

NDVI MEASUREMENTS OF NEOTROPICAL SAVANNA PHYSIOGNOMIES A GRADIENT OF: BIOMASS, STRUCTURE AND PHENOLOGY CHANGES

Humberto N. de MESQUITA JR **

* University of São Paulo, Brazil

Dep. Of General Ecology, Institute of Biosciences
LEPaC - Lab. of Landscape Ecology and Conservation
beto@ib.usp.br

Working Group V/III

KEY WORDS: Difference Vegetation Index, Classification, Dynamics, Climate, Season, Cerrado, Phenology, and Vegetation Physiognomies.

ABSTRACT

The NDVI (normalized difference vegetation index) has shown to be a good predictor of green vegetation density for several vegetation types. The Brazilian xeromorphic vegetation, called Cerrado, comprises a physiognomic gradient (grass, herbs, shrubs, and trees) according to the environmental conditions. Cerrado physiognomies varying from predominant herbaceous to predominant arboreal physiognomies, starting with *Campo*, to *Campo Cerrado*, to *Cerrado stricto sensu*, to *Cerradão*, and Seasonal Semi-deciduous Forest. Cerrado vegetation changes its greenness seasonally due its tropical climate: greenness behavior of grasses is annual like (lose all green leaves in driest period) and arboreal greenness behavior is semi-deciduous (some individuals lose all green leaves in driest period). The unconcern of that phenological change is one of the causes of several misclassifications of the Cerrado physiognomies when classified using orbital data. The objective of this study was analyzing NDVI variation of gradient physiognomies of Cerrado seasonally. The gradient of physiognomies and their seasonal variation were analyzed through Landsat-TM images (orbit 220, point 075) on five different dates, during almost a year (June, July August and November 1995 and January 1996). Each physiognomy was showed its variation in time using a vegetation index model (NDVI). The methodology adopted here includes the identification of the physiognomies in the field and in geo-coded image. The NDVI derived from Landsat images was compared to the total volume (indirect measurement of biomass) and with modeled NDVI obtained by the proportional contribution of herbaceous and arboreal components of Cerrado. The results also suggest the structure and greenness phenology of vegetation need to be consider in order to analyze the Cerrado physiognomies of the neotropical savannas. It was observed that: each physiognomy changes its greenness differently seasonally, depending on the herbaceous stratum and canopy extensions; and there is a period that is more suitable to analyze each Cerrado physiognomy using orbital data. The phenological pattern of senescence and new leaves growing for Cerrado physiognomy could be established through NDVI. The gradient physiognomies express a structural variation of herbaceous and arboreal components. The specific structure of each physiognomy causes a different annual change in the total green biomass. From that results achieved we proposed a testable hypothesis. Filling in the gaps in the curves using more dates, the model will be ready to be validated, using, of course, other Cerrado areas.

1 INTRODUCTION

According to Coutinho (1978), the term *Cerrado sensu lato* (*Cerrado s.l.*) covers the range of savanna physiognomies, from grassland to arboreal types of vegetation. Depending on the stage that Cerrado has been reached in the continual process of ecological readjustment to achieve 'equilibrium', it will have more participation of herbaceous or arboreal component. Such a concept of ecological equilibrium varies according to soil type and water supply (Sarmiento, 1992), and can be grouped into five principal physiognomic structures: *Campo Limpo*, *Campo Sujo*, *Campo Cerrado*, *Cerrado s.s. and Cerradão*, respectively. Considering the Cerrado biome, other physiognomies such as riparian forest and seasonal semideciduous forest are also presented (Eiten, 1978).

The complexity of the *Cerrado* physiognomies and their seasonal variations are responsible for many misclassifications, not only in the field but also when orbital remote sensing is used. The reason for that misclassification is the leaves lost during the dry period, and the new leaves offspring during the rainy period (Sarmiento, 1984), which strongly change the spectral responses registered by remote sensors in the visible and infrared bands. Several attempts have been made to correctly identify those physiognomies using satellite images, especially using vegetation indices.

