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JUNE 1980

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Space Administration

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16. Abstract

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ABSTRACT

Relationships between the quantity of mixed prairie rangeland vegetation and Landsat MSS response were studied during four growing seasons at test sites throughout the United States Great Plains region. A Landsat derived parameter, the Normalized Difference (ND) was developed from theoretical considerations for statistical estimation of the amount and seasonal condition of rangeland vegetation. The ND parameter was tested for application to local assessment of green forage biomass and regional monitoring of range feed conditions and drought. These investigations have shown that for grasslands in the Great Plains with near continuous vegetative cover and free of heavy brush and forbs, (1) the Landsat digital data can provide a useful estimate of the quantity of green forage biomass (i.e., within 250 kg/ha), and (2) at least five levels of pasture and range feed conditions can be adequately mapped for extended regions.

*This is a preprint of an article submitted to Photogrammetric Engineering and Remote Sensing The basic elements of this article were originally presented at the Symposium on Rangeland Remote Sensing at the 30th Annual Meeting of the Society for Range Management in Portland, Oregon, February 17, 1977.

CONTENTS

USING LANDSAT DIGITAL DATA FOR ESTIMATING GREEN BIOMASS

INTRODUCTION

Proper management of rangeland requires timely information about vegetation conditions for individual management units, as well as for greater geographical areas. Prior to the Landsat era adequate information about this resource could not be obtained efficiently and effectively for management decisions. Accurate forage production information is very difficult and expensive to obtain through ground surveys Current reports about regional range feed conditions, although useful, are not timely and contain human bias, which results in inaccuracies (Gray, 1975).

Several rangeland studies, conducted concurrently with those summarized in this paper, have shown that Landsat imagery and computer compatible tape (CCT) data have the potential for providing much of the forage information required by the ranch manager. Thomas (1975) found that Landsat was useful in a multistage sampling scheme for estimating current rangeland productivity. Maxwell (1976) was successful in mapping standing crop biomass of rangeland in 560 kg/ha classes for three dates, using a ratio of Landsat MSS Channel 7 to Channel 5. Tompson (1977) found that biomass differences of approximately 450 kg/ha could be discriminated on Landsat color composite imagery for mixed prairie rangeland in Western Canada.

Duggin et al (1975) detected significant differences in Landsat (MSS) reflectance data resulting from small differences in stocking rates between pastures in Australia. Carneggie (1974) found that quantitative determinations of the occurrence of germination, the peak of foliage production, and the period of drying could be made from a temporal sequence of Landsat MSS radiance data. Poulton et al. (1975) reported that Landsat imagery provided the first practical opportunity for making an objective and unbiased regional assessment of the condition of California's annual forage crop throughout its life cycle

The Landsat-1 Great Plains Corridor project, the results of which form the foundation of this paper, was designed to evaluate Landsat capability for quantitatively monitoring the progression of phenological development from south Texas northward through North Dakota. The study employed a network of ten test sites in the MIxed Prairie grassland association at established range research stations in the six Great Plains states (Figure 1). Ground observations, recorded every eighteen days at each site, included green biomass, phenology of dominant species, moisture content of the vegetation, weather information, and certain site conditions. Cloud-free Landsat-1 MSS data were acquired and analyzed for all ten sites for several dates coincident with ground samples.

The Throckmorton test site (Figure 1) in the Rolling Red Plains of north central Texas was used to undertake a more intensive analysis of Landsat green biomass measurement capability. Eighteen high quality ground/Landsat data sets were acquired and analyzed for a 23-month period encompassing parts of the 1972-1974 growing and dormant seasons. Four data sets were later added from the 1975 growing season.

A follow-on Landsat-2 investigation, also reported herein, was conducted during the 1975 growing season and evaluated the techniques developed for green biomass measurement for monitoring regional range feed conditions. In addition, other special applications of the green biomass measurement techniques are demonstrated and priority needs for research are indicated.

SPECTRAL ANALYSIS CONSIDERATIONS

Sun Angle Correction

Changing atmospheric and illumination conditions were anticipated as a serious problem for making temporatl comparisons of digital data values from Landsat. An investigation of the changes in solar intensity resulting from sun angle variations resulted in the application of a solar angle correction for all radiance data used in these investigations.

The mathematical relationship of the intensity of solar radiation falling on a horizontal plane is presented by Robinson (1966). In this model, solar intensity is a function of the solar constant I_o, and the solar elevation γ. The relationship

$$I_H = I_o \sin_\gamma$$

was used to correct all MSS digital data for changes in solar intensity as a function of solar elevation angle.

