TEXTURE MEASURES FOR THE QUANTIFICATION OF SPATIAL VARIABILITY OF VEGETATION IN SAVANNA LANDSCAPES

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Key words: Variance, skewness, kurtosis, SAVI, heterogeneity

Understanding interactions between the biotic and the abiotic world can be a key contributor to efforts at the conservation and management of biodiversity. The use of multi-scale remote sensing through vegetation index images can aid in the mapping of vegetation assemblages especially in savanna environments where spatial heterogeneity is a characteristic feature. Texture measures such as variance, skewness and kurtosis were derived using moving windows in vegetation index images derived from Landsat TM and ETM+ sensors for years 1984, 1990, 1996 and 2001 for the savanna landscape in Kruger National Park (KNP). In order to account for soil factor contributing to the reflectance as captured by the sensor, Soil Adjusted Vegetation Index images were derived for the selected years. The hierarchy of spatial scales in operation in the natural environment were mimicked by having heterogeneity and diversity calculated at the patch scale, which was set as the base/operational scale in addition to the local and landscape scales pertaining to the lower and higher ends of the spatial hierarchy. Results confirm the influence of abiotic environment in determining the heterogeneity of vegetation. Basalt derived soils were seen to support more diversity in vegetation compared to granite underlain landscapes.

Introduction

As the largest biome covering approximately 70% of the earth's surface (Scholes and Archer, 1997) and between 40% to 65% of the African continent (Augustine, 2003), an accurate understanding of the biome and the nature of processes operating in the same assumes significance in efforts aimed at the conservation of biotic diversity. Savannas are highly dynamic, diverse and productive ecosystems (Gillson, 2004) and is home to abundant and diverse assemblage of wild herbivores (Keesing and Young, 2014) especially megaherbivores (Owen-Smith 1988). As important components of the African savanna, the herbivores shape the plant communities they depend on and are in turn influenced by the spatiotemporal variation in the quantity and quality of the forage (Winnie *et al.,* 2008). This connects to the 'habitat heterogeneity hypothesis' where it is assumed that structurally complex habitat provides more niches and diverse ways of exploiting the environmental resources thereby contributing to increase in species diversity (Bazzaz, 1975; Tews *et al.,* 2004; Otto *et al.,* 2014). Patchiness or spatial heterogeneity is an important aspect for savanna ecosystems (Pickett and Cadenasso, 1995; Turner, 2005; Otieno *et al.,* 2011) as is its variability across spatial and temporal scales (Crews and Young, 2013). The present research looks at satellite remote sensing, specifically texture measures operating on vegetation index images as a means of quantifying vegetation heterogeneity across spatial scales in the savanna environments of Kruger National Park (KNP), South Africa.

Located between 22°25′ to 25°32′ S latitudes and 30°50′ to 32°20′ E longitudes, KNP is South Africa's premier conservation initiative and extends over an area of 21,000 sq kms. KNP ranks as one of the world's principal national parks, the salient features being (i) its size; (ii) its largely unspoilt ecosystem; (iii) the structural and species diversity of its biota (Joubert, 2004). The climate is subtropical with summer rains between October and April and the annual rainfall varies from 700 mm in the south to 400 mm in the north. The topography of the park is generally flat, with gently undulating plains, at a mean altitude of 260 m above sea level. Soils in the western half of KNP tend to be sandy, light and of granitic origin, while those in the eastern half are dark, clayey and of basaltic origin. The present study focused on the southern half of the park as shown in figure 1.

