Aerospace Video Imaging Systems for Rangeland Management

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ABSTRACT: This paper presents an overview on the application of airborne video imagery for assessment of rangeland resources. Multispectral black-and-white video with visible/near-infrared (0.4 to 1.1 μm) sensitivity; color-infrared, normal color, and black-and-white mid-infrared (1.45 to 2.0 μm); and thermal infrared (1.0 to 5.5 μm) video have been used to detect or distinguish among many rangeland and other natural resource variables such as heavy grazing, drought-stressed grass, phytomass levels, burned areas, soil salinity, plant communities and species, and gopher and ant mounds. The digitization and computer processing of video imagery have also been demonstrated. Video imagery does not have the detailed resolution of film, but these results have shown that it has considerable potential as an applied remote sensing tool for rangeland management. In the future, spaceborne video systems may provide additional data for monitoring and management of rangelands.

INTRODUCTION

RANGELAND AREAS are often too large and inaccessible to determine their characteristics and extent by ground surveys. Because of the great expanse of rangelands and their lower productivity per unit area, rapid and low-cost evaluation procedures are needed to acquire information for the proper management of these lands. Remote sensing techniques provide a timely, cost effective means of obtaining reliable data for these areas (Tueller, 1982). Both aerial photography and satellite imagery have proven useful for classifying and mapping plant communities, distinguishing plant species, monitoring changing conditions, determining phytomass, and detecting a variety of rangeland ecological ground conditions (Driscoll and Coleman, 1974; Young *et al.*, 1976; Gausman *et al.*, 1977; Tueller, 1982; Carneggie *et al.*, 1983; McGraw and Tueller, 1983; Tucker *et al.*, 1985; Everitt *et al.*, 1987).

Over the past several years video imaging technology has emerged as a new remote sensing tool for natural resource assessment (Manzer and Cooper, 1982; Edwards, 1982; Vlcek, 1983; Meisner and Lindstrom, 1985; Nixon *et al.*, 1985; Everitt and Nixon, 1985; Vlcek and King, 1985; Nixon *et al.*, 1987; Mackey *et al.*, 1987; Mausel, 1988). Video technology has many attributes that are attractive for remote sensing, but the most prominent are its real-time monitoring capability and the immediate availability of the electronic signal for both visual interpretation and digital processing. Video data are relatively inexpensive to acquire, and the time between acquisition, availability, and utilization can be hours instead of the weeks, or even months, with other remote sensing multispectral systems (Mackey and Jensen, 1988). The ability to obtain imagery in very narrow spectral bands (0.05 to 0.10 μm) and in the mid-infrared (1.35 to 2.5 μm) water absorption region of the spectrum is another attractive characteristic of video (Nixon *et al.*, 1985; Everitt *et al.*, 1986a).

Our objective is to illustrate the potential of video remote sensing for a variety of rangeland management applications.

GENERAL PROCEDURES

Video imagery presented in this paper were acquired with five video systems: (1) a black-and-white four-band system with visible/near-infrared (NIR) (0.4 to 1.1 μm) sensitivity (Nixon *et al.*, 1985); (2) a multispectral false color system (0.4 to 1.1 μm) that acquires selectable three-band color composite imagery generated by an encoder and its simultaneously synchronized black-and-white narrowband image components (Nixon *et al.*, 1987); (3) a black-and-white monoband system with mid-infrared (MIR) (1.45 to 2.0 μm) sensitivity (Everitt *et al.*, 1986a); (4) a Sony* CCDV9 camcorder color video system; and (5) a Panasonic AG-450 camcorder color video system. The video cameras used in the first three systems have tube-type sensors, whereas the two camcorder systems have solid-state CCD sensors. Standard format Beta recorders were used with the first three systems while the Panasonic system was equipped with super VHS format. The Sony system had 8-mm format. Additional information about the video systems can be obtained from the references.

Video imagery was generally obtained with video systems mounted vertically in the floor of a fixed-wing aircraft. Altitudes from which imagery was taken and the geographic locations are given in the Results and Discussion. Video images shown here were photographed from an image display monitor.