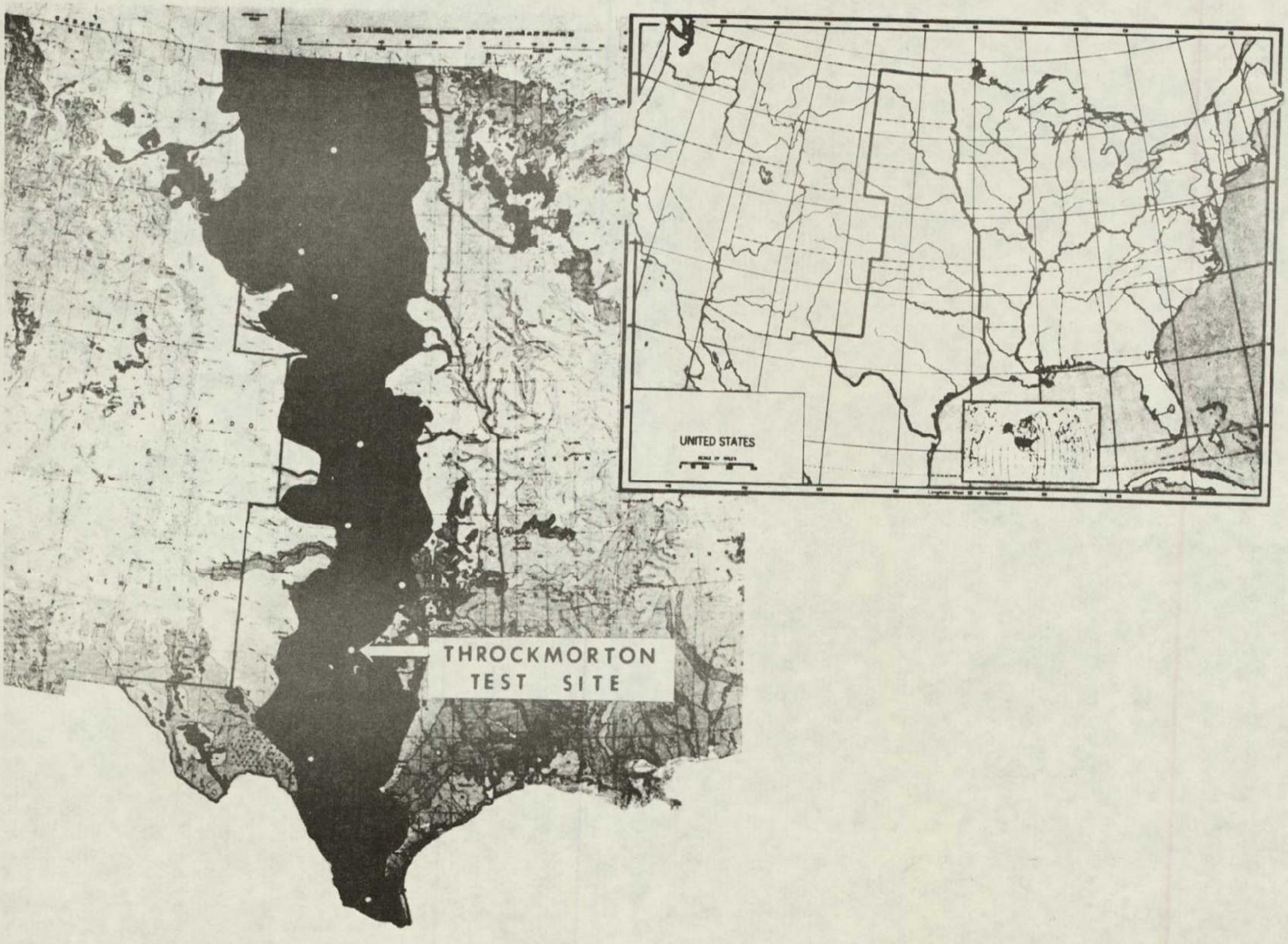

Figure 1. Great Plains Corridor formed by the Mixed Prairie grassland association and the associated test site network

Early tests confirmed that the solar angle correction removed most of the variation due to solar angle (Rouse et al. 1973a) thus permitting temporal comparison at a given test site and among test sites for a given Landsat cycle. Further investigations (Rouse et al 1973b) confirmed the contentions that the sun angle correction is adequate to provide meaningful signatures from Landsat MSS data under clear sky conditions.

Development of the Normalized Difference Technique

It is well established that the foliage of green plants differentially absorb and, consequently, differentially reflect energy in the visible and near-infrared regions of the electromagnetic spectrum. Figure 2 shows hypothetical spectral responses of green and dormant (or dry) herbaceous vegetation in relation to the Landsat MSS spectral bands. Since the red band energy (MSS Band 5) is strongly absorbed and the near-infrared band energy (MSS Bands 6 and 7) is more strongly reflected by dense green vegetation, the difference between the red and near-infrared reflectance should provide a useful index of the greenness of a vegetation scene. This fundamental relationship suggests a useful concept for monitoring natural vegetation changes.

As vegetation changes from green to brown, the radiance difference will be proportionally reduced. It would also be expected that greater quantities of green plant material per unit area will result in stronger absorption of red energy because of the greater quantities of chlorophyll. Similarly, increases in near-infrared reflectance will occur due to increased leaf volume. Consequently, the difference between the red and near-infrared Landsat radiance measurements should increase with greater quantities of green biomass

Although the simple ratio of near-infrared reflectance has been used as a measure of relative greenness, location-to-location, cycle-to-cycle, and location-within-cycle deviations will likely occur as a large source of error. Also, the simple ratio is not easily normalized for systematic variations in incoming radiation. Thus, the difference in the near-infrared and red reflectance values, normalized over the sum of these values, was developed as an index value and was referred to as the "vegatation index."