The phenological events detectable by remote sensing are flowering, leaves abscission, and new leaves growing; all of them at landscape level. The importance of considering the phenological changes (leaves lost during the driest season and offspring new leaves growing during the rainy season) is more noticeable when the vegetation analysis by NDVI is done temporally (Curran *et alii*, 1992; Franklin *et alii*, 1993; Anderson *et alii*, 1993; Blackburn & Milton, 1995; Batista *et alii*, 1997).

The phenological analysis, mainly in tropical ecosystems, are needed to classify images, since the vegetation can be recognized, considering that each point of the image represents determined space and time (Morain, 1974). The long term temporal studies of global changes using NDVI has pointed out the importance of considering the phenology of the vegetation caused by climatic seasonal variation (Tucker *et alii*, 1985; Fung & Tucker, 1986; Millington *et alii*, 1992; Sannier *et alii*, 1998). Particularly in *Cerrado*, some studies has pointed the importance of considering the vegetation phenology (França, 1994), *Cerrado stricto sensu* e *cerradão* (Santos & Shimabukuro, 1993; Lacruz *et alii*, 1994).

The seasonal modeling of the relationship between vegetation and climatic seasonal variation allows one to distinguish different types of vegetation according to its phenological characteristics (Samson, 1993).

Orbital remote sensing can offer good perspectives to the quantitative modeling of vegetation phenology. By means of global analyses, with high temporal frequency of images, phenology models were proposed to world vegetation (Kremer & Running, 1993; Ehrlich *et alii*, 1994). The temperature is the most important factor to changes in deciduous forests and rainfall to savannas (Di, 1994; Shinoda, 1995; Moulin *et alii*, 1997). Specifically in the case of savannas, it is necessary to consider the phenological variation of the herbaceous and arboreal component. Each component has different level of phenological changes they when are exposed to the same climatic seasonal variation (Fuller *et alii*, 1997).

2 STUDY SITE

The study site is a conservation unit named Pé-de-Gigante, created in 1970, with a preserved area of approximately 1225ha. The vegetation is composed by a gradient of all *Cerrado* physiognomies, one little spot of Semi-deciduous Seasonal Forest and, along the stream, Riparian Forest in degraded state. That conservation unit is located in the district of Santa Rita do Passa Quatro - SP (47°37'W, 21°37'S), 250km north of the city of São Paulo.

The relief is moderately flat with altitudes ranging from 590m to 740m which contains Paulicéia's stream head. The region substrate is geologically formed by alluvial erosion of arenitic formations. The deposition of sediments results in poor soil, and close to the stream the soil is even poorer. This ground configuration is covered by *Cerrado* physiognomies varying from predominant herbaceous to predominant arboreal physiognomies, starting with *Campo*, to *Campo Cerrado*, to *Cerrado stricto sensu* (type II and I) and finishing with *Cerradão*. The *Cerrado stricto sensu* has two possible variations: type 1 is composed of trees, shrubs and herbs, and grass; type 2 is composed of small trees, with few contribution of grass. There are other vegetation types in the area: the seasonal semi-deciduous forest, riparian forest, and vegetation in areas with a high slope (pioneer plants mixed with *Cerrado* species).

Climatically the region is classified as a tropical seasonal with wet summers and dry winters which correspond to "Cwa" of Koeppen's Climatic Classification (1948). The climatic diagram (Walter, 1955), show the seasonal distribution of the rainfall during the year as shown in the Figure 2. The mean annual precipitation is 1475mm year⁻¹ and the mean monthly temperature is around 23oC with small variation, but the mean daily variation is about 20oC.

3 METHODS

Five sets of the satellite Landsat-5 Thematic Mapper (scene 220/075) were used: July 05th, August 28th of 1995 and January 29th, July 23rd, 1996, June 8th, 1997. The images were geographically registered and digitally processed with the software IDRISI (Clark University at USA). The five images of the study area (182 x 182 pixels) were registered to 30mx30m resolution.