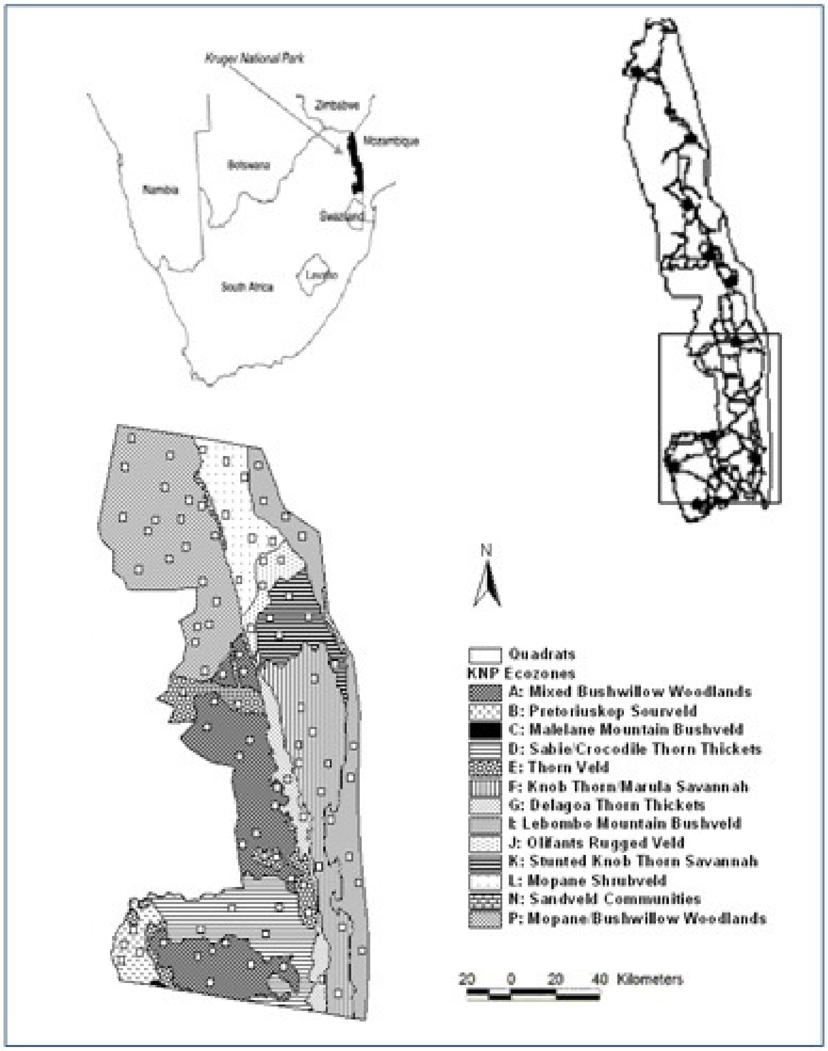

Figure 1. Southern Africa showing the location of Kruger National Park. Extract shows the study area with the different ecozones and the location of quadrats limiting the operation of texture measures.

The study used remotely sensed images from the Landsat series of sensors, TM and ETM+ for the dates, 27 August 1984, 25 June 1990, 13 September 1996 and 4 July 2002. Based on published research (Chaideftou *et al.,* 2012), an interval of six years was fixed between instances of image capture to monitor ecologically relevant change as reflected by changes in vegetation heterogeneity. Images were selected for both summer and winter seasons with the aim of identifying seasonality factor in heterogeneity trends. 1:50,000 scale topographic maps published by the Chief Directorate of Surveys and Mapping were used to from base line data on the physical and cultural aspects of the study area. Areas of specific geomorphology, macro-climate, soil and vegetation pattern and associated fauna were demarcated and termed as landscapes, in a pioneering research by Gertenbach (1983). For park management purposes, landscapes that were similar in ecological characteristics were aggregated into ecozones. Given the broad scale division of KNP into a basaltic east and a granitic west (Venter *et al.,* 2003), the study chose to focus on two ecozones each from the granitic: A (Mixed Bushwillow Woodlands) and D Sabie/Crocodile Thorn Thickets, and basaltic: G (Delagoa Thorn Thickets) and F (Knob Thorn/Marula Savanna). Quadrats were used to help focus the analysis as well as increase the local detail and to ensure the purity of vegetation pixels.

Methodology

Raw digital numbers were converted first to at-satellite radiance and then to at-satellite reflectance using the expressions contained in Markam and Barker (1986). At-surface reflectance were derived by correcting for atmospheric effects using a technique which combined the frequently used Dark-Object-Subtraction (DOS) (Chavez, 1988) and the popular radiative transfer model: Second Simulation of the Satellite Signal in the Solar Spectrum (6S) (Vermote *et al.,* 1997). The ETM+ image for 30 May 2001 was received as orthorectified and hence all other images were co-registered to this image using 32 control points and a second order polynomial transformation with an RMS error of less than half a pixel.