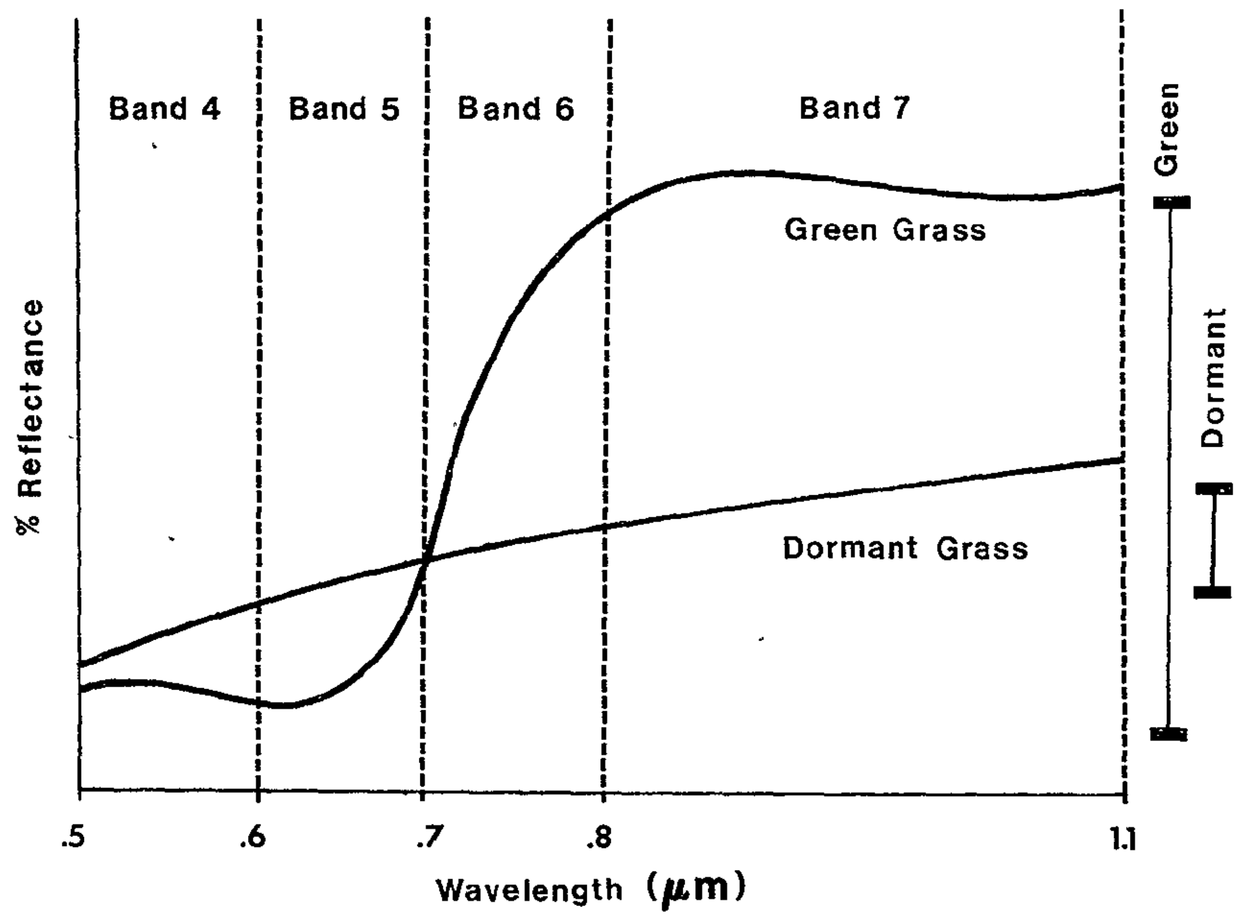

Figure 2. Hypothetical green and dormant plant response in the Landsat MSS bandpasses and the corresponding Band 7 minus Band 5 responses

$$\text{Vegetation Index (VI)} = \frac{\text{Near IR-Red}}{\text{Near IR+Red.}} \tag{1}$$

Since the development of the Vegetation Index by the authors (first reported in Rouse, et al., 1973a), several researchers have developed other vegetation measurement spectral parameters, which have also been called vegetation indexes. The term "vegetation index" has thus become a general term referring to any one of these parameters. Consequently, the authors have elected to rename this parameter the Normalized Difference or ND, which better describes the nature of the index model.

Square root transformations are sometimes applied to data that approximate a Poisson distribution, such as frequently occurs with count data or when n is high; e.g >30. Landsat original data are in terms of count values. For this reason, and in order to avoid working with negative ratio values, as well as to avoid the possibility that the variance of the ratio would be proportional to the mean, a square-root transformation was applied. The resulting "transformed vegetation index" or TVI was then defined as:

$$TVI = \sqrt{VI + 0.5}$$

where VI is the Vegetation Index (1) or Normalized Difference (ND). The theoretical range of values for the ND and TVI are -1.0 to +1.0 and $\sqrt{-0.5}$ to 1.22, respectively.

Histograms of nontransformed ND data generated since the development of the TVI parameter appear to more closely follow the normal distribution than the Poisson distribution, however, and the TVI data histograms are virtually identical to those for ND (Deering, 1978). Consequently, it may be that the transformation is unwarranted. This should be examined further. In any event, it is apparent that the transformation is not a drastic change.

The TVI and ND values will theoretically increase as the difference between MSS Band 7 (or MSS Band 6) and MSS Band 5 becomes greater due to increased absorption of red energy and increased reflection of near infrared energy by healthy, green plant material. This general principle is valid for reflective red and near infrared measurements from any remote sensor, such as airborne multispectral scanners, aerial photos, the proposed spaceborne Thematic Mapper, etc. It should be noted that the vegetaion index acronyms, such as ND and TVI, are generally modified by a number to denote which spectral bands have been used in the basic parameter for a specific sensor system. For example, when the Landsat MSS Band 6 is used as the near infrared measurement in the ND or TVI parameters, they are called ND6 and TVI6, respectively; as in contrast to ND7 and TVI7 which use MSS Band 7.

RESULTS AND DISCUSSION

Relationships of Normalized Difference to Biomass Parameters

After testing several band ratios and individual MSS band values for data from the ten GPC sites, it was found that the difference between MSS Band 5 and MSS Band 6 (ND6), instead of MSS Band 7 (ND7), is generally more consistent for the detection and quantitative evaluation of green biomass differences (Rouse et al., 1974). The close relationship between the ND6 parameter and oven-dried green biomass at the Throckmorton, Texas test site (i.e., data collected continuously during a twenty-three month period from August 1972 through June 1974) is presented in Figure 3. These data plus four additional dates of Landsat coverage coincident with ground sampling in 1975 provide twenty-two data sets for analysis at the Throckmorton test site.

