Seasonal Variation of Heterogeneity in the Tallgrass Prairie: A Quantitative Measure Using Remote Sensing

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ABSTRACT: Remote sensing may be a tool to quantitatively measure the change in heterogeneity that takes place in a landscape over a growing season. Seven different SPOT satellite scenes of the Konza Prairie Research Natural Area were analyzed to assess the potential of using textural algorithms as a quantitative measure of seasonal variation in heterogeneity. Unburned watersheds usually have greater heterogeneity than annually burned watersheds. However, the greatest amount of heterogeneity as measured by textural analysis occurs in those areas with a mixture of forest and upland tallgrass prairie. Results suggest that remote sensing textural algorithms, in combination with normalized vegetation difference indices, can provide insight regarding both temporal changes that occur seasonally and the influences of periodic spring fires and management practices on the tallgrass prairie ecosystem.

INTRODUCTION

FIRE IS CONSIDERED a necessary component for the preservation and maintenance of the North American tallgrass prairie (Hulbert, 1969; Owensby and Smith, 1973; Towne and Owensby, 1984). In the absence of recurrent fire, litter accumulates, plant production declines, plant composition changes, and woody species invade (Abrams *et al.*, 1986; Bragg and Hulbert, 1976; Briggs *et al.*, 1989; Knapp and Seastedt, 1986).

Landscape heterogeneity relative to the frequency of fire within a landscape, however, is an important component of understanding the tallgrass prairie ecosystem. Annual burning of tallgrass prairie reduces the diversity of both vegetation and various grassland birds and mammals (Collins and Gibson, in press; Kaufman *et al.*, in press; Finck and Briggs, unpubl data). Gibson (1988) reported on the fluctuation (i.e., non-directional irregular changes induced through yearly climatic variation), regeneration, (i.e., cyclic succession; recovery from a fire), and landscape heterogeneity of tallgrass prairie burned every four years. He reported that vegetation community patterns were related primarily to original landscape heterogeneity and secondarily to the burning cycle. Furthermore, he found that watersheds remain distinct from each other in spite of the same treatment effect (fire).

Allen and Wyleto (1983) reported that the scale of analysis is critical to what is deemed important in determining community composition within the tallgrass prairie. The ability to detect environmental heterogeneity depends on the scale of measurement (Wiens, 1989). For example, climatic fluctuations and watershed differences would represent large-scale effects, fire frequency within a watershed may represent an intermediate effect, while different soil types within a watershed would represent a small scale effect. All of these factors interact within the context of landscape heterogeneity to maintain the tallgrass prairie. Thus, a quantitative tool to measure and aggregate landscape heterogeneity in the tallgrass prairie over various spatial scales as well as under different management plans is needed.

Recovery from spring burning and seasonal growth patterns of an adjacent annually burned (over a period of 15 years) and long-termed unburned (not burned for 15 years) tallgrass prairie is shown in Figure 1. As illustrated, any measure of heterogeneity in the tallgrass prairie must also include a temporal component in addition to a spatial component. Remote sensing, through its repetitive acquisition of digital image data using various types of electromagnetic energy, may provide such a tool. An investigation is therefore warranted of textural algorithms as applied to remote sensing data in an attempt to quantitatively measure heterogeneity of tallgrass prairie landscapes.

Nellis and Briggs (1987) used band ratioing of digital numbers associated with a Landsat Thematic Mapper scene to discriminate between burned and unburned areas within a tallgrass prairie. However, such direct measures of spectral reflectance do not give a quantitative measure of heterogeneity within a landscape unit. In our earlier paper (Nellis and Briggs, 1989), we used texture analysis as a quantitative tool to measure the effect of spatial scale on various landscapes within the Konza tallgrass prairie of Kansas under various management treatments.

Textural algorithms generate a value that can reflect the amount of heterogeneity within a landscape. Such algorithms generally measure the similarity between a central picture element in a subset of the image matrix and the surrounding picture elements in a moving image window.

Texture can also be described as fine or coarse. As spatial patterns become more definitive in an image and extend over many pixels, a coarse texture results (Haralick *et al.*, 1983).