Soil Adjusted Vegetation Index

Vegetation index images served as the basis for the analysis on spatial aspects of change and to determine if seasonal and inter-annual change in vegetation indices can be equated to change in landscape pattern. This was based on the idea that the magnitude of vegetation index change over a chosen time period indicates seasonal variability in spectral reflectance or class/category change over time. In addition to avoiding variability errors introduced by classification-dependent measures, spatial analysis of vegetation index images should do without the need for in situ measurements as opposed to the ground-truthing requisite for multispectral classification. Given the structural openness that is characteristic of the savanna landscape, it was important that the selected vegetation index was able to account for the contribution of soil reflectance in the derived vegetation reflectances. The success of any vegetation index in mapping out vegetation is dependent on how well it is able to depict actual vegetation differences amidst widely varying soil, atmosphere, and sun-target-sensor variations (Huete, 1995). The Soil Adjusted Vegetation Index (SAVI) is a spectral transformation technique that minimizes background influences, specifically soil brightness, from spectral vegetation indices involving red and near-infrared wavelengths. It does this by introducing a soil calibration factor ‘L’:

$$SAVI = [\rho_{nir} - \rho_{red} / (\rho_{nir} + \rho_{red} + L)] * (1 + L)$$

wherein ρnir and ρred are the reflectances in the near-infrared band and the red band respectively. The value of L was taken as 0.5 as recommended for areas with intermediate vegetation densities (Huete, 1988).

Texture

Texture is an areal construct that defines the local spatial organization of spectral values and is a function of the spatial and radiometric scales (Laymon and AlHamdan, 2005). Spatial structure (pattern) and contrast (or intensity) (Ojala and Pietikyinen, 2002) are considered to be component features of texture. Texture analysis is focussed on the quantification of spatial variations in imagery, as a means of extracting information. In performing texture analysis, the grey value relationships between the current pixel and the pixels next to it are calculated on the basis of a certain texture measure e.g., mean, standard deviation, contrast, correlation, energy, entropy, etc. The grey values of the output image represent the local texture criterion of the input image. Portrayed as the spatial variations in the image tone (Buesch *et al.,* 2005), texture can be seen as a reflection of the underlying variation in the landscape or the relationship between elements of surface cover. Therefore, it follows that texture contains structural information, as the variation of image tones is related to changes in the spatial distribution of image components (e.g., vegetation) (Wulder *et al.,* 1998). Textural analysis can be considered to be a quantitative measure of landscape variability, especially when combined with vegetation index data (Wessman, 1992, 1994; Wu *et al.,* 2000).

The present study contends that, SAVI being an expression of green biomass, the distribution patterns of its frequency can be used to explain the characteristics of a given ecosystem using time-series data. Asymmetry in the frequency distribution of SAVI in the case of a seasonally variant ecological system such as the savanna would be pointing towards a change in vegetation structure and pattern brought about by possible changes in the operation and influence of ecosystem drivers such as soil moisture, fire, herbivory *etc*.

The variance and the closely-related standard deviation are measures of how spread out a distribution is. In other words, they are measures of variability. For instance, in the case of grazing systems a double-normal distribution can be taken as an indication of the existence of two populations (overgrazed and undergrazed areas) coexisting in the same field, while a normal distribution would suggest that there exists no distinct grazing pattern (Aiken *et al.,* 1997; Gibb and Ridout, 1988). This observation can be extended to argue that measures describing the nature and shape of an NDVI frequency distribution can be used as indicators of the structure and pattern of the vegetation making up a given landscape patch. For the purposes of the present study, spatial variability was quantified using textural measures of variance, skewness and kurtosis, each of which was calculated at three window sizes: 3*3, 31*31 and 61*61 pertaining to the hierarchic levels of micro, patch and landscape for the four years considered in the study – 1984, 1990, 1996 and 2002. This involved the passing of moving windows of predetermined size (*e.g.,* 31*31) over the entire vegetation index image, pixel by pixel and the calculated texture measure (*e.g.,* kurtosis) being assigned to the focal (central) pixel.