Black-and-white multispectral video images of interest were digitized using an image processor interfaced to a computer. Procedures used for digitization have been described previously (Everitt *et al.*, 1988a,1988b,1989). Digitized images were enhanced by various image processor functions that included registration, contrast stretch, train and prepare functions to obtain digital data, and computer classification programs.

Additional ground reference data were collected at the study sites at or near the time imagery was obtained. Data were recorded relative to plant species, density, cover, phytomass, soil type, and soil surface conditions. Correlation and regression techniques were used to analyze and interpret data (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

GRASS PHYTOMASS

A pilot study was conducted to evaluate single-band video and video-band-based vegetation indices (composite images) for

*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. government.

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their potential to assess phytomass production within grass plots that were fertilized with five rates of nitrogen (N) (Everitt *et al.*, 1986b,1988b). Eleven single-band images (Table 1) were acquired of the grass plots six weeks after application of five rates of N fertilizer (0, 56, 112, 168, and 224 kg N/ha). Thirteen vegetation indices were produced on an image processor from the various single-band images: green/red, NIR/blue, NIR/green, NIR/yellow-green, NIR/yellow, NIR/orange, NIR/orange-red, NIR/dark orange-red, NIR/red, NIR/dark red, NIR/deep dark red, normalized difference vegetation index NDVI, and transformed vegetation index (TVI). Digital data were obtained from the 24 images and regressed on amounts of phytomass (Table 2). Coefficients of determination from four single-band images (orange-red, red, dark red, and NIR) were significant. Moreover, r^2 values calculated from 12 of the indices were significant (all at $p = 0.01$). The only nonsignificant r^2 coefficient was obtained from regressing TVI digital data on amount of phytomass. Although the r^2 coefficients from the indices varied, a qualitative evaluation of the various composite images showed them to be similar (with the exception of TVI) for separating among the fertilizer treatments (Figure 1). These results indicated that both single-band video and video-vegetation indices can be useful to assess the amount of grass phytomass production, but the indices were superior to the single-band images. The large number of narrowband filters available for various wavebands makes video a valuable remote sensing tool because the multispectral images can be subjected to computer image processing techniques to produce numerous vegetation indices and digital data can be obtained from the various band combinations.

In another experiment, MIR video was evaluated to determine its potential to assess phytomass production within the grass plots shown in Figure 1 (Everitt *et al.*, 1986a). MIR digital data were inversely related to grass phytomass production ($r^2 = 0.62$, $p = 0.05$). Differences among grass plots (treatments) were primarily caused by water content related to a total volume of green phytomass, rather than to percent plant water content *per se*.

Results given here indicate that video imagery may be an effective tool for assessing grass phytomass production on rangelands, providing that the grasses are actively growing. These findings should be useful to range resource managers interested in using remote sensing techniques to estimate the animal carrying capacities of large and inaccessible rangeland areas.

Soil Salinity

Many of the world's rangelands are affected by salinity (Carter, 1975). The detection of these areas is important to range scientists and wildland ecologists involved in using and managing these soils. A study was conducted to evaluate the potential of multispectral video imagery for distinguishing saline soils (Everitt *et al.*, 1988a).

Table 1. Narrowband Filters Used on Video Cameras.

Filter	Sensitive Waveband (μm)
Blue	0.467 – 0.473
Green	0.516 – 0.524
Yellow-green	0.543 – 0.552
Yellow	0.573 – 0.583
Orange	0.586 – 0.595
Orange-red	0.614 – 0.625
Dark orange-red	0.633 – 0.645
Red	0.644 – 0.656
Dark red	0.656 – 0.668
Deep dark red	0.712 – 0.725
Near-infrared	0.815 – 0.827

Figure 2 (lower) shows the red (0.644 to 0.656 μm) narrowband video image of a saline rangeland area near Roma, Texas. The saline clay range sites have a lighter gray to white tone that can be easily separated from the darker tones of the sandy loam sites. The road on the left side of the image also has a white tone. Other white areas are essentially bare soil areas or "slicks" with surface deposits of sodium and calcium salts (mostly calcium) which severely limit plant growth (Fanning *et al.*, 1965; Everitt *et al.*, 1977). The saline sites could also be distinguished in the green (0.516 to 0.524 μm) and NIR (0.815 to 0.827 μm) narrowband images (not shown), but they were more clearly delineated in the red image. However, the saline sites could be easily distinguished in the color-infrared (CIR) video composite (not shown). Additional saline sites could be easily separated from nonsaline sites on other imagery taken in this area, with the red narrowband and CIR composite images being best.