Measures of interdependence of pixels are commonly made by quantitatively examining the variability of pixels within a specified block of picture elements (Haralick and Shanmugan, 1974; Haralick, 1979; Hsu, 1978; Frank, 1984; Wang and He, 1990). However, there is no widely accepted texture measure appropriate for all landscape monitoring applications. Statistical textural features, though, have been used to measure the similarity or differences between a central picture element in a subset image matrix and the block of surrounding elements (Shih and Schowengerdt, 1983). Nellis and Briggs (1989), for example, have used Landsat Thematic Mapper (TM), Landsat Multispectral Scanner (MSS), and density sliced aerial photography to demonstrate the advantages of textural information in combination with reflectance information for improving image classification and interpretability.

The size of landscape features can also bias the texture measure. Landscape unit size is normally adjusted for by selecting a neighbor dimension appropriate for a particular study area. For example, a 3 by 3 picture element neighbor may be more

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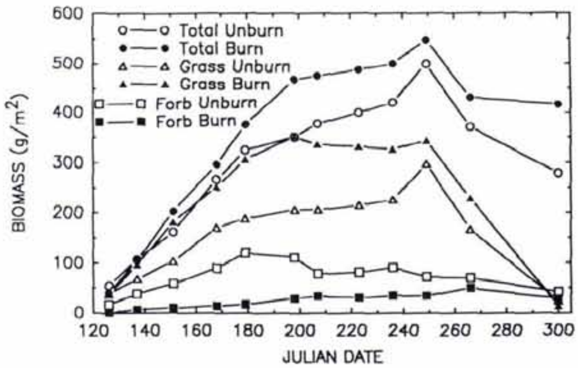

FIG. 1. The seasonal pattern of several components of aboveground biomass on two adjacent ungrazed watersheds on KPRNA--one annually burned and the other a long-term unburned. Solid items = burned site, while clear items = unburned site. Circles = total aboveground biomass; triangles = grass biomass; squares = forbs and woody plant biomass. Total aboveground biomass production includes live grass, forbs, woody plants, and current year's dead biomass.

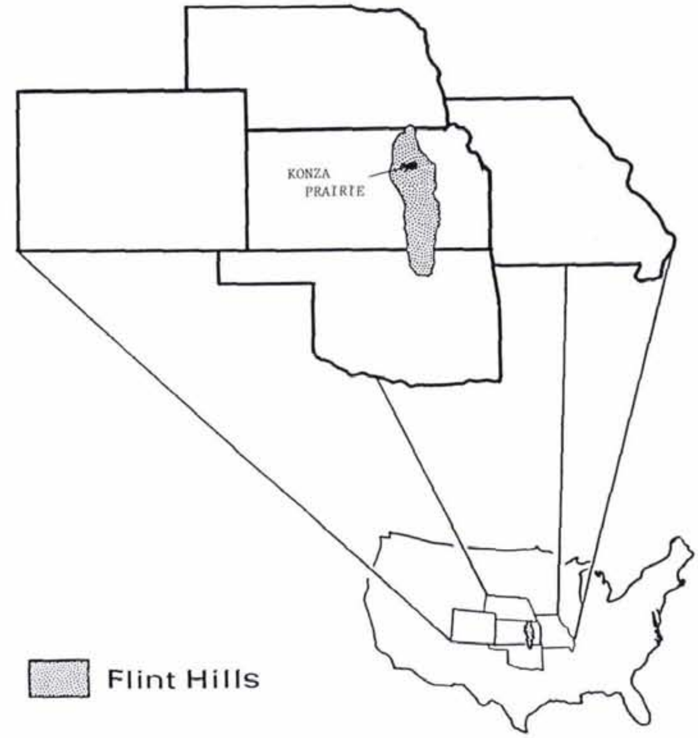

FIG. 2. The Kansas Flint Hills.

appropriate in diverse landscapes, and a 10 by 10 window in a homogeneous landscape.

The objective of our study was to use texture analysis as applied to SPOT HRV multispectral data sets throughout a growing season in the tallgrass prairie to monitor the changes in heterogeneity that occur within various landscape units. Texture was determined by measuring the maximum difference between the largest and smallest digital numbers in a landscape unit neighbor (pixel matrix). These values were then used to evaluate the effect on landscape structures associated with various management practices commonly used in the Flint Hills.