Measures of variability: Variance, Skewness and Kurtosis

Any investigation into the character of surface variability often begins with an analysis of the moments of the variable (Cosh *et al.,* 2007). The moments are most commonly taken about the mean. The first moment about the mean is zero and the second moment about the mean is the variance. The third moment is related to the skewness, and the fourth moment is related to the kurtosis of a distribution. The variance filter makes use of the average pixel values within a so-called moving window where the middle pixel value is replaced by the average value calculated from all surrounding pixels. The skewness filter measures how much the data within the moving window are skewed and in which direction, whereas kurtosis measures how much the data values are clustered towards the mean. Given that mean, variance, skewness and kurtosis are commonly used measures to describe the characteristics of a frequency distribution; the objective of the analysis was to find out if the spatio-tremporal dynamics of savanna landscapes could be explained using these measures on the vegetation index images.

Variance is calculated as: $s^2 = \frac{\sum (X-M)^2}{N-1}$

where X is the DN value for the given pixel, N is the number of pixels in the window, M is the mean of pixels within the moving window where x_{ij} is the value of the pixel at row 'i' and column 'j'.

Skewness for univariate data X, X_2, ..., X_N,, calculated as the third order moment about the mean follows the expression: :

$$\gamma_1 = \frac{\sum(X_i - \mu)^3}{(n-1)\sigma^3}$$

where μ is the mean, σ is the standard deviation and n is the number of data points. Kurtosis for univariate data X, X_2, ..., X_N, follows the expression: $\gamma_1 = \frac{\sum(X_i - \mu)^4}{(n-1)\sigma^4}$ where μ is the mean, σ is the standard deviation and n is the number of data points.

Skewness characterizes the degree of asymmetry of a distribution around its mean. A set of observations is symmetrically distributed (0 skewness) if its graphical representation is symmetric with respect to a vertical axis passing through the mean. For a positively skewed distribution, the mean is larger than the median, whereas for a negatively skewed distribution the median is larger than the mean, though for discrete variables this can change (von Hippel, 2005). A substantial proportion of the observations will be less than the mean in the case of a positively skewed and vice versa for a negatively skewed one. Typical values for skewness range from -3 to +3. Kurtosis measures the degree of peakedness of a distribution relative to that of a normal distribution and is measured as the fourth order moment about the mean. A symmetrical distribution with positive kurtosis indicates a greater than normal proportion of the variable being measured located along the tails, and in the very centre of the distribution, whereas negative values for kurtosis indicate the spread of data values away from the mean. Higher values for kurtosis suggest the data are concentrated near the centre of the distribution, whereas lower kurtosis values indicate the data are more dispersed through the shoulders of the distribution. When used to describe vegetation dynamics in savanna environments where soil moisture availability is the major physical determinant of vegetation activity, lower values for kurtosis for an NDVI frequency distribution may be an indication of a longer growing season (see references in Bonsal *et al.,* 1999) – summer rainfall starting early and continuing for a longer time than usual. The spread out nature of the distribution (from the mean) can be taken as an indication of the diversity present in the data or the variability in vegetation conditions at broader spatial scales (Chen and Brutsaert, 1998).

In the case of savanna systems this increase in variability could, for instance, be triggered by changes in the operational behaviour of the system components. An obvious example would be the changes in the extent and intensity of the fire regime caused by the surplus availability of fuel. In contrast, higher values for kurtosis would point to the clustering of data values around the mean and hence similarity in vegetation intensity across the study area. Literature demonstrates the use of these two measures to quantify variability. It is argued that skewness and kurtosis are pertinent parameters that can bring additional information linked to the structure and pattern of vegetation along with the quantification of photosynthetic activity provided by the NDVI. This view is supported by Donoghue *et al.* (2007) who suggest that distribution measures such as skewness or the coefficient of variation can be used to provide a broad view of the vegetation structure in a given patch of forest

In order to ensure that heterogeneity was calculated for vegetation pixels alone and to increase the local detail on the derived spatial heterogeneity information, quadrats of size 2 by 2km were plotted over vegetation index images (Figure 1). Three preconditions were necessary in quadrat selection, in order to attribute the changes in local image skewness and kurtosis to change in the spatial variability of vegetation rather than *ex situ* factors. These include that the quadrats: (i) were not located on a stream channel; (ii) were away from recent burn scars and (iii) were not areas of the image that were covered by cloud. With the aim of capturing maximum vegetation conditions for individual landscape units, a minimum number of four quadrats were ensured for each landscape for each of which the measures of variance, skewness and kurtosis were calculated. Limiting the calculation of texture measures to quadrats ensured that only areas dominated by vegetation were analysed for spatial variability as opposed to bare patches of soil.

