph by the target weed.

Everitt (1985), Everitt and Villarreal (1987), and Everitt *et al.* (1984, 1987) used the following techniques to successfully identify several important weeds of southwestern rangelands.

Plant canopy reflectance was measured in the field using an Exotech[3] spectroradiometer at

[3] Trade names are included for the benefit of the reader and do not imply endorsement of or a preference for the product listed by the U.S. Department of Agriculture.

0.05 µm increments over the 0.45 to 0.90 µm spectral region as described by Leamer *et al.* (1973). Measurements were made with a sensor that had a 15° field-of-view generally placed 3 m above each plant canopy. Measurements were made on six or seven randomly-selected canopies of each plant species or a mixture of species, between 1100 and 1500 hrs under sunny conditions.

Aerial photographs were made with Kodak Aerochrome conventional color (0.40 to 0.70 µm) type 2448 and color-infrared (CIR) (0.50 to 0.90 µm) type 2443 films. Most photos were taken with twin Hasselblad 500-EL cameras (150 mm lens, 5.7 x 5.7 cm format) with filter packets and aperture settings as described by Everitt (1985). Some CIR photos were taken with a Fairchild KA-2 camera (305 mm lens, 23 x 23-cm format) with filter packet and aperture setting as described by Everitt *et al.* (1984). Photos were taken from cameras mounted on the floor of a fixed-wing aircraft between 1100 and 1500 hrs under sunny conditions.

Ground truth reconnaissance was conducted at the various study sites at or near the time imagery was obtained and, generally, after viewing positive film transparencies on a light table. Ground photographs were taken to help interpret aerial photographs relative to plant species, density, cover, and soil surface conditions.

Image analyses used and I^2S image processor interfaced to a computer to digitize the images from the conventional color and CIR film transparencies of some of the study sites. Several computer classification programs were used on the various scenes to determine the percentage of the area occupied by plant species in each transparency. Computer classified images were displayed on a color monitor or produced with a color printer.

Scientific names of plants not mentioned in text but listed in Table 2 and Figure 2 are given in Table 1. An analysis of variance was performed on the reflectance data. Differences among means was tested by Duncan's multiple range test at 0.05% probability.

Table 1. Scientific names of plants mentioned in Table 2 and Figure 2, but not mentioned in the text.

Common name	Latin name	Family name
Bermudagrass	*Cynodon dactylon* (L.) Pers.	Gramineae
Brasil	*Condalia hookeri* M.C. Johnst.	Rhamnaceae
Buffelgrass	*Cenchrus ciliaris* L.	Gramineae
Cenizo	*Leucophyllum frutescens* (Berl.) I.M. Johnst.	Scrophulariaceae
Lotebush	*Ziziphus obtusifolia* (T. & G.) Gray	Rhamnaceae
Texas persimmon	*Diospyros texana* Scheele	Ebenaceae

Rangeland Weeds Identified

False Broomweed

False broomweed (*Ericameria austrotexana* M. C. Johnst.; Compositae) is an evergreen shrub averaging 1 m tall occurring on well-drained clay and clay loam soils on south Texas rangelands (Mayeux *et al.* 1980). It suppresses the growth of desirable species, is difficult to control and appears to be increasing in abundance (Mayeux *et al.* 1980, Mayeux and Hamilton 1982).

Everitt *et al.* (1984) measured canopy reflectance for false broomweed and six associated species and mixtures of species at three wavelengths in April 1982 (Table 2). At the two visible wavelengths (0.55 and 0.65 µm) they could not separate false broomweed from the associated species. However, at the 0.85 µm near-infrared wavelength, false broomweed had significantly lower reflectance than the other species. Reflectance measurements made on the same species in August 1983 followed the same general pattern. The similarity between false broomweed and the associated species at the visible wavelengths was probably due to similar green foliage colors (Gausman 1985). The low near-infrared reflectance of false broomweed was attributed to its erectophile (erect-leaf) canopy structure which caused it to have lower vegetative density (more gaps and breaks) in its canopy and darker inner canopy shadowing than the other species. The other species had planophile (horizontal-leaf) or intermediate (mixed-leaf) canopy structure. Vegetation density and near-infrared reflectance are positively correlated until a stable reflectance is reached (Myers and Allen 1968).