STUDY SITE

Konza Prairie Research Natural Area (KPRNA) is a tallgrass prairie located in the Flint Hills region about 10 km south of Manhattan, Kansas (Figure 2). This 3487-ha area is largely native grassland dominated by big bluestem (*Andropogon gerardii*), little bluestem (*A. scoparius*), Indiangrass (*Sorgastrum nutans*), and switchgrass (*Panicum virgatum*). Konza Prairie Research Natural Area is representative of the Flint Hills Upland, a band of rolling hills roughly 70 kilometres wide, extending across Kansas from near the Nebraska-Kansas border south to Oklahoma (Figure 2). The hills were formed by the erosion of the underlying Permian limestone and shale sediments. The hills are characteristically steep-sided with distinctive benches above the limestone members. Soils on slopes and uplands are typically shallow and rocky while larger valleys have deep, permeable soils. Elevation on KPRNA ranges from 320 metres to 444 metres, with most of the land in the range of 366 to 427 metres. Slightly more than six percent of KPRNA is wooded by gallery forest (narrow bands of woody vegetation along the stream channels), dominated by bur oak (*Quercus macrocarpa*), hackberry (*Celtis occidentalis*), and chinquapin oak (*Q. muehlenbergii*).

Under an experimental plan initiated in 1971, different watershed units (catchment basins) were placed under a variety of prescribed burning (mid-April) regimes ranging from annual, 2-, 4-, 10-, and 20-year (long term unburned) intervals (Marzolf, 1988).

MATERIAL AND METHODS

Seven different SPOT HRV satellite scenes (with a 20-meter resolution) of the Konza Prairie Research Natural Area were used to determine the value of textural algorithms for examining seasonal variation in landscape diversity. The HRV SPOT system has three bands of electromagnetic energy sensitivity (channel 1, 0.50 to 0.59 micrometres; channel 2, 0.61 to 0.68 micrometres; channel 3, 0.79 to 0.89 micrometres). Scenes were selected based on cloud cover (less than 5 percent) and zenith view angle (less than 5 degrees). The scenes, collected in 1987 (20 March, 10 April, 01 May, 26 June, 28 July, 13 September, and 30 October), were geometrically co-registered using at least 30 ground points. In addition, to facilitate across-date comparisons, the scenes were radiometrically normalized using pseudoinvariant features and corrected for solar zenith angle after procedures developed by Schott *et al.* (1988) with modifications for use with the HRV SPOT system. These modifications simply involved matching the appropriate SPOT HRV channels with the one suggested by Schott *et al.* (1988) for their work using Landsat Thematic Mapper (TM) data sets. This approach corrected for changes in atmospheric propagation, illumination effects, and sensor response differences in the multitemporal HRV SPOT data. Other factors are more difficult to correct (i.e., shadowing from vegetation), and may have some impact on the resulting digital values used in this analysis.

Normalized difference vegetation indices (NDVI) of each scene were calculated using the equation

$$(\text{channel } 3 - \text{channel } 2)/(\text{channel } 3 + \text{channel } 2),$$

as NDVI has been successfully used in the Flint Hills for biomass comparisons between burned, unburned, grazed, and ungrazed areas (C. L. Turner, unpubl. data) (Figure 3). A textural contrast algorithm was then applied to each NDVI generated scene. For comparative purposes, the textural algorithm was also applied to each individual channel. The textural algorithm (after Jensen, 1986) involved passing a 3 by 3 window min-max texture operator through each image. The higher the resulting textural number (approaching 256), the greater the degree of contrast or heterogeneity. Textural contrast values were then compared to KPRNA watershed burning treatments and resulting landscape composition.