Results

Figure 2 plots the variance of SAVI across time for the hierarchy of scales considered for the study. For each ecozone SAVI variance was calculated by averaging the SAVI values for individual quadrats within them at local, patch and landscape scales. The variation in vegetation intensity (as measured by variance) across ecozones is lower in 1996 compared to other years at the local scale, with the highest variability in the first two time-points. This trend in SAVI variance show no significant difference between granitic and basaltic ecozones across the hierarchy of spatial scales: Local ($P = 0.755$); Patch ($P = 0.378$) and Landscape ($P = 0.551$), considered for the study.

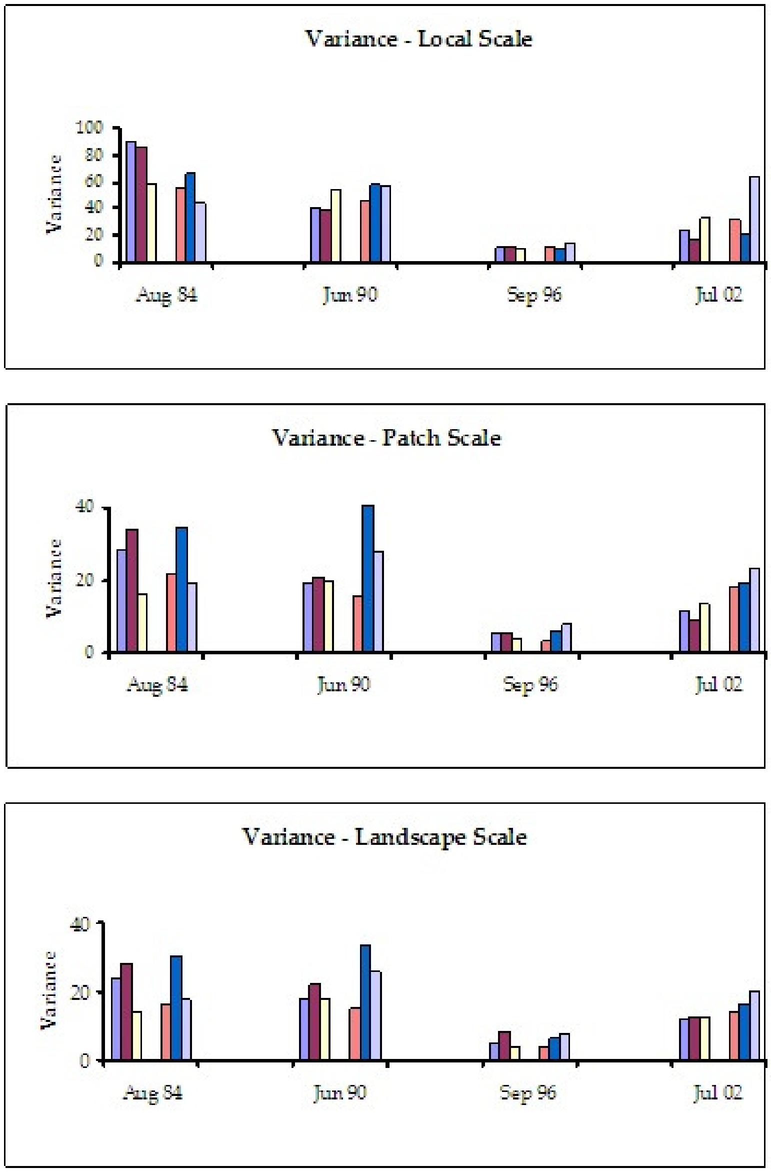

*Figure 2. Variance of SAVI showing the magnitude and variability of vegetation intensity across ecozones grouped according to their geologic origin. Moving windows of three different dimensions were used to measure variability at local (3*3 pixels), patch (31*31 pixels) and landscape (61*61 pixels) scales. Error bars show one standard deviation. For each year, the first groupng of ecozones are granitic – A, D and P whereas the second grouping involves basaltic ecozones – F, G and L.*