Topographic data, on scale 1:10,000, from IGC - Institute of Geography and Cartography of São Paulo, were used to produce a digital elevation model (DEM) with U.T.M. grid of 10 x 10 meters resolution. Based on the DEM image, ten points were selected and used to resample, by nearest neighbor, the positioning of the five images. The resampling result was compared with the field's reference points, at the same locations, sampled with Global Positioning System (GPS) and the overall root mean square (RMS) error was 21 meters.

The digital numbers (DNs) of the images were converted to physical values of exoatmospheric reflectance, in order to account for DN's linearization processes and for solar elevation angle variation, peculiar to tropic latitudes.

At first, the at-satellite radiance values were derived from DN conversion into radiance (Markham & Barker, 1986), and then to exoatmospheric reflectance "ρ" (Mesquita Jr & Bitencourt, 1997). Combining these reflectance images as follow:

$$NDVI = \frac{\rho_{\text{near infrared}} - \rho_{\text{red}}}{\rho_{\text{near infrared}} + \rho_{\text{red}}}$$

will result in an image that describes the green leaf density per area. From now on it will be called NDVI image.

The methodology adopted here includes the identification of the physiognomies in the field and in geo-coded image. The NDVI derived from Landsat images was compared to the total volume (indirect measurement of biomass) and with modeled NDVI obtained by the proportional contribution of herbaceous and arboreal components of Cerrado.

In order to describe the physiognomic gradient of Cerrado vegetation in the field, we estimated the herbaceous and arboreal component contribution using a non-destructive method. To do so, we measured height and perimeter, at ground level, of each individual, in an area of 1ha (40 sample areas of 25m x 10m). All individuals were classified in 8 height classes (<0,5m, <1m, <3m, <5m, <7m, <9m, <12m, >12m) considered as a contribution layers of each physiognomy. To obtain the modeled NDVI was assumed that lower classes had more proportional contribution of herbaceous component and taller classes had more proportional contribution of arboreal component. Its greenness behavior and the rainfall distribution during the year determined the contribution of each component. Physiognomies described on the sample quadrates in the field were associated with a range of NDVI, obtained on the same geographical position.

Modeled NDVI was obtained by the proportional contribution of herbaceous and arboreal components of Cerrado according to the Equation below:

$$NDVI_{\text{modeled}} = \sum \{ [(f_a \cdot NDVI_{\text{max}}) + (f_h \cdot NDVI_{\text{min}})] \cdot f_c \}$$

layer contribution factor (f_c) = partial volume contribution (from less 0.5m to bigger than 12m)
 herbaceous component (f_h) = i/j
 arboreal component (f_a) = j/i
 layers number (n) = 8
 $i = 0...(n-1)$
 $j = (n-1)...0$

The maximum and minimum NDVI intervals were used as a threshold of NDVI variation of herbaceous and arboreal components of each physiognomy (Figure 1a). Its limits were determined by a conceptual model of variation of Cerrado physiognomies along a time of climatic seasonal variation. The climatic seasonal variation of rainy and dry periods is carried out with herbaceous and arboreal leaf changes. The absence and senescence of Cerrado species are not quite similar or synchronized, but most of herbaceous lost their leaves at begging of dry winter and some species of tree like began to lost their leaves, and continuous losing as much as perpetuate the driest period (Figure 1b).