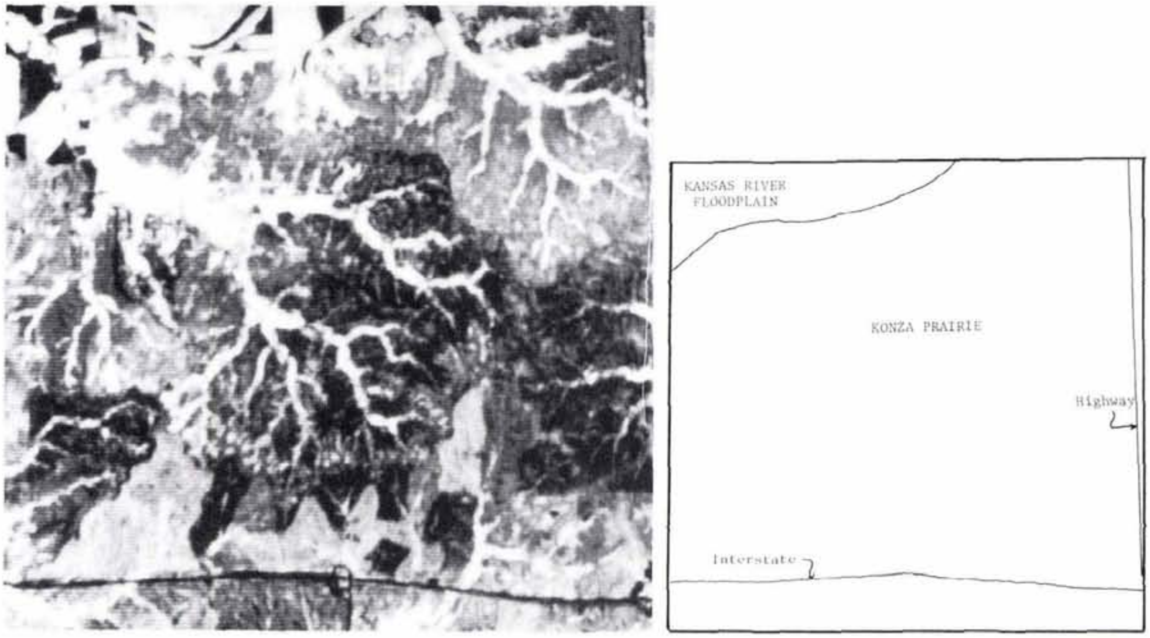

FIG. 3. SPOT HRV Normalized Vegetation Difference Indice of the Konza Prairie Research Natural Area on 01 May 1987.

Fourteen landscape areas (Table 1) indicative of land-use practices in the Flint Hill regions were selected to monitor seasonal changes. Because these areas were co-registered, it was possible to obtain spectral readings on the same geographical area from each geometrically corrected scene.

RESULTS AND DISCUSSION

Heterogeneity (degree of landscape contrast), as determined by utilizing texture algorithms on channel one (0.50 to 0.59 micrometres), was higher (values ranging from 40 to 120) in the early part of the growing season for all landscape types (Figure 4). This early season contrast is probably due to variability present in the standing previous year's dead vegetation (i.e., between the standing vertical stems and mixed lodging of dead stems) and a lack of leaf cover in forest canopy allowing greater response from numerous understory components.

The measure of textural contrast, however, was most dramatic in the early season for riparian areas of mixed deciduous forest and native grassland (values from 40 to 120). As the soils warm and with reduced competition resulting from the late spring burns, C_4 grass (big bluestem, little bluestem, and Indian grass) production increases dramatically, thereby reducing the degree of heterogeneity in the areas with more frequent burning (i.e., watersheds 1D and 2D). In addition, in the riparian areas, trees leaf out in late April-early May. The result is a relatively rapid decrease in textural contrast, which may be due to more uniform canopies of trees and grasses obscuring the landscape diversity in the lower understory (down to a textural values of approximately 40). As variability in senescence begins to dominate in late summer and early fall, the degree of heterogeneity increases as measured by the textural algorithm (e.g., watershed 2D and 4B; Figure 4).

The lowest degree of seasonal variability in textural contrast was obtained for a winter wheat field/fallow field (Figure 4). The uniformity of the wheat stand in the early spring and same uniformity after harvest in stubble and mulch is reflected in the consistent low textural values (values of textural contrast of about 40).