With regard to heterogeneity, values for skewness display weakly decreasing trends at the local scale, weakly increasing trends at the landscape scale and no trend at the patch scale (Figure 3). The decrease in skewness (hence increase in heterogeneity) at the local scale does not show significant differences across the geologic makeup of ecozones. At the patch and landscape scales, there is a suggestion of heterogeneity decreasing (skewness increasing) more over time in basaltic than granitic ecozones. Statistical tests suggest that at local scale, the differentiation in spatial heterogeneity between granitic and basaltic ecozones show significant differences during periods of climatic extremes (*e.g.,* 1990 drought conditions). At coarser scales no significant difference exists across the geologic makeup of ecozones.

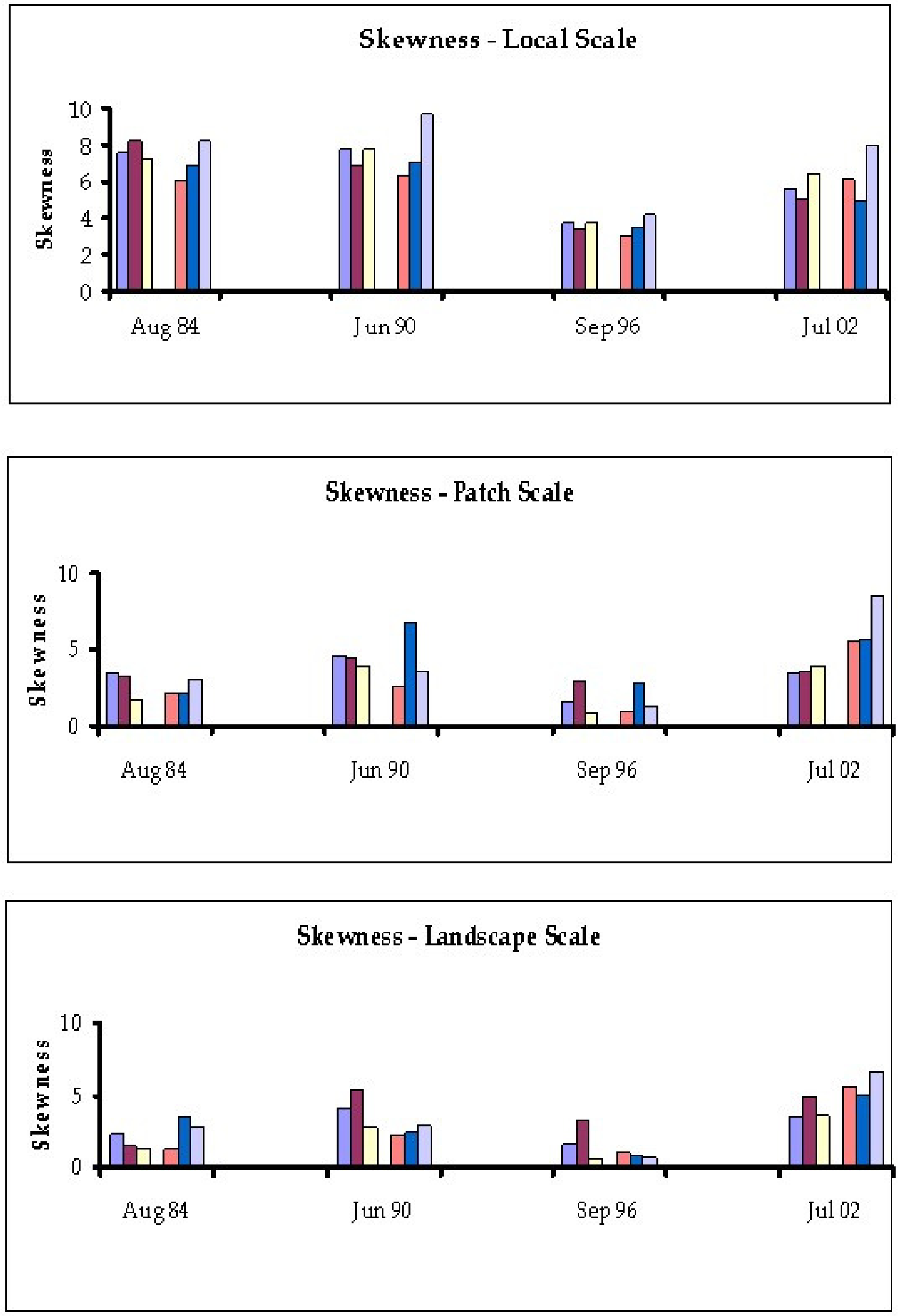

*Figure 3. Skewness of SAVI showing the spatial heterogeneity of vegetation across ecozones grouped according to their geologic origin. Moving windows of three different dimensions were used to measure heterogeneity at local (3*3 pixels), patch (31*31 pixels) and landscape (61*61 pixels) scales. For each year, the first groupng of ecozones are granitic – A, D and P whereas the second grouping involves basaltic ecozones – F, G and L.*