Green biomass ranged from near zero during late winter dormancy to over 2100 kg/ha in October 1975. The linear relationship of green biomass with ND6 was highly significant ($r^2 = 0.91$) for the twenth-two dates (Figure 4) Individual Landsat MSS band values and several Landsat spectral vegetation indices developed by other researchers (Richardson and Wiegand, 1977; Kauth and Thomas, 1976) were found to be not as well correlated as ND6 with herbaceous green biomass at Throckmorton (Table 1). All vegetation indices using MSS Band 6 were better correlated with ground measurements than indices using MSS Band 7 data Although the relationship was essentially the same for ND6 and the simple Band 6/Band 5 ratio at this site, it is anticipated that the normalization feature of the ND6 parameter will facilitate better comparisons among locations and enable more universal application of the vegetation index.

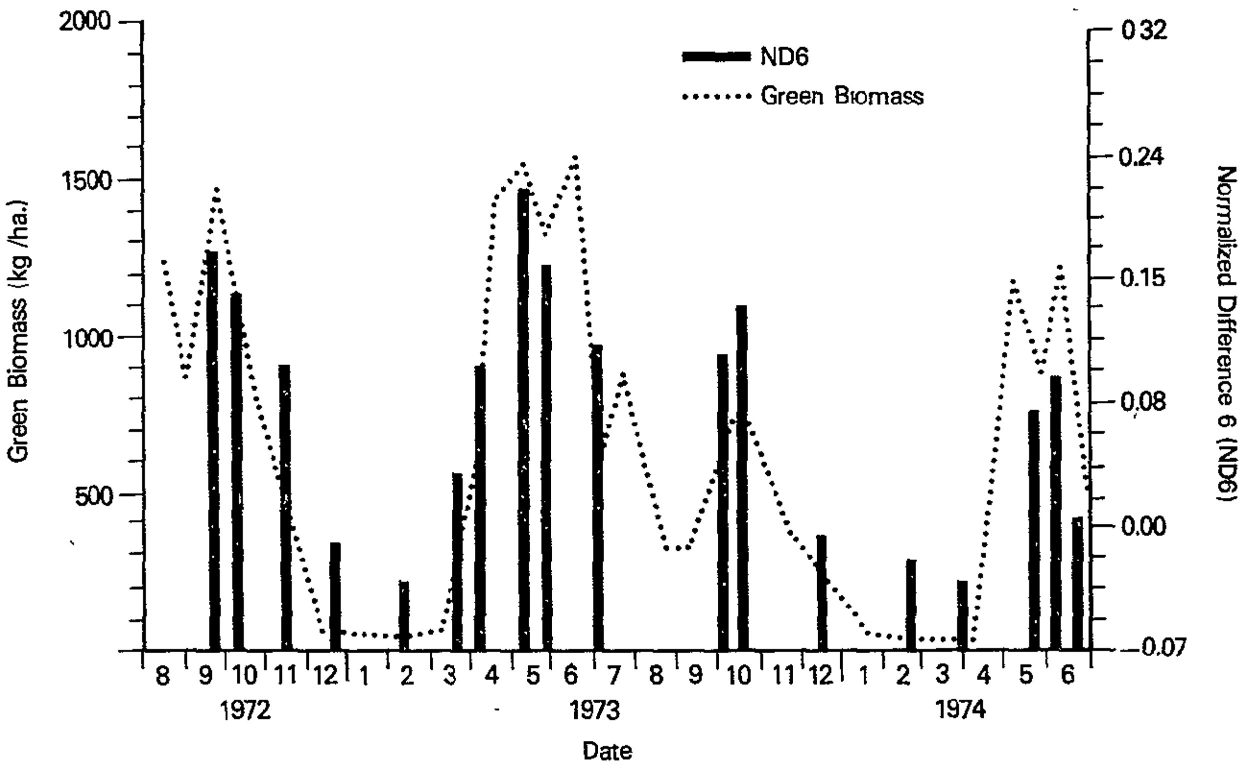

Figure 3. Relationship between the Landsat-derived ND6 values and green biomass measured at the Throckmorton, Texas test site