In channel 2 (red wavelength band), the pattern of textural

TABLE 1. LANDSCAPE AREAS MONITORED OVER THE GROWING SEASON

2D	Ungrazed area, biennial burned since 1977, last burned in 1986
1D	Ungrazed area, annually burned since 1977, last burned in 1987
UB	Long-term ungrazed, unburned not burned for 15 years
10	Ungrazed area, burned every 10 years, last burned in 1981
4B	Ungrazed area, burned every 4 years, last burned in 1986
C1	Long-term ungrazed, unburned for 7 years
PO	Grazed by domestic cattle, not burned in 1987
WH	Grazed by domestic cattle, burned in 1987
KI	Mixture of forest and grassland
GA	Mixture of forest and grassland
SH	Mixture of forest and grassland
NA	Mixture of forest and grassland
FA	Winter wheat field in 1987
AG	Soybean field in 1987

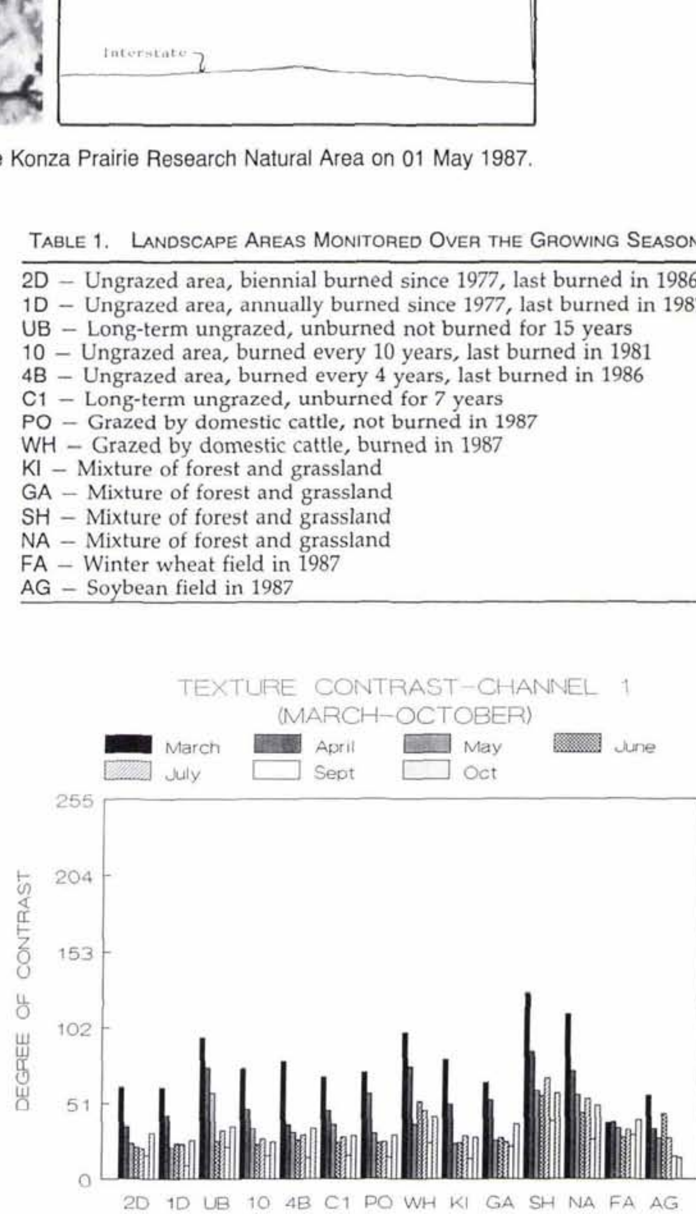

FIG. 4. Degree of Textural Contrast for channel 1 of the SPOT HRV satellite for the seven dates. Key for area is explained in Table 1.

response across landscape units (Figure 5) is very similar to that for channel 1. The primary difference is the stronger vegetation response due to chlorophyll absorption in the 0.61 to 0.68 micrometre range. The result of this greater sensitivity is a higher level of textural variability (an increase of 10 to 20 percent) in landscape response (based on a higher degree of difference noted in the SPOT data for vegetative vigor in the spring) along with a more accurate level of textural reduction with senescence in the fall.