At the local scale ecozones show remarkably similar trends in spatial diversity (as measured by kurtosis) across time and between ecozones (Figure 4). This is due in part to the more derived nature of the kurtosis calculation (the fourth moment calculated with only nine data at the local scale) than variance and skewness. Higher values of kurtosis indicate clustering of data values around the mean and hence lower diversity within the data and *vice versa.* At the patch and landscape scales, Figure 4 suggests slightly higher kurtosis in SAVI values for basaltic than granitic soils, as well as considerable variation between years and between ecozones. On conducting a Mann – Whitney test it was found out that ecozones exhibit no significant difference in spatial diversity across geologies (local diversity: $Z = -1.088$, $P = 0.291$; patch diversity: $Z = -1.732$, $P = 0.089$; landscape diversity: $Z = -1.386$, $P = 0.178$). The main feature of the kurtosis graphs at these scales is the relatively low kurtosis in 1996, especially for basaltic ecozones. Substantial fires occurred along the central and southern parts of KNP during 1996, causing severe destruction of vegetation within the affected parts (Govender, 2003), probably stimulating grazing of the new, tender grasses growing after the fires. Ecozones P and L (mopane woodland and shrubland respectively) were the only ones untouched by fire at the time within the study area. Given that mopane is an important part in the diet of the elephant population in southern Africa, and that both these ecozones fall within the high-impact elephant zone of KNP (Joubert, 2004), it may be that ecozones P and L experienced increased elephant herbivory in 1996.