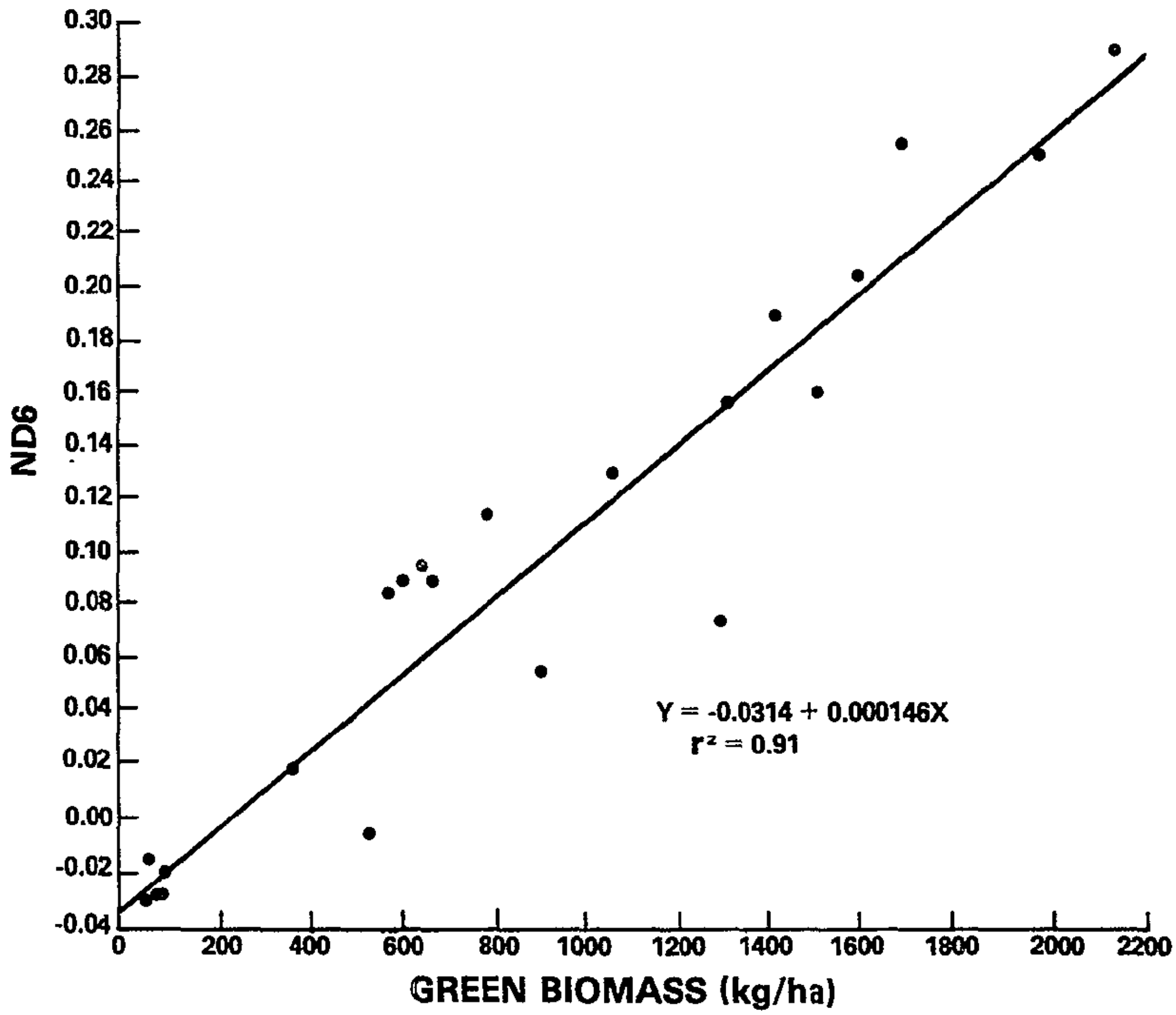

Figure 4. Linear regression of the Landsat-derived ND6 vegetation index parameter on herbaceous green biomass dry weight at the Throckmorton, Texas test site during four growing seasons (1972-1975)

Table 1
Coefficients of determination for linear regression analysis of Landsat MSS Bands and ratio parameters on herbaceous green biomass for twenty-two dates at Throckmorton, Texas

MSS Band or Simple Ratio	Coefficients of Determination r^2	Vegetation Index†	Coefficients of Determination r^2
Band 4	.68**	ND7	.82**
Band 5	.67**	ND6	.91**
Band 6	.08**	PVI7	.72**
Band 7	.02	PVI6	.79**
4/5	.03	GVI	.88**
6/5	.89**	DVI	.72**
7/5	.80**	SBI	.52**

**Significant at the 0.01 probability level.

†Formulae for vegetation indices:

(a) Normalized Difference with Band 7 or ND7 = (MSS7–MSS5)/(MSS7+MSS5) (Deering et al., 1975; Deering, 1978)

(b) Normalized Difference with Band 6 or ND6 = (MSS6–MSS5)/(MSS6+MSS5) (Deering et al., 1975, Deering, 1978)

(c) Perpendicular Vegetation INdex 7 or PVI7 = $((Rgg5-Rp5)^2 + (Rgg7-Rp7)^2)^{1/2}$ (Richardson and Wiegand, 1977)
where, Rgg5 = 0.851 Rp5 + 0.355 Rp7
Rgg7 = 0.355 Rp5 + 0.148 Rp7
Rp5 = MSS5
Rp7 = MSS7

(d) Perpendicular Vegetation Index 6 or PVI6 = $((Rgg5-Rp5)^2 + (Rgg6-Rp6)^2)^{1/2}$ (Richardson and Wiegand, 1977)
where, Rgg5 = –.498 + 0.543 Rp5 + 0.498 Rp6
Rgg6 = 2.734 + 0.498 Rp5 + 0.457 Rp6
Rp5 = MSS5
Rp6 = MSS6

(e) Green Vegetation Index Model or GVI = –0.290 MSS4 – 0.562 MSS5 + 0.600 MSS6 + 0.491 MSS7 (Kauth and Thomas, 1976)

(f) Difference Vegetation Index or DVI = 2.4 MSS7-MSS5 (Richardson and Wiegand, 1977)

(g) Soil Brightness Index or SBI = 0.433 MSS 4 + 0.632 MSS5 + 0.586 MSS6 + 0.264 MSS7 (Kauth and Thomas, 1976)

Total oven-dry herbaceous biomass at Throckmorton during the twenty-two date period ranged from a low of 1530 kg/ha to 2850 kg/ha. None of the Landsat parameters given in Table 1 were found to be significantly correlated with the total standing herbage. Consequently, the approach does not appear to have application for direct estimation of total usable forage.

Vegetation moisture content at Throckmorton typically ranged from 10% to 50%, although one winter sample recorded moisture content close to zero. The ND6 parameter was found to be well correlated with vegetation moisture content ($r^2 = 0.79$). Since green biomass and moisture content describe vegetation conditions, the Throckmorton test site data provide convincing evidence that the ND6 parameter can be used to monitor herbage production, range readiness, drought, and range feed conditions for mixed prairie rangeland vegetation.

Factors Affecting Biomass Estimation

Although ND6 provides a quantitative measure of the amount of green vegetation on mixed prairie rangeland, there are a number of factors that may cause scene reflectance changes which are not related to green biomass and consequently contribute to measurement error Also, the composition and continuity of the total vegetation cover may affect the ability to accurately measure herbaceous green biomass.