In channel 3 (the near IR), the pattern (Figure 6) is quite different from that for Channels 1 and 2. For most landform units, the June SPOT data provided the highest measure of textural values. This high level of heterogeneity is probably due to two strongly related factors: high precipitation and active plant growth during the June period (Figure 1). Abrams *et al.* (1986) summarized ten years of aboveground biomass data and climatic variables on Konza. Growing season precipitation was the most important variable associated with the aboveground biomass. June has the highest average amount of precipitation (16 percent of the total annual rainfall (Bark, 1987)). The high sensitivity of the near infrared to vegetation response and the subtlety of canopy structure can be detected with the textural algorithm. The seasonal variation in senescence intensity is also elaborated with channel 3 textural values.

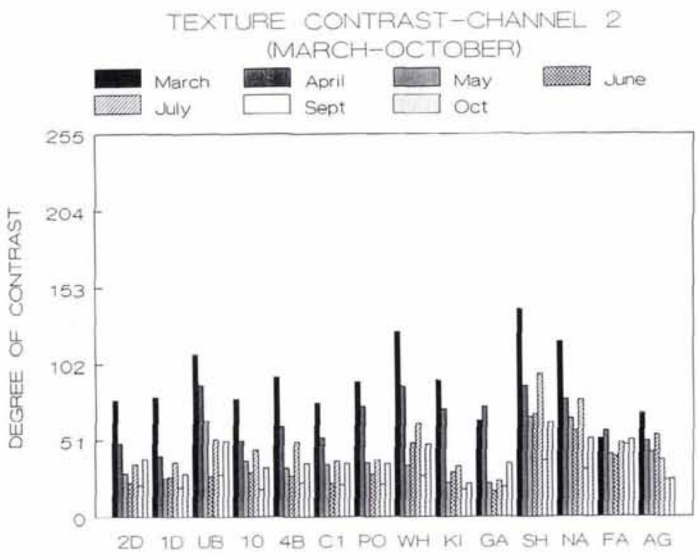

FIG. 5. Degree of Textural Contrast for channel 2 of the SPOT HRV satellite for the seven dates. Key for area is explained in Table 1.

Applying the textural algorithm to the NDVI, the textural pattern (Figure 7) is very similar to that for channel 3. The primary difference, however, relates to a consistently higher textural value for the NDVI data relative to the channel 3 data. This is most probably due to the greater sensitivity of the NDVI values to greenness and net primary productivity over that of channel 3 alone. Once again, the peak period of textural heterogeneity in most landscapes occurred in June and July (Figure 7). Highest textural values (greater than 200) were generated in the mixed forest/grasslands units. Watersheds left unburned for extended periods of time (8 years or more – e.g., UB; Figure 7) had moderate textural response values, but consistently higher than regularly burned watersheds (2D and 1D). The textural values highlighted the contrast between burned and unburned watersheds. The higher textural contrast values for unburned watersheds is probably due to a greater amount of tree cover (primarily eastern redcedars (*Juniperus virginiana*) and American elms (*Ulmus americana*)) mixed with woody shrubs (i.e., summacs (*Rhus aromatica*) and buckbrush (*Symphoricarpos orbiculatus*)) all mixed with native tallgrass prairie grasses.

CONCLUSIONS

Limited empirical information exists documenting the impact of landscape treatments (e.g., fire and grazing) on landscape diversity across a temporal time scale. A texture algorithm, when applied to individual SPOT channel data sets, and NDVI provide a quantitative approach to assist in understanding landscape heterogeneity in the tallgrass prairie ecosystem. Each channel provided some measured response in landscape contrast to changes in plant vigor and higher primary productivity.