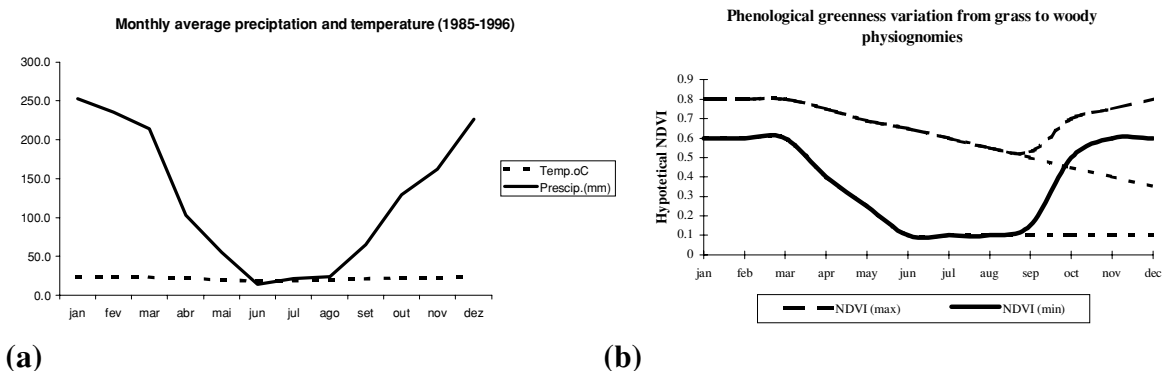


Figure 1 - (a) Monthly average temperature and precipitation of the study area and (b) the hypothetical seasonal changes of grass and tree layers by NDVI.

4 RESULTS

Figure 2 presents the physiognomic gradient of *Cerrado* from predominant herbaceous to predominant arboreal. The gradient can be clearly associated with the increase of biomass (measured indirectly by non-destructive method - total volume). The field observation of the gradient revealed that many structural vegetation variables (canopy rough, total volume and proportional participation of herbaceous and arboreal component) change gradually.

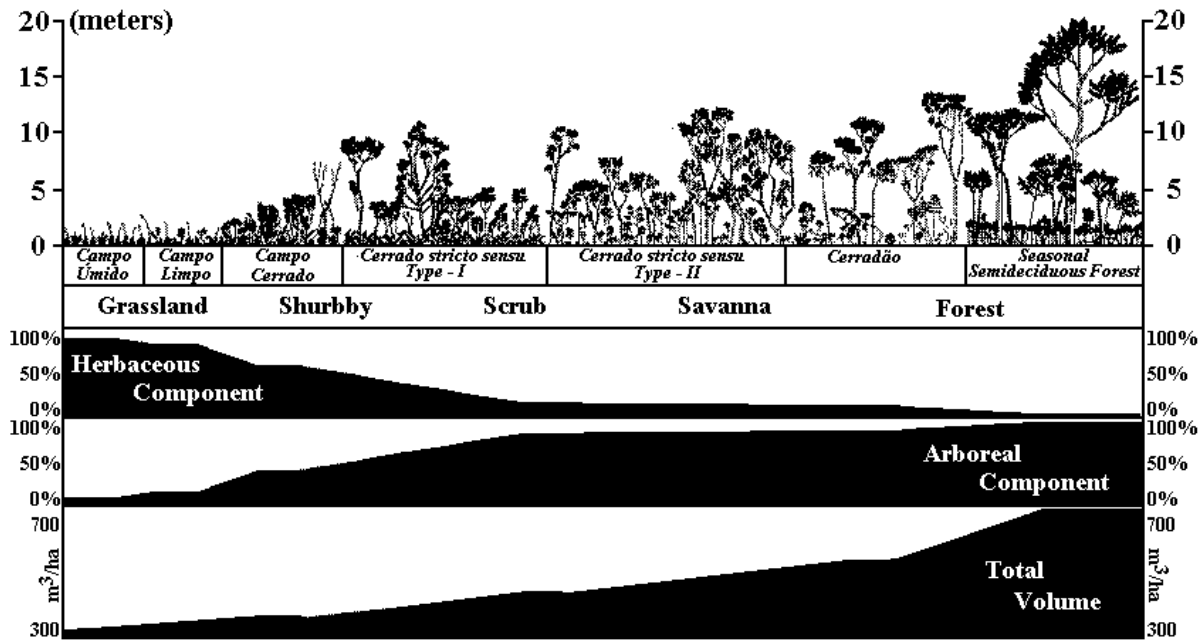


Figure 2. Physiognomies gradient and volume contribution of herbaceous and arboreal component.

In the field, the Cerrado gradient of physiognomies was measured by total volume. Each plot sampled in the field was associated with the average NDVI of the same geographic coordinates. The total volume (phytomass estimator) in field was high correlated with the NDVI average of the same physiognomy (Figure 3). The correlation coefficient of measured NDVI in relation to total volume (Jun=0.56, Jul=0.44, Aug=0.51, Nov=0.47 and Jan=0.58) was lower than measured NDVI in relation to modeled NDVI (Jun=0.80, Jul=0.64, Aug=0.78, Nov=0.78 and Jan=0.83). The linear fits between predicted and observed values of NDVI were significant ($p < 0.05$). The slope of linear fits of the observed NDVI in relation to the volume suggests that the inter-season image dates (Jun=0.000144, Jul=0.000136, Nov=0.000128) can distinguish the physiognomies better than the rains and the dry season (respectively jan=0.000089 and aug=0.000117).

The results show that both of the extreme conditions of the annual season variation gives less information about vegetation than the inter-annual conditions, probably due to precipitation and temperature. The results obtained here gave us an insight of how these two components (herbaceous and arboreal) can contribute to the annual changes in the spectral response detected by satellite.

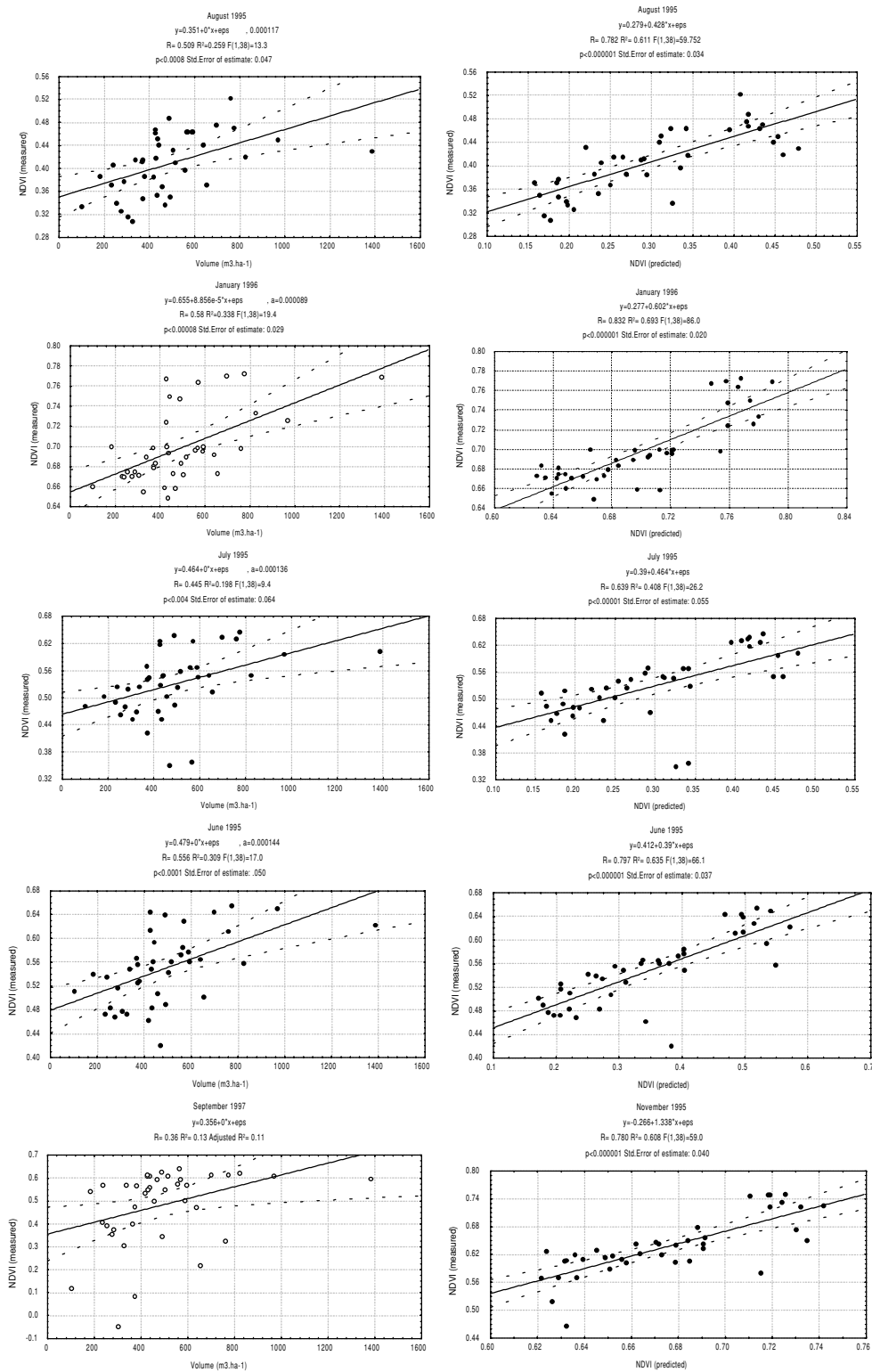


Figure 3 - Scatter plots of NDVI vs. cylindrical volume and NDVI extracted from Landsat images on five different dates. The NDVI measured was compared with NDVI obtained by hypothetical model.

5 CONCLUSIONS

Knowing that the phenological changes may affect the green leaves proportion by leaf lost and the NDVI can detect that changes, the use of this index to estimate the green vegetation would be straight. The correlation between phytomass (estimated by total volume) and NDVI was high, and is in accordance with the correlation obtained with other studies (Bitencourt-Pereira, 1986; Valeriano & Bitencourt-Pereira, 1988).

The range of variation of the average NDVI in the dates shows that each physiognomy has a different response to climatic changes. Grasses physiognomies have the biggest range and the forest types the lowest range. These range variation has been noticed for African vegetation types (Tucker et al., 1985, Millington et al., 1992).

During the dry period, the arboreal components tend to lose their leaves whereas the herbaceous components usually maintain the dead leaves. Because the herbaceous components generally presents short roots, it is supposed to be more sensitive to dryness whereas the arboreal portion, with longer roots, may go further for water supply (Sarmiento, 1984 and 1992).

Those ecophysiological responses can also be related to the variation in temperature and precipitation.

The results also suggest the structure and greenness phonology of vegetation need to be consider in order to analyze the Cerrado physiognomies of the neotropical savannas. It was observed that: each physiognomy changes its greenness differently seasonally, depending on the herbaceous stratum and canopy extensions; and there is a period that is more suitable to analyze each Cerrado physiognomy using orbital data. The phenological pattern of senescence and new leaves growing for Cerrado physiognomy could be established through NDVI. The gradient physiognomies express a structural variation of herbaceous and arboreal components. The specific structure of each physiognomy causes a different annual change in the total green biomass. From that results achieved we proposed a testable hypothesis.

The best discrimination of *Cerrado* physiognomies by satellite data needs to consider the phenology of leaves greenness seasonal variation of the vegetation. The absence of knowing about the proportional participation of each component and their greenness variation could influence to cause a misclassification of Cerrado physiognomies.

The images on five dates are not enough to build a model but gave a good hint about the seasonal variation of the Cerrado physiognomies. The theoretical model presented here needs to be modeled with more database, adjusted, tested or validated. We absolutely encourage people to test this hypothesis in other vegetation types with the same kind of physiognomic and seasonal variation. This method can be applied to other Savannas, where the participation of herbaceous and arboreal components changes gradually and in different rates.

ACKNOWLEDGMENTS

This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and part research funding by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP). The authors wish to tank DAAE-Departamento de Águas e Energia Elétrica that gave us all climatic data, to Geography Department of University of São Paulo and Environmental Agency