The status of vegetation is intrinsically related to environmental functions, consequently, weather may directly and indirectly influence spectral reflectance of objects in a scene. Precipitation (wetting effect) and temperature (drying effects) have been shown to be important in determining the reflectance characteristics of the surface soil, dead plant material and live vegetation (Rouse et al., 1974). Dew on the plant and soil surfaces at the time of satellite overpass may drastically affect the spectral response (Rouse et al., 1974). In view of these influences, it is probable that some of the variation in Landsat ND6 measurements can be accounted for by weather data.

For the 22 data sets at Throckmorton, which showed a high correlation between ND6 and green biomass ($r^2 = .91$), maximum daytime temperature on the day of the Landsat overpass contributed significantly to the reduction of the error sum of squares. When ND6 was adjusted for the temperature effect the coefficient of determination was increased to 0.93. Although this temperature-related influence is probably a sine function associated with seasonal evapotranspiration regimes, the small but significant influence may be an important correction for critical measurements.

Rangelands are dynamic ecosystems which inherently express short term physiological and phenological variation as well as short-term and long-term variation in species composition and ground cover. During the early part of the growing season the dormant herbaceous vegetation lies close to the ground on most grasslands of the Great Plains region. Consequently, most of the green biomass is visible from the vertical projection during spring greenup. Typically, drought stress may be experienced during the late spring and early summer. This effect along with maturation of early season plants causes many of the herbaceous plants to "brown out," leaving a scene composed largely of standing dormant plant material. When subsequent rains cause regrowty, new green plant material may be obscured from the vertical view by the standing brown vegetation. Analysis of 94 ground/ Landsat data sets from eight Great Plains Corridor test sites for which the TVI6 parameter was evaluated revealed that the vegetation index parameter was most sensitive to differences in green biomass in the winter and spring (Table 2). As would be expected, TVI6 (and hence ND6) was least sensitive during the summer and early fall. The vegetation index data were best correlated with green biomass during the spring. Maturation of the plants, which results in flowering and seed head production as the growing season progresses, may cause spectral reflectance changes in plants even though the plants are still green. This effect contributes to the lower correlation observed during the summer and fall. In addition, physiological changes, such as moisture stress, may also cause seasonal changes in the spectral reflectance of green vegetation and alter the relationship between ND and green biomass.

Analysis of data from the Weslaco test site in south Texas during the Landsat-1 investigation revealed that brush canopy cover could create serious problems in trying to relate Landsat measurements to herbaceous biomass. The Weslaco test site had a predominantly evergreen overstory brush canopy cover of greater than 20% and maintained a green appearance throughout most of the year. In addition to being drought tolerant, the brush plants are deeply rooted and able to extract moisture at depths much lower than most grasses. Due to the "evergreen" brush components in the vegetative

Table 2
Beta coefficients for green biomass and coefficients of determination for linear regression analyses of TVI6 on green biomass adjusted for vegetation moisture content for eight Great Plains Corridor test sites. ND6 relationships would be similar.

Season	Number of Data Sets	Green Biomass β-coefficient ($\times 10^{-2}$)	r^2
Spring	35	.054	.82**
Summer	24	.007	.22**
Fall	21	.020	.53**
Winter	14	.178	.60**
All Data	94	.028	.60**

** Regressions significant at the 0.01 probability level.

scene at Weslaco the ND6 values remained relatively high throughout the year and were not significantly related to the ground-measured herbaceous green biomass ($r^2 = 0.27$).

The impact of site-related factors, such as ground cover and species composition, on rangeland scene reflectance is not clear. The Great Plains Corridor project study results suggest that there is some threshold value of green biomass, possibly as great as 500 kg/ha, below which the Landsat estimate of green biomass is unreliable. However, further study will be necessary in order to establish the threshold level and to understand the relationships of ground cover and brush canopy on scene reflectance.

Applications for Rangeland Management

Information for rangeland management can be derived from the Landsat ND6 parameter for both regional and local uses. The Great Plains Corridor projects have demonstrated that Landsat MSS data have potential for regional monitoring of range readiness, drought, and range feed conditions. Local assessment of forage production and woody plant cover are also possible.

Regional Monitoring. The Landsat-1 investigation demonstrated that the vernal advancement could be monitored through its northward movement in the Great Plains (Rouse et al., 1974). Since the greatest sensitivity for detection and estimation of green biomass from Landsat MSS data occurs in the winter and spring (Table 2), Landsat should be ideally suited for monitoring range readiness, the time when range plants have developed sufficiently to provide adequate forage for livestock grazing. Of course, adequate and timely Landsat data acquisition and processing is required for range readiness determination.

Landsat capability for monitoring and mapping the areal extent of range feed conditions and regional drought in the Great Plains Corridor were tested in a follow-on investigation. A computer mapping technique was developed and implemented to produce isoline maps of given parameters (e.g., ND6; green biomass; and feed condition classes) for a 6.25 million hectare test site (the ETSA) in north central Texas and southern Oklahoma (Figure 5). The ND6 parameter was used to estimate green biomass as an index to vegetation conditions for three Landsat overpass periods in 1975 for the ETSA, and in the fall of 1975 for the Great Plains Corridor. Range feed condition maps were compared with ground truth data collected throughout the regional study site, with weather records and with the USDA Statistical Reporting Service (SRS) Pasture and Range Feed Condition maps (Deering et al., 1977). These evaluations indicated that the regional range feed condition mapping technique was adequate to detect and map the areal extent of at least five levels of vegetation conditions (Figure 5). These evidences indicate that the Landsat-derived maps classified and portrayed the areal extent of the range feed conditions more accurately than the SRS maps (Deering et al., 1977).