It appears that a texture algorithm applied to either channel 3 or NDVI produced from the SPOT HRV digital data is most applicable to tallgrass prairie to detect various management treatments. The most significant amount of contrast was detected using channel 3 or the NDVI (Figures 6 and 7) although

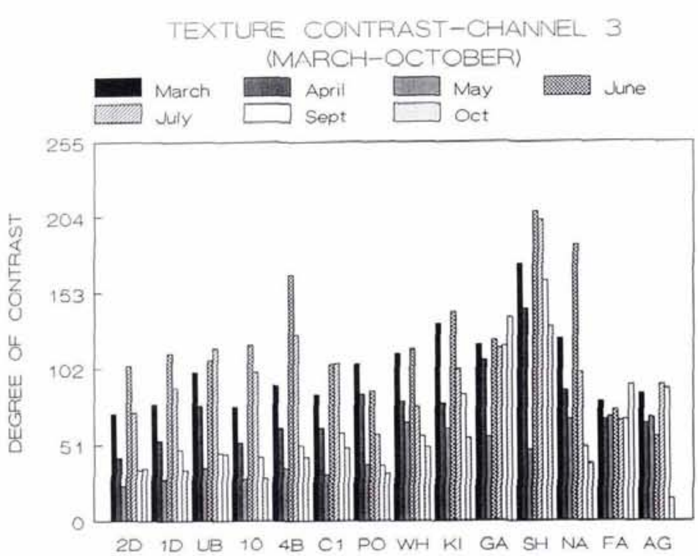

FIG. 6. Degree of Textural Contrast for channel 3 of the SPOT HRV satellite for the seven dates. Key for area is explained in Table 1.

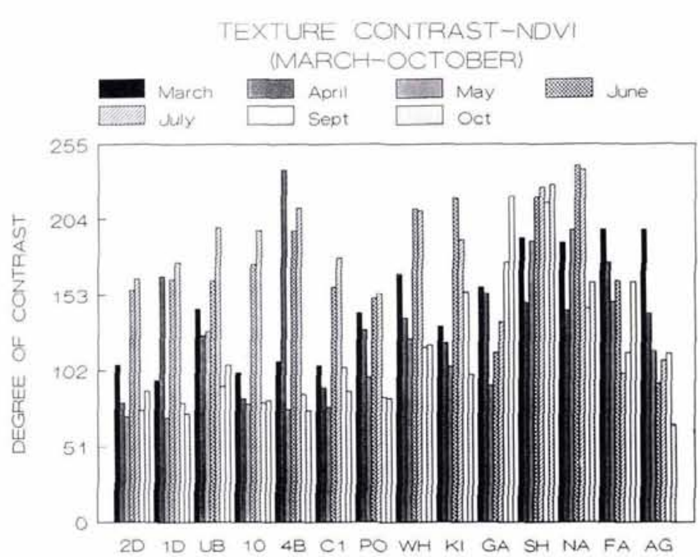

FIG. 7. Degree of Textural Contrast for NDVI generated scenes of the SPOT HRV satellite for the seven dates. Key for area is explained in Table 1.

NDVI contrast values were generally greater between areas of different management treatments. In addition, the texture algorithm applied to SPOT HRV derived NDVI values supported Collins and Gibson's work (in press) that annual burning reduces the diversity of tallgrass prairie landscapes. Both 1D and 2D (an annual and biennial burned watershed) had consistently lower values than the watersheds burned every four years or left unburned (Figure 7), suggesting that these areas had lower landscape heterogeneity (i.e., lower species diversity). Those areas which have been grazed by cattle (i.e., PO and WH) had similar texture values to those areas left unburned, even though WH was burned and PO was not burned, suggesting that grazing increases the landscape heterogeneity. Collins (1987) found that burning and grazing had significant effects on the invariant structure of the tallgrass prairie and Senft *et al.* (1987) reported that cattle grazing in shortgrass prairie also affected species diversity. These results suggest that textural algorithms applied to SPOT HRV derived NDVI can detect changes in vegetation communities induced by either fire or grazing.

The texture algorithm applied to SPOT HRV derived NDVI allowed detection of areas with the highest amount of landscape heterogeneity; the narrow bands of gallery forest surrounded by tallgrass prairie (Figures 4 to 7). These areas contain an eastern deciduous forest community intermingled with the tallgrass prairie ecosystem (Freemen and Hulbert, 1985; Freemen and Gibson, 1987).

Landscape ecology must consider new measures of heterogeneity in order to detect different landscape treatments and/or effects (Wiens, 1989). Remote sensing, coupled with textural algorithms, offers empirical confirmation to document treatment responses (both burning frequency and grazing) in a temporal framework for understanding landscape diversity in the complicated tallgrass ecosystem.

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