Figure 2 (upper) shows the computer classification of the digitized red narrowband video image (Figure 2, lower) of the saline rangeland area. Saline areas appear black and nonsaline areas appear white. A comparison of the computer classification of the digitized red image to the conventional red image showed that the computer generally delineated the saline areas from nonsaline areas. The computer estimated that 28.8 percent of the image had saline soils. In contrast, the computer estimated that 30.0 percent of the photointerpreter's overlay map of the image was comprised of saline soils. These differences were judged to be minimal. Most of the differences can probably be attributed to the photointerpreter's overlay map where subjective boundary lines were drawn due to the grading between saline and nonsaline soils. However, the inability of the computer to separate the roads from the saline soils in the video image also contributed to the differences. These results showed that computer analyses of video images may be a useful technique to determine area estimates of saline soils on rangelands.

Detection of Plant Species and Other Variables

Multispectral single-band video imagery has proven useful for distinguishing among plant species on rangelands (Everitt and Nixon, 1985; Everitt *et al.*, 1987a). False broomweed (*Ericameria austrotexana* M. C. Johnst.) could be separated from other plant species in NIR (0.85 to 0.89 μm) video imagery, while the weed woolly stemodia [*Stemodia tomentosa* (Mill.) Greenm.] could be distinguished in imagery acquired with a blue (0.42 to 0.45 μm) filter. The blue filter was also best for distinguishing the shrub cenizo [*Leucophyllum frutescens* (Berl.) I. M. Johnst.] from other rangeland species.

CIR and normal color video have also been used to distinguish among plant species on rangelands. Everitt and Nixon (1985b) showed that CIR video had considerable potential for distinguishing among woody plant species on Texas rangelands. CIR video has also been used to distinguish weed infestations on rangelands. Plate 1 (upper) shows a CIR video image of a rangeland area near Alice, Texas infested with the weed silverleaf sunflower (*Helianthus argophyllus* L.). Silverleaf sunflower has a distinct pink image compared with the darker magenta-red images of other woody plant species and the blue-gray image of dormant herbaceous vegetation and litter. Soil has a whitish-gray image. The distinct image response of silverleaf sunflower was attributed to its densely white pubescent foliage which caused it to have higher visible light reflectance (0.50 to 0.75 μm) than the other associated plant species (Gausman *et al.*, 1977).

Plate 1 (lower) shows an oblique normal color video image of a rangeland area near Yuma, Arizona infested with saltcedar (*Tamarix chinensis* Lour.). Saltcedar has a distinct yellowish-orange color that can be easily delineated from the various gray tones of other rangeland vegetation and the white tone of soil. This

TABLE 2. REGRESSION EQUATIONS AND COEFFICIENTS OF DETERMINATION (r^2) OF DIGITAL COUNT DATA FROM 11 SINGLE BAND VIDEO AND 13 VIDEO INDICE COMPOSITE SCENES OF THE GRASS PLOTS ON PHYTOMASS (KG/HA).

Dependent Variable	Independent Variable	Equation	r^2
	Single bands		
Phytomass	blue digital	$y = -5172.2 + 520440/x$	0.41 N.S.
"	green "	$y = -3795.0 + 763420/x$	0.29 N.S.
"	yellow-green "	$y = -6455.8 + 1410300/x$	0.40 N.S.
"	yellow "	$y = -1556.8 + 553530/x$	0.35 N.S.
"	orange "	$y = -3764.6 + 879530/x$	0.43 N.S.
"	orange-red "	$y = -5301.0 + 1093000/x$	0.61*
"	dark orange-red "	$y = -1331.9 + 410110/x$	0.45 N.S.
"	red "	$y = -3567.6 + 782500/x$	0.58*
"	dark-red "	$y = -3828.2 + 667850/x$	0.70**
"	deep dark red "	$y = -6924.0 + 1080200/x$	0.39 N.S.
"	NIR "	$y = -4712.6 + 58.0x$	0.67**
	Indices		
"	green/red digital	$y = 13918.0 + 436.93x$	0.77**
"	NIR/blue "	$y = -3538.5 + 70.136x$	0.80**
"	NIR/green "	$y = -3021.2 + 125.89x$	0.73**
"	NIR/yellow-green "	$y = -3072.1 + 195.48x$	0.74**
"	NIR/yellow "	$y = -1251.4 + 112.54x$	0.64**
"	NIR/orange "	$y = -2332.8 + 122.96x$	0.74**
"	NIR/orange-red "	$y = -2535.3 + 30.419x$	0.79**
"	NIR/dark orange-red "	$y = -1237.2 + 26.974x$	0.71**
"	NIR/red "	$y = 636.75 + 18.905x$	0.72**
"	NIR/dark red "	$y = -2096.2 + 30.297x$	0.85**
"	NIR/deep dark red "	$y = -4332.0 + 146.31x$	0.88**
"	NDVI NIR-red/NIR + red "	$y = -4031.0 + 243.76x$	0.63**
"	TVI (NIR-red)/(NIR + red) + .5 "	$y = 14281.0 + 83.85x$	0.51 N.S.

**Significant at 0.01 probability level.
*Significant at 0.05 probability level.
N.S. = not significant.

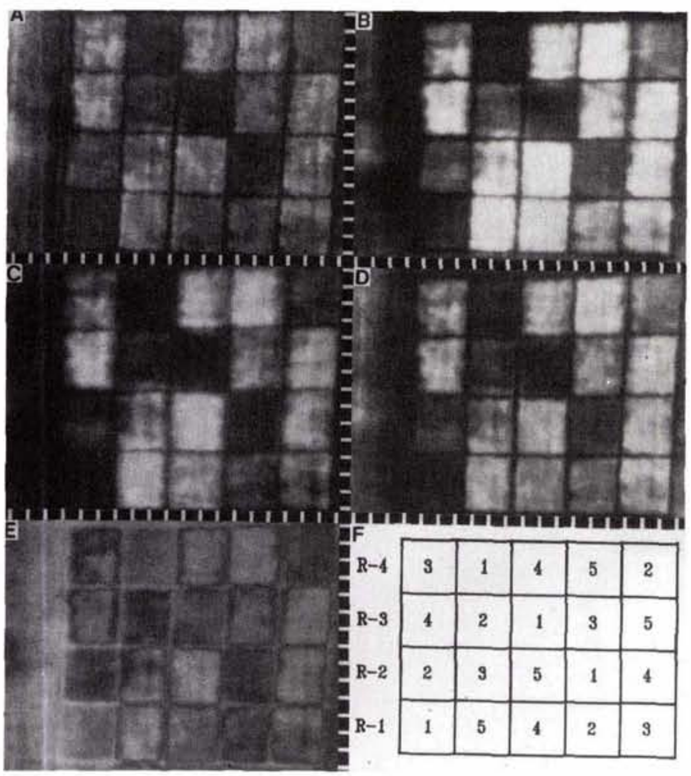

FIG. 1. (A) Green/red, (B) NIR/orange-red, (C) NIR/deep dark red, (D) NDVI, and (E) TVI composite images, and (F) plot diagram of grass plots with different levels of nitrogen fertilizer. Treatments: (1) nonfertilized; (2) 56 kg N/ha; (3) 112 kg N/ha; (4) 168 kg N/ha; (5) 224 kg N/ha.

image was acquired in December when the leaves of saltcedar had turned a yellowish-orange to orange-brown color prior to leaf drop.

CIR and multispectral single band video imagery have also been used for detecting many other rangeland variables. CIR video has been used successfully to distinguish heavily grazed and vigorous rangeland vegetation (Everitt *et al.*, 1987), while blue or red band and red band imagery were optimum for detecting pocket gopher (*Geomys personatus* True) and harvester ant (*Pogonomyrmex barbatus* F. Smith) mounds, respectively (Everitt and Nixon, 1985a). NIR video has been used to assess burned rangeland (Everitt *et al.*, 1987a), whereas MIR (1.45 to 2.0 μm) video has proven useful for distinguishing between heavily stressed and lightly stressed grass (Everitt *et al.*, 1986a).

PLANT COMMUNITY MAPPING

Lulla *et al.* (1987) evaluated three common vegetation indices (NIR/red, NIR/green, and NDVI) to discriminate among broad vegetation types in a rangeland environment in southern Texas. They showed that vegetation indices aided in the discrimination of tree cover, grassland, and various densities of rangeland shrub vegetation, and demonstrated the utility of cluster algorithms with videographic data. The techniques of applying ecological scales of community measurement to video data are being developed. This could result in quantitative assessment of rangeland communities.

CIR video imagery was evaluated for distinguishing among native plant communities on the Welder Wildlife Refuge in southern Texas (Everitt *et al.*, 1989). Drawe *et al.* (1978) described the vegetation of the refuge and produced a map showing 16 plant communities on the area. The plant communities were classified on the basis of dominant plant species or groups of plants.

Plate 2-A shows the CIR video image of a portion of the refuge

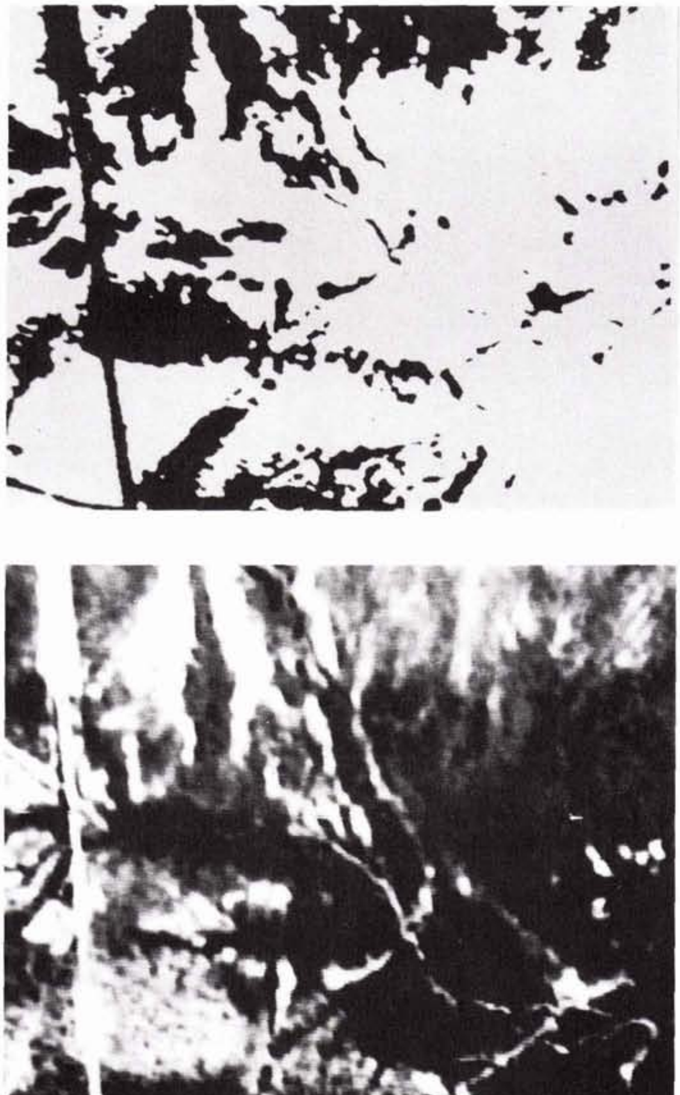

FIG. 2. Red narrowband video image (lower) of a saline rangeland area near Roma, Texas. The image was acquired at an altitude of 1500 m and has a width of coverage of 1 km. Computer classified image (upper) of the digitized red narrowband image of the saline rangeland area. Saline areas appear black and nonsaline areas appear white.

with 11 plant communities in June 1988. Plate 2-D shows the plant community map (Drawe *et al.*, 1978) of the area. The map legend is given below the figures. Several of the plant communities can be visually distinguished in the CIR image: Riparian woodland (bright red), Chaparral-Mixed grass (dark red), Spiny aster-Longtom (dark brown-black and magenta), and Halophyte-Short grass (white). The Chittimwood-Hackberry community (small, bright red area) can also be delineated, but its image is similar to that of the Riparian woodland. The similarity in visual responses between the Chittimwood-Hackberry and Riparian woodland communities was attributed to the dominance of hackberry (*Celtis laevigata* Willd.) in both communities. The gray signature scattered throughout the image and that dominates several communities is dormant herbaceous vegetation. The area was under semi-drought conditions at the time of this study and, consequently, there was little green herbaceous plant material with the exception of that in the more lowland areas (e.g., Spiny aster-Longtom community). Dark areas in the Spiny aster-Longtom, Huisache-Mixed grass, and Woodland-Spiny aster communities were generally dominated by the subshrub spiny aster (*Aster spinosus* Benth.). The dark image response of spiny aster was due to its low NIR reflectance (Everitt *et al.*, 1987b). The only water in the image was the river, as the ephemeral lakes and ponds contained no water at the time of image acquistion. However, the extensive Spiny aster-Longtom community in the lower left of the image had a lot of exposed mud (black areas scattered throughout community) whose signature was similar to that of spiny aster. The Halophyte-Short grass community is comprised of saline soils which severely limit plant growth and result in sparse vegetative cover on these areas; thus, this community appears barren on the image.

The supervised maximum likelihood computer classification of the CIR video image is shown in Plate 2-B. The procedure produced a six-feature classification of the image. Halophyte-Short grass (white), Riparian woodland (bright red), Chaparral-Mixed grass (dark red), and water (black) are evident in the classification, but there is some misclassification of most of these communities with the exception of water. The Chittimwood-Hackberry and Spiny aster-Longtom communities can also be delineated, but their spectral signatures produced variable color schemes (bright and dark red). Sparsely vegetated areas and roads throughout the image were classified as Halophyte-Short grass communities. The maximum likelihood procedure appeared to accurately classify areas dominated by dormant herbaceous vegetation.

GEOGRAPHICAL INFORMATION SYSTEMS

Plate 2-C shows the digitized plant community map of the Welder Wildlife Refuge that was registered to the CIR video image of the area. The ability to register ground truth maps or other map and photographic products to video images will be of interest to range managers wishing to use video in geographical information systems (GIS) for routine operations. Predictive models of vegetation condition and biomass yield could be developed for each individual plant community and driven by periodic updates of video imagery. Production could then be estimated for the different plant communities on a continuing operational basis. For example, ranchers could use this information to help rotate pastures to prevent overgrazing. Estimates of wildlife populations could be made based on spectral models of habitat condition, and estimates of likely wildlife population could be made for each community.

The need to actually classify plant conditions spectrally could be eliminated because digitized maps would automatically delineate the video data associated for each plant community. Then specialized models for each plant community would use the delineated video data for estimates. In view of the relatively poor maximum likelihood classification results obtained for the video data used in this study, the benefits of a GIS would be very helpful. Most ranchers know where the plant communities are, and this knowledge can be put to good use.

VIDEO IMAGING FROM SPACE: THE SPACE SHUTTLE EXPERIMENTS

Video cameras form an integral part of the cargo bay equipment to monitor bay activities and related real time applications on space shuttle experiments. In recent years, an intensified effort has been initiated to assess the potential of video imaging from space. An infrared CCD camera was flown in 1986 aboard the

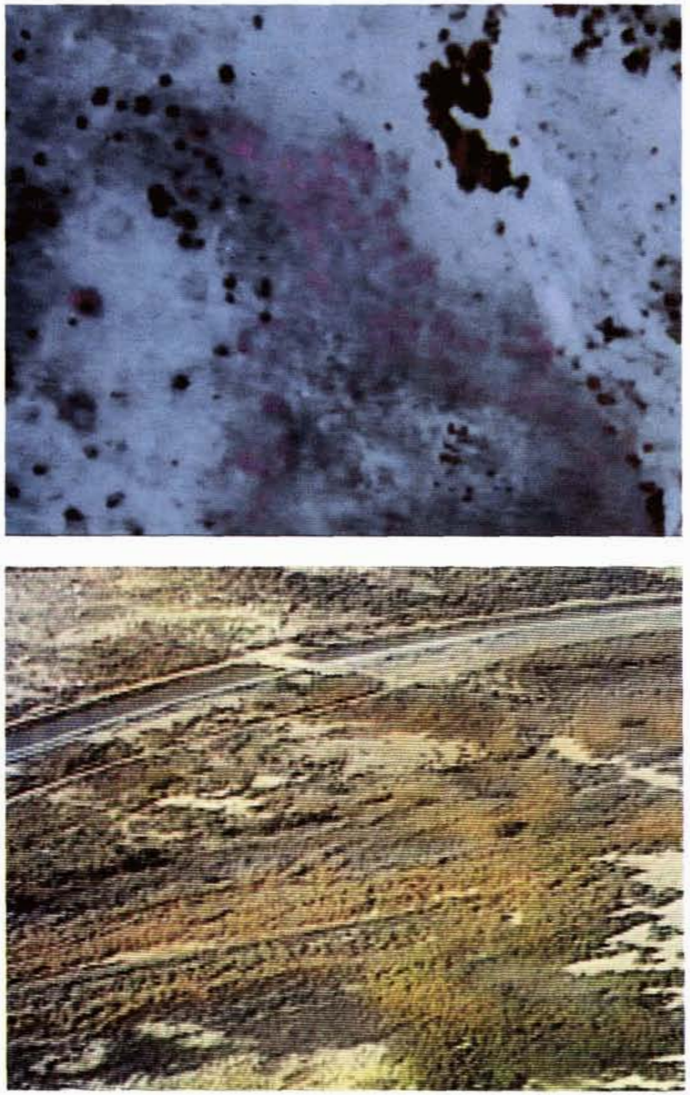

PLATE 1. Color-infrared video image (upper) of a rangeland infested with silverleaf sunflower near Alice, Texas. Silverleaf sunflower has a pink image. The image was acquired at an altitude of 780 m. Oblique normal color video image (lower) of a rangeland area infested with saltcedar near Yuma, Arizona. Saltcedar appears yellowish-orange. The image was obtained at an altitude of 600 m.

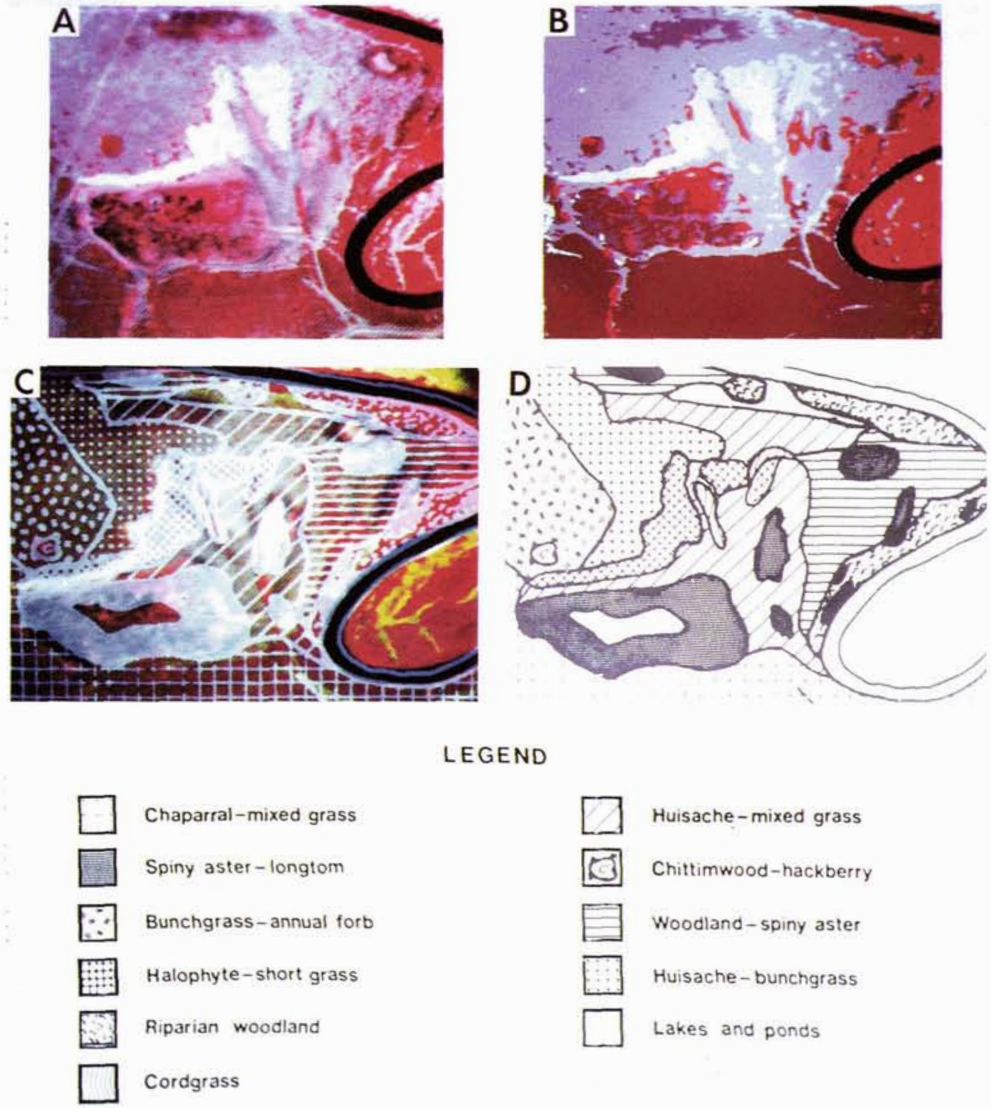

PLATE 2. Color-infrared video image (A) of a portion of the Welder Wildlife Refuge near Sinton, Texas; supervised maximum likelihood classification (B) of the video image; digitized plant community map registered to the video image (C); and plant community map (D) of the area. The map legend is given in the lower portion of the figure. The video image was acquired at an altitude of 3000 m and has a width of coverage of 2 km.

space shuttle Columbia. The camera was equipped with a platinum silicide CCD device with a spectral range of 1 to 5.5 μm. Groppe *et al.* (1987) reported that the performance of this camera showed that spaceborne thermal imaging of Earth was possible with the current technology. Sites monitored included the Amazon River basin and Central American volcanoes.

An 8-mm camcorder color video camera was used aboard the space shuttle Atlantis (ST5-30) for preliminary evaluation of the use of such technology for spaceborne applications. Earth views recorded by the crew from the shuttle windows provided sharp, crisp images of various scenes. The zoom capability of the camcorder was an advantage as well. Imagery from this system is being evaluated by scientists at Johnson Space Center. An example of imagery is shown in Figure 3 which depicts a large playa lake and surrounding rangeland use of an area near Durango, Mexico. Analysis shows that imagery is useful for seasonal information on land use and environmental patterns. These types of data are often valuable as an ancillary source of verification data for multisensor studies. Lulla (1989) has discussed the details of the shuttle video imaging activities and their potential applications for biotic resources.

CONCLUSIONS

We have presented data in this paper which demonstrates the applicability and versatility of airborne video imaging systems for assessing a variety of ecological ground conditions of rangelands. Although video imagery has lower resolution than photography, it can provide range managers with quick turnaround, inexpensive remote sensing data. Video remote sensing may have its most immediate value in combination with image processing and classification systems, thus allowing the application of computer processing to the data.

The development and design of video systems for use in remote sensing applications are still in exploratory stages. Continuing development in all areas of video technology should lead to improvements in the effectiveness and utility of aerial videography for management of rangelands and other natural resources.

FIG. 3. Black-and-white photograph of a camcorder color image from the space shuttle Atlantis (165 nm altitude). An area 45 km North of Durango, Mexico is imaged to the playa lake Laguna de Santiaguilla in full water (generally depicted as dry on maps) and rangeland use around this lake which is flanked by portions of the Sierra Madre Occidental. This image captured the seasonal profile of the playa lake which has the deeper upper portion (darker) and shallower bottom half (lighter) clearly discerned.

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