Applications for Ranch Management. Probably the most obvious application of green biomass estimates obtained from Landsat is the measurement of forage production. ND estimates of green biomass could be used to measure standing herbage and to monitor changes in green biomass for estimating seasonal or annual forage production. Such an approach could be implemented for estimating forage production on rangelands and tame pastures, and possibly for determining the amount of supplemental feeds available for livestock production. Although Landsat monitoring of forage

Extended Test Site Area

Green Biomass September 1975

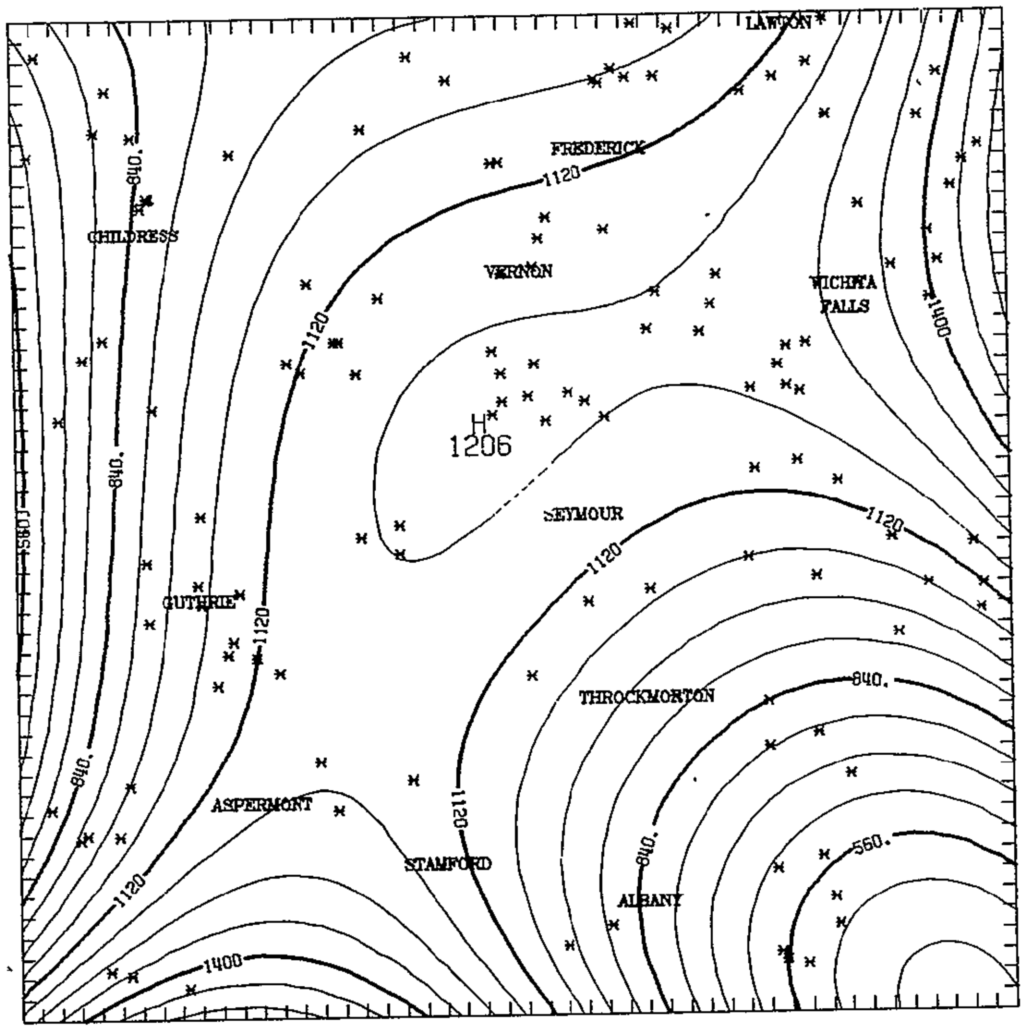

Figure 5. Isolines of green biomass in the 6.25 million hectare intensive regional study area in north central Texas and southern Oklahoma. The ND6 estimates of green biomass were calculated using data from four Landsat scenes acquired on September 22 and 23, 1975 Four of the range feed condition classes are represented during this sample period (very poor, 250-750 kg/ha, fair to poor, 750-1300 kg/ha; good to excellent, 1300-1500 kg/ha; excellent, >1500 kg/ha).

production may be economically practical only for large ranch operations such quantitative information could be supplied on a subscription basis.

Following the development and testing of the ND parameter, an interactive color TV display system was used to produce color-coded maps of green biomass on the 3000 ha (7200 acres) Texas Experimental Ranch at Throckmorton (Deering et al., 1975). Eight levels of green biomass were mapped for individual grazing units or pastures. Available ground truth data acquired from a separate study indicate that the ND6 estimates of herbaceous standing crop were accurate to within 250 to 300 kg/ha, as had been predicted from statistical estimates. These procedures could be used to display range feed conditions on the local level.

It is possible to selectively map the distribution and density of certain range plants from ND green biomass measurements, based on a knowledge of their differential phenological development. For example, by selecting a time during the year when most of the herbaceous range vegetation is dormant, green woody plants are well contrasted and their contribution to the scene reflectance is easily measured. Mesquite, a noxious woody plant on many Texas rangelands, remains green and viable during the seasonal summer drought normally experienced in July and August. An evaluation of the amount of green biomass within a scene during the summer dormant season has successfully been related to the density or canopy cover of mesquite (Figure 6). In many areas where evergreen brush species occur, the winter dormant period provides a similar contrast between the evergreens and the herbaceous understory and/or deciduous woody species.

The validity of this approach to measuring brush density has been demonstrated on rangelands in both the Texas Rolling Red Plains and Edwards Plateau regions. Landsat's capability for temporal reassessment of noxious brush infestations makes it a potent tool for determining the spread of noxious plants or for measuring the reduction of infestations due to brush control. Grass response following removal of brush and longevity of brush control should also be readily monitored.

Figure 6a. High altitude color-infrared aerial photograph of an 18,000 ha (70 sq. mi. or 45,000 acres) area of mesquite infested rangeland. Brush control is evident by the lighter tones of the grasses. Heaviest stands of mesquite are seen as darker tones. Original photography was 1:60,000 scale acquired on August 5, 1973 (NASA Mission 248, roll 27, frame 43).

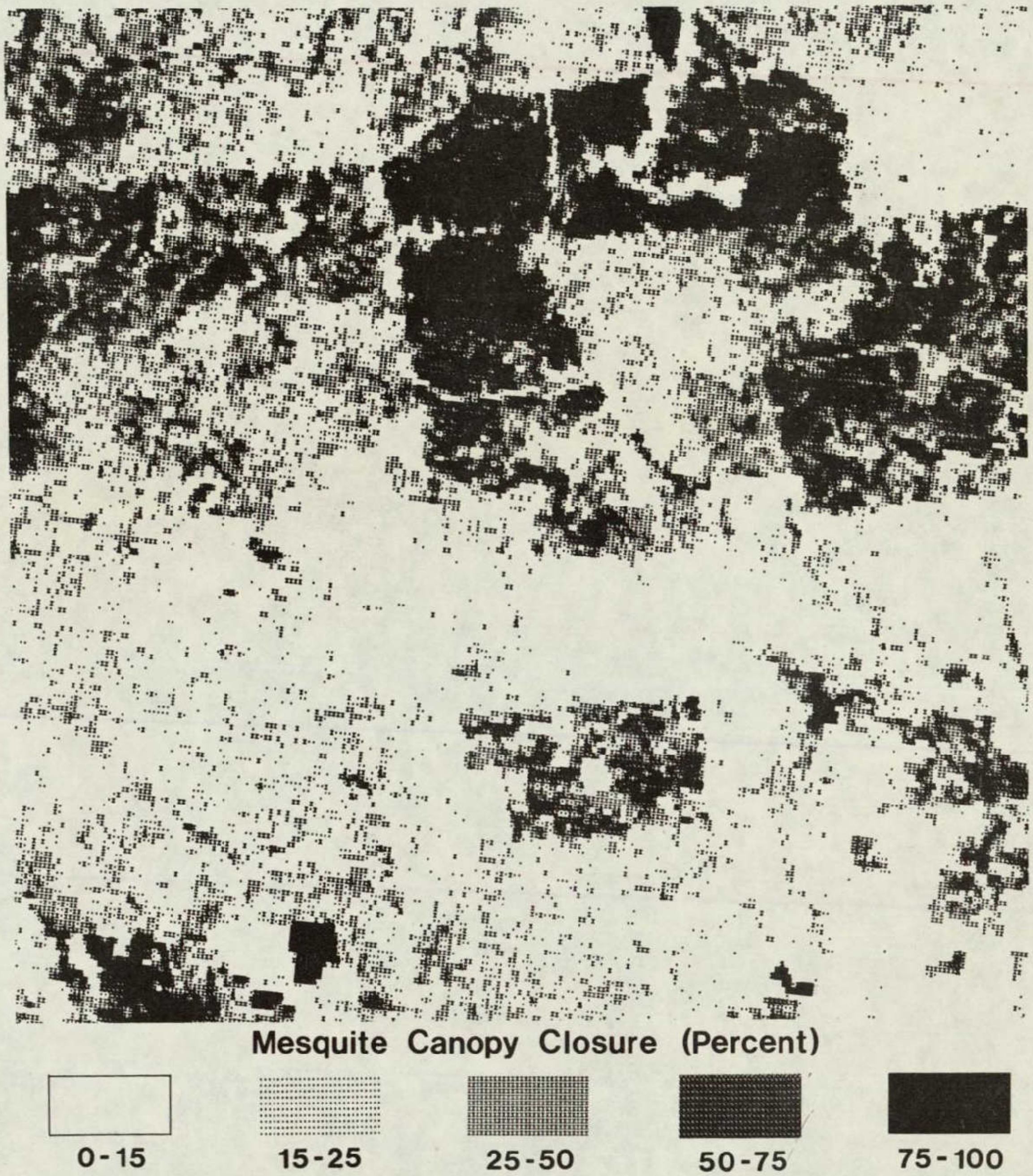

Figure 6b. Map of mesquite cover generated from Landsat ND6 values for the area in Figure 6a. The Landsat scene used was acquired on July 4, 1973 (Obs. I.D. No. 1346-16413).

NEEDS FOR FURTHER DEVELOPMENT

The Landsat MSS digital data, expressed in the form of the Normalized Difference (ND), is a potentially powerful tool for obtaining much needed information about our rangeland resources. Research presented in this paper shows the validity of the hypothesis that green biomass can be quantitatively assessed and several applications of the procedure have been suggested. Considerable additional research is needed, however, to adequately define the capabilities for the use of Landsat-type remote sensors as rangeland information sources.

Priority research needs for developing ND or some similar vegetation index as a useful tool for monitoring rangeland include: (1) evaluation of the impact of site-related factors, such as ground cover, standing vegetation, and species composition on rangeland scene reflectance; (2) determination of thresholds of green biomass detection for different range types and range sites; (3) evaluation of temporal influences, such as plant maturation, seasonal litter accumulation, surface soil moisture, and sun elevation effects on rangeland scene reflectance; (4) evaluation of spectral regions other than the four current Landsat MSS channels and in other strategies for measuring range scene components other than green biomass; and (5) evaluation of pixel-to-pixel variations in Landsat-type data as a source of information about rangeland.

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