Table 2. Mean canopy light reflectance of various rangeland plant species made April 1982, near Edinburg and Raynondville, Texas.

Plant species or mixture	Canopy reflectance values (%)[1] Wavelengths, µm 0.55	0.65	0.85
Bermudagrass (*Cynodon dactylon* [L.] Pers.)	6.0 *c*	4.0 *d*	29.7 *b*
Brasil (*Condalia hookeri* M.C. Johnst.)	7.1 *b*	3.7 *d*	31.2 *b*
Buffelgrass (*Cenchrus ciliaris* L.)	8.3 *a*	6.1 *c*	35.2 *a*
Cenizo (*Leucophyllum frutescens* [Berl.] I.M. Johnst.	8.2 *a*	8.9 *a*	25.2 *c*
False broomweed (*Ericameria austrotexana* M.C. Johnst.)	4.6 *d*	3.6 *d*	19.9 *d*
Honey mesquite (*Prosopis glandulosa* Torr.)	4.6 *d*	2.6 *e*	31.0 *b*
Mixed grasses and forbs	8.0 *a*	7.7 *b*	30.1 *b*

[1] Values within columns followed by the same letter do not differ significantly at the 0.05% probability level, according to Duncan's Multiple Range Test.

In CIR aerial photos (1:5000 scale), false broomweed was easily distinguished from other rangeland vegetation at 20 widely scattered sites in south Texas, on various dates (April to August). It had a characteristic reddish-brown image in contrast to red and various magenta images of other plant species. The dark image of false broomweed was primarily attributed to its low near-infrared reflectance, but its generally low visible reflectance also contributed to its image response. Its erectophile canopy structure probably contributed greatly to its image.

Broom Snakeweed and Spiny Aster

Broom snakeweed (*Gutierrezia sarothrae* [Pursh.] Britt. and Rusby; Compositae) is an abundant, noxious, composite shrublet 15 to 90 cm tall found on southwestern rangelands of the United States and Mexico (Lane 1985). It often reduces forage production (Ueckert 1979), is poisonous, and causes great losses of livestock (McGinty and Welch 1987). Spiny aster (*Aster spinosus* Benth.; Compositae) is another troublesome composite averaging 1 m tall found on clay soils along ditches, swales, stream bottoms, and other low mesic areas of the southwestern United States and Mexico. It is difficult to control and on portions of the Texas Coastal Prairie it often occurs in dense stands that eliminate forage production on rangelands (Mayeux *et al.* 1979, Mutz *et al.* 1979).

Broom snakeweed has an erectophile canopy structure that produced a dark-brown to black image in CIR photographs (1:10000 scale) that was easily distinguished from the various

shades of magenta, red, and light brown of other plant species and the white image of soil (arrow in Fig. 1A) (Everitt *et al.* 1987). In plant canopy reflectance measurements broom snakeweed had significantly lower (P = 0.05) near-infrared reflectance than eight other associated species when it was in its mature vegetative stage (June to September in south Texas). Ground truth surveys on 12 scattered sites selected from CIR transparencies of rangeland areas in south Texas and eastern New Mexico resulted in correct visual identification of broom snakeweed at all locations. Light to moderate stands (≤50% canopy cover) were distinguished on 1:5000 scale CIR photographs, while dense stands (≥75% canopy cover) could be distinguished on 1:10000 scale photographs. Broom snakeweed could not be distinguished from other plant species and soil in CIR photos when it was in its flowering and post-flowering stages (October).

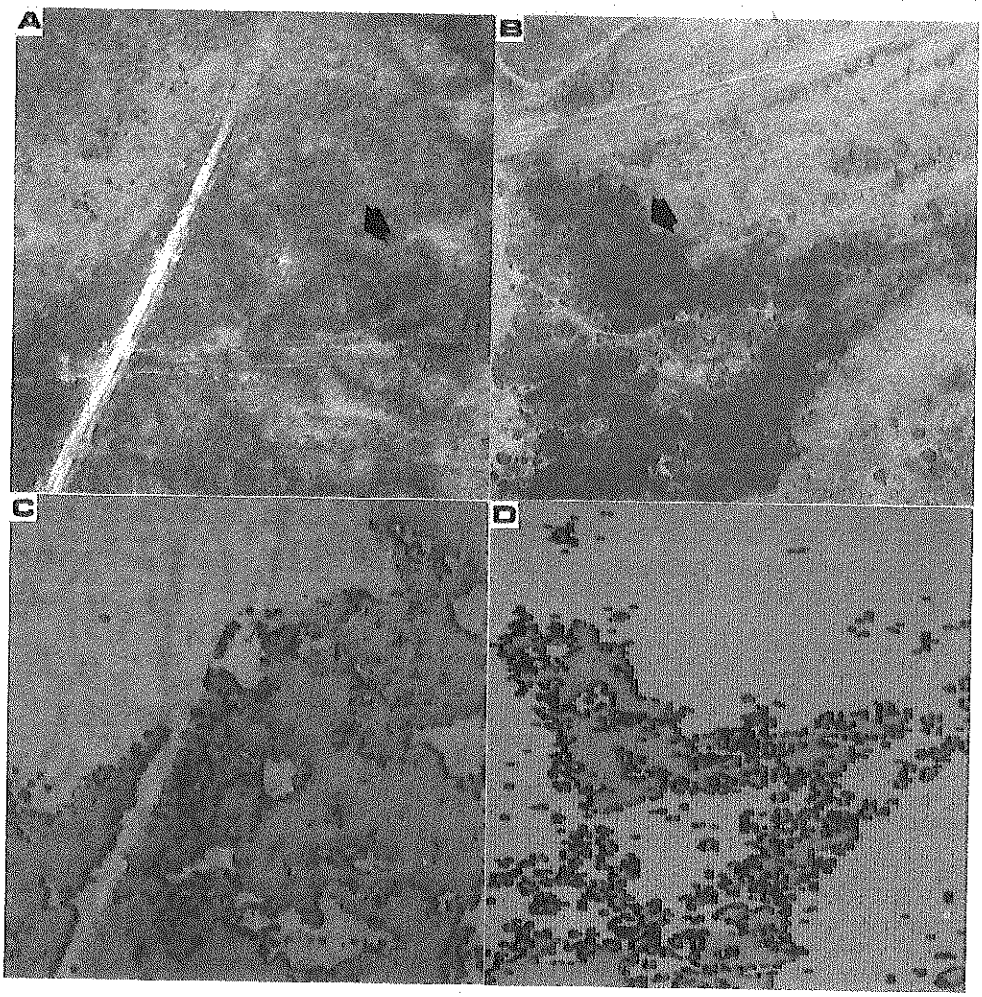

Figure 1. Prints A and B color-infrared positives: A) Broom snakeweed near Tatum, NM, August 1984; arrow points to typical dark-brown to black image of broom snakeweed in 1.5 x enlargement of 70 mm photograph (original scale 1:10000). B) Spiny aster near Tivoli, TX, August 1985; arrow points to typical dark reddish brown image of spiny aster in part of a 23 cm photograph (scale 1:3500). Prints C and D are image analyses and computer- generated identification maps of the CIR photographs in A and B. Broom snakeweed and spiny aster are coded red in each print, other vegetation and soil are coded blue. In C, 67.1% of the image area is broom snakeweed; in D, 30.1% is spiny aster.

Spiny aster (arrow in Fig. 1B) also has a dark reddish-brown to black image that is readily distinguished from the magenta and red images of the other plant species (Everitt *et al.* 1987). This was attributed to its erectophile canopy structure, as with false broomweed and broom snakeweed. In plant canopy reflectance measurements spiny aster had significantly lower near-infrared reflectance than three associated species when it was in various vegetative stages (May, July, and September). Ground surveys at nine sites selected from CIR transparencies (1:2000 to 1:5000 scale) of rangeland areas in south Texas gave 100% correct identification of spiny aster at this time. CIR photographs were not taken of spiny aster in its flowering stage (October), but reflectance data indicate that it may be difficult to distinguish from other plant species at this time.

A comparison of the computer-generated identification maps (Figs. 1C and 1D) with the CIR photographs (Figs. 1A and 1B) indicates that areas where broom snakeweed and spiny aster occur generally were delineated by the computer. Areas where broom snakeweed or spiny aster occur are coded red. The computer classified 67.1% of Fig. 1A as broom snakeweed and 30.1% of Fig. 1B as spiny aster. A photo-estimate method (Hardy and Hunt 1975) classified 62.4% of Fig. 1A as broom snakeweed and 27.2% of Fig. 1B as spiny aster, differences that are minimal. Everitt *et al.* (1987) attributed some of the differences to the photo-estimate where subjective boundary lines were drawn due to the grading of plant species and soil from one type to another. They attributed other differences to the computer classification technique that is based on discrete spectral classes, wherein a decision is made concerning each pixel.

Blackbrush

Blackbrush (*Acacia rigidula* Benth.; Leguminosae) is a common shrub usually 1 to 3 m tall that occurs on a variety of soil types in southern Texas and northern Mexico. It often is a serious weed on rangelands, especially where other shrub species have been removed (Scifres 1980). During late winter or early spring, blackbrush produces small cream to light yellow flowers that cover the entire plant (Everitt 1985).

During flowering, blackbrush had significantly higher ($P = 0.05$) visible (0.45 to 0.75 μm) reflectance than six other associated plant species and mixtures of species in March 1983 (Fig. 2). The light yellow flowers of blackbrush produced a higher visible reflectance than the green foliage of the other species (Gausman 1985). In the near infrared (0.75 to 0.90 μm) spectral region, however, blackbrush could not be distinguished from honey mesquite (*Prosopis glandulosa* Torr.; Leguminosae). In overhead views of the canopies, the two species had similar densities, which probably prevented their separation in the near-infrared spectral region (Myers and Allen 1968). Also, Everitt (1985) could not separate blackbrush from associated species in either the visible or near-infrared spectral regions during the vegetative stage in July.

Blackbrush could be distinguished from the other plant species on both conventional color and CIR aerial photographs when it was flowering, but it was easier to distinguish on the conventional color photos because the flowers retained their light yellow color (Everitt 1985). On CIR photos, the flowers gave a whiter image that was difficult to distinguish from the soil. In conventional color photos in March 1983 at 18 sporadic sites in south Texas, flowering blackbrush was easily distinguished from other species at all locations. Blackbrush was distinguished most easily in conventional color photos at scales of 1:3000 or 1:4000, whereas in CIR photos the 1:3000 scale was best. Blackbrush in the vegetative stage could not be distinguished from surrounding vegetation on either CIR or conventional color photos taken at various south Texas locations in April, May, July, and September 1983.

Huisache and Mexican Palo-verde

Huisache (*Acacia farnesiana* [L.] Willd.) and Mexican palo-verde (*Parkinsonia aculeata* L.) (both Leguminosae)) are abundant woody legumes found on rangelands of southern Texas. Both species average 2 to 4 m tall. Huisache occurs on a variety of soil types, but reaches its greatest density on medium to heavy textured soils (Scifres *et al.* 1982). It often becomes a

serious brush problem on rangeland following soil disturbance by mechanical brush control methods such as root plowing (Mutz *et al.* 1978). Mexican palo-verde often grows in association with huisache, but is found on fewer soil types, primarily in drainage ways, lowland areas, and fertile upland sites. Mexican palo-verde is also a troublesome species, but is less aggressive than huisache and does not usually create a severe management problem (Scifres 1980).

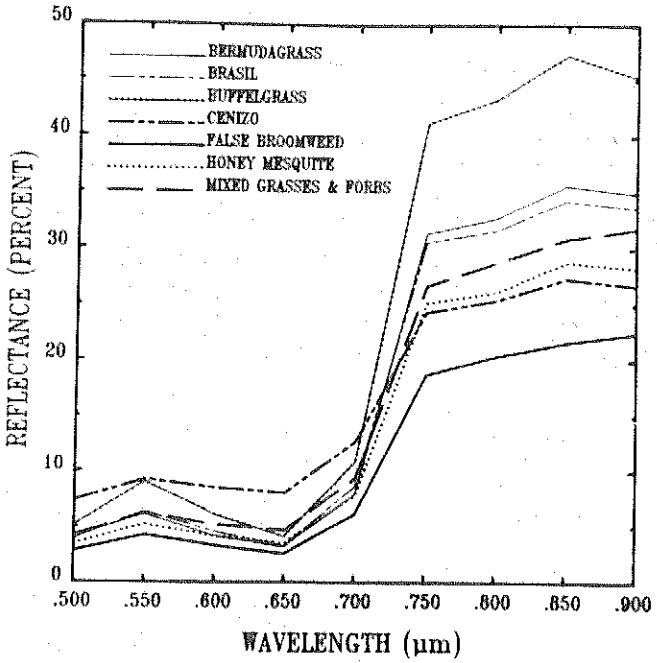

Figure 2. Canopy light reflectance for blackbrush (flowering) and other associated species or mixtures of species on rangelands near La Joya, TX, March 1983, measured in the field by a spectroradiometer.

Like blackbrush, both huisache and Mexican palo-verde have a prominent appearance when they flower. Huisache produces small orange-yellow flowers in February or March that encompass the entire canopy, giving it a striking golden appearance. Mexican palo-verde produces a heavy bloom of yellow flowers in mid-April or early May that gives it a conspicuous yellow-green coloration.

Huisache, a golden color in conventional color positive prints (arrow in Fig. 3A), is easily distinguished from surrounding vegetation (various green and gray tones) and soil (white tone). On CIR photos, however, huisache has a yellowish- or brownish-magenta image that could not be distinguished, possibly because of in-canopy shadowing (Everitt and Villarreal 1987). Ground truth surveys for ten scattered south Texas rangeland sites, selected from conventional color positive transparencies, gave 100% correct recognition of flowering huisache. Huisache generally does not flower until plants are about 1 m tall. Consequently, immature plants could not be detected at some sites. Optimum photographic scales for distinguishing flowering huisache were 1:5000 or 1:6000.

Mexican palo-verde is a typical pink in CIR positive prints (Fig. 3B), compared with darker shades of red and reddish-brown of other herbaceous and woody plant species, white of bare soil, and gray of grass and litter. It has a light-green to yellowish-green image on conventional color photos that was difficult to distinguish; also, non-flowering immature Mexican palo-verde plants (generally < 1 m tall) could not be detected. Ground surveys gave 100% correct identification of flowering Mexican palo-verde for eight sporadic rangeland

conventional color photos that was difficult to distinguish; also, non-flowering immature Mexican palo-verde plants (generally < 1 m tall) could not be detected. Ground surveys gave 100% correct identification of flowering Mexican palo-verde for eight sporadic rangeland sites selected from CIR positive transparencies; the best photographic scales for distinguishing flowering plants were 1:7000 and 1:8000. Neither huisache or Mexican palo-verde could be distinguished from surrounding vegetation on either CIR or conventional color aerial photos when in their vegetative stages (Everitt and Villarreal 1987). In computer classifications of digitized transparencies, huisache was coded gold (Fig. 3C) and Mexican

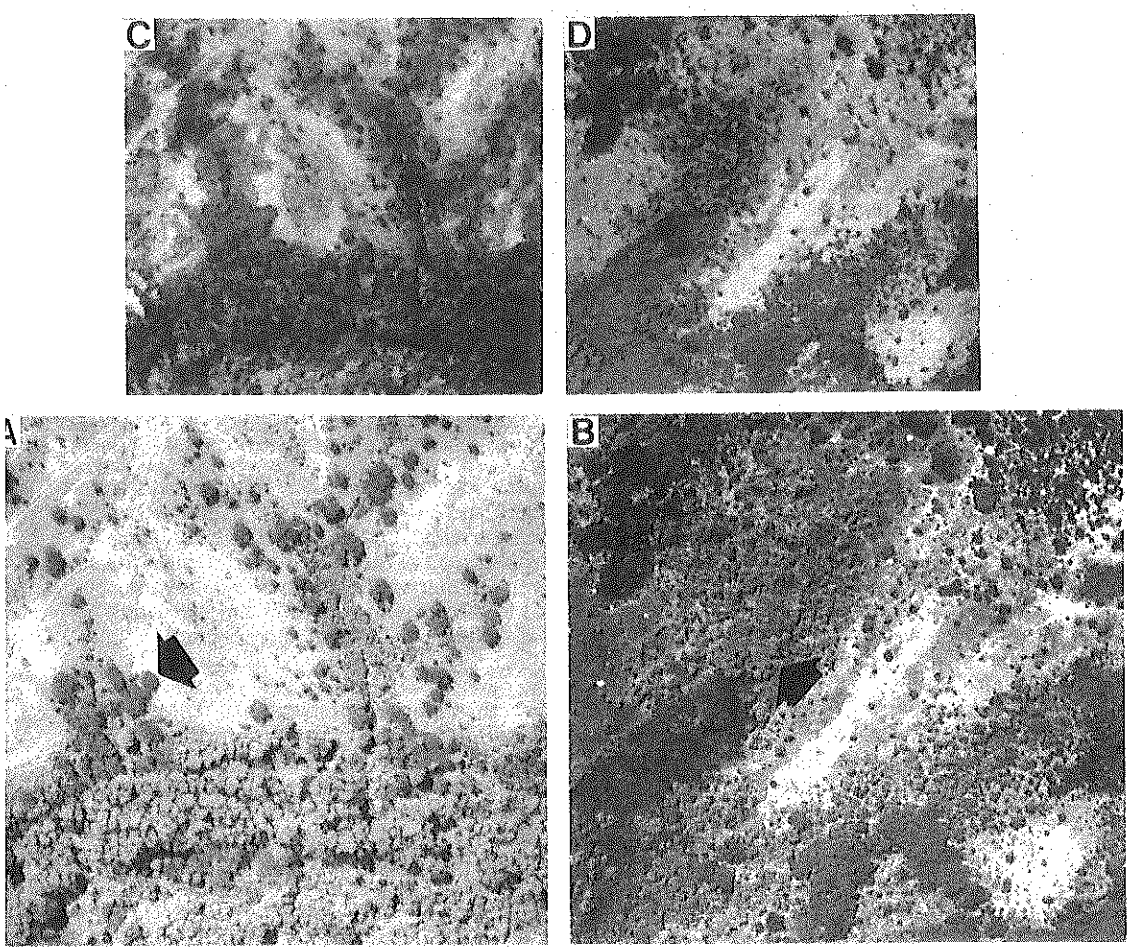

Figure 3. Prints A and B are two weeds of Texas rangelands: A) Huisache: conventional color positive taken near Sinton, TX, March 1986. The arrow points to the characteristic golden image when in flower (4X enlargement of part of a 70 mm photo taken at a original scale of 1:6000). B) Mexican palo-verde: color-infrared positive near Mission, TX, April 1984. The arrow points to the characteristics pink image when in flower (4X enlargement of part of an original 70 mm photo taken at a original scale of 1:8000). Prints C and D are computer-classified digitized images of A and B. In print C, huisache is coded gold; in D, Mexican palo-verde is coded orange.

palo-verde orange (Fig. 3D). The computer clearly delineated areas of mature huisache in a comparison of the computer-classified transparency (Fig. 3C) to the conventional color print (Fig. 3A). The computer classified 11.3% of Fig. 3A as huisache, whereas a photo-estimate method (Hardy and Hunt 1975) classified 13.3% as huisache; Everitt and Villarreal (1987) judged such differences to be minimal because of discrepancies between the two techniques. However, in a comparison of the computer-classified transparency (Fig. 3D) to the CIR print (Fig. 3B), the computer did not accurately identify all areas where Mexican palo-verde occurred even though these areas were visually distinct. This was evident in the lower center of the print where the computer identified portions of the dense stands of hackberry (*Celtis laevigata* Willd.; Ulmaceae) and honey mesquite trees (red color) as Mexican palo-verde. Conversely, the computer underestimated the density of Mexican palo-verde near the center of the print (see arrow). The dark shadowing within the dense stand of Mexican palo-verde may have contributed to its misclassification. The computer classified Mexican palo-verde as 20.8% of Fig. 3B whereas the photo-estimate procedure classified it as 18.0%. Although these percentages did not differ greatly, ground truth data substantiated the photo-estimate was clearly more accurate.

These results showed that conventional color and CIR aerial photographs can be useful tools for detecting huisache or Mexican palo-verde when they are flowering, but nonflowering, immature plants (< 1 m tall) cannot be detected. Aerial surveys should be made in February or March to detect huisache and in mid-April or early May to detect Mexican palo-verde. Computer-based image analyses of conventional color positive transparencies showed that mature huisache infestations on rangelands can be accurately identified and that the area infested can be accurately measured. The identification and measurement of Mexican palo-verde was somewhat less accurate.

Saltceder

Eight species of *Tamarix* (Tamaricaceae) have been introduced into the United States from Europe, Asia, or Africa for ornamentals, windbreaks, and erosion prevention of stream banks. Two deciduous species (saltcedars), *Tamarix ramosissima* Ledeb. and *Tamarix chinensis* Lour. (both shrubs to 8 m tall), are invaders of riparian sites of the southwestern United States and northern Mexico (Baum 1967). These two very similar species form dense, low thickets that displace native vegetation, impede water flow, increase sedimentation and narrowing of river channels (which also increase flooding), use much water, and increase soil salinity (Horton and Campbell 1974).

We are currently evaluating the potential of both CIR and conventional color aerial photography for detecting and monitoring saltcedar infestations in Arizona, New Mexico, and Texas. We are obtaining aerial photos at different phenological stages on various dates during the growing season. Preliminary findings indicate that saltcedar can be distinguished from other plant species and soil in both CIR and conventional color aerial photos (1:3500 to 1:7000 scale) in November and December when its leaves turn a yellowish-orange color prior to leaf drop. At this time, saltcedar had a whitish-pink image in CIR photos, while in conventional color photos it retained its yellowish-orange color.

Conclusions

CIR and conventional color aerial photography can be useful tools for remote sensing of herbaceous and woody plant species on rangeland and other wildland areas of the southwestern United States. Season is an important variable for detecting many plant species on aerial photographs because reflectance often varies at different times during the year and many species are distinguishable only when in a specific phenological stage. Computer-based image analyses of both CIR and conventional color film positive transparencies can be used to measure the area infested by noxious plant species.

Acknowledgments

We thank R. L. Bowen and M. R. Davis for obtaining aerial photographs and producing illustrations, R. Villarreal for his image processing, and M. A. Alaniz for his assistance in the field and laboratory. We also thank J. Rorabaugh for collecting ground truth data of saltcedar.

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