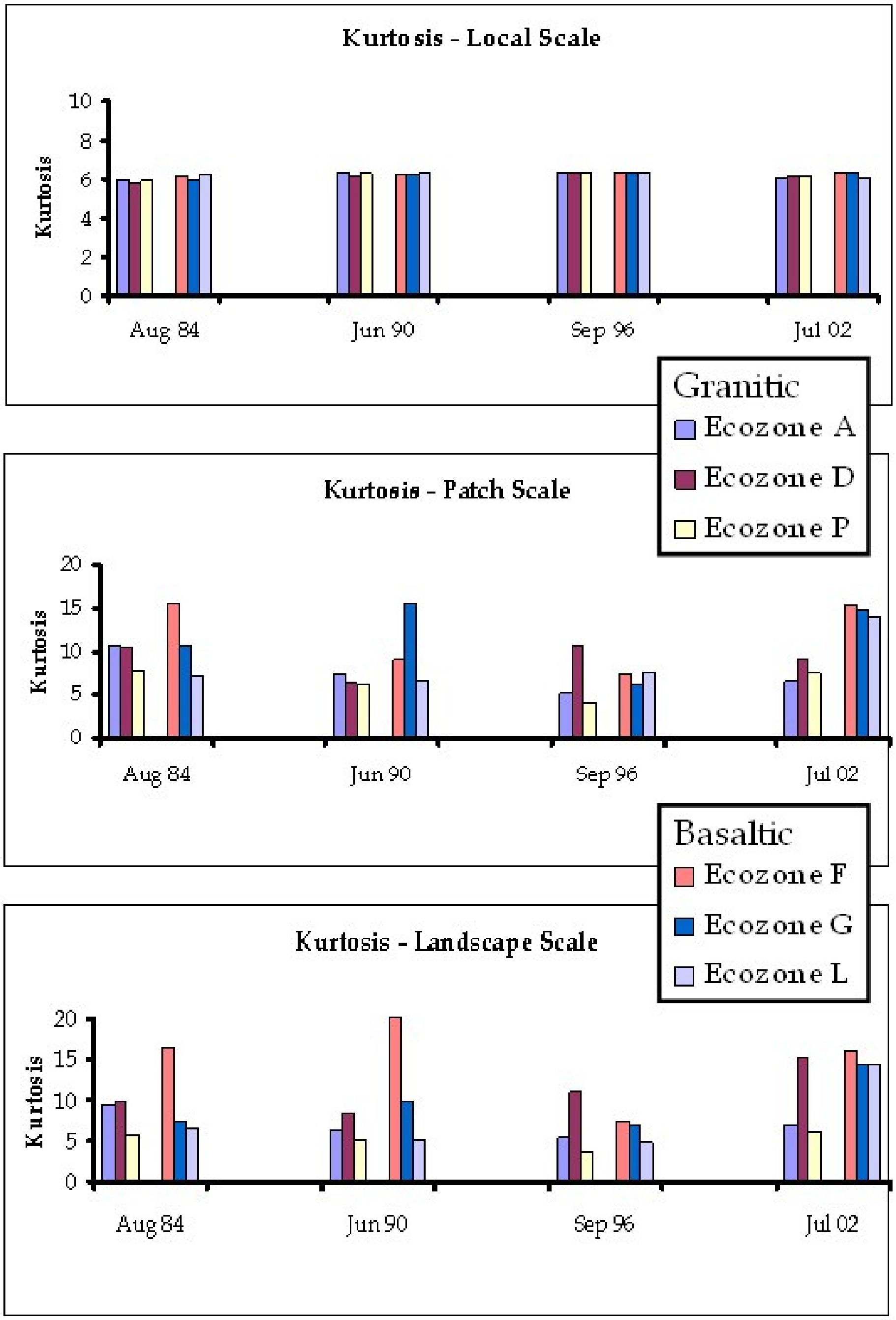

*Figure 4. Kurtosis of SAVI showing spatial diversity of vegetation across ecozones grouped according to their geologic origin. These were calculated using moving windows at local (3*3 pixels), patch (31*31 pixels) and landscape (61*61 pixels) scales. For each year, the first groupng of ecozones are granitic – A, D and P whereas the second grouping involves basaltic ecozones – F, G and L.*

Conclusion

In short, testing for the significance of trends in heterogeneity and diversity suggests that, except for diversity (kurtosis) at patch and landscape scales, the trends are significant (0.05 level). Mann – Whitney test conducted for assessing the influence of climatic extremes on vegetation variability suggests significant results for all measures of variability except for hetereogeneity (skewness) and diversity (kurtosis) at patch and landscape scales. Here, measures of spatial variability (variance, skewness and kurtosis) were the test variables. As grouping variable, the study time period being divided into a dry period (1984 – 1990) and a wet period (1996 – 2002) were used. At patch and landscape scales, measures of heterogeneity and diversity has more to do with variability between particular years than across dry and wet time periods. This suggests that the extreme climatic conditions did not have significant effects in determining the spatial variability of vegetation at higher spatial scales (patch and landscape) but had moderately significant effects at the local scale. Furthermore, heterogeneity and diversity show more differences across spatial scales than the geologic makeup of the area. The spatial analysis of SAVI images using texture measures of skewness and kurtosis has highlighted the contrasting nature of vegetation heterogeneity and diversity across ecozones, suggesting interesting differences between scales, climatic conditions and geologies. In addition there appears to be a general trend of decreasing vegetation (SAVI) variability over time in KNP, with the other variation(s) superimposed on this. Biotic processes, as with abiotic, could be spatially structured, with some controls operating at smaller spatial scales than others. Measured spatial variability of vegetation and the spatial structure of a given landscape are both functions of the scales at which the landscape is defined, as well as the operational rates of the spatially explicit processes (endogeneous and exogeneous) that drive the landscape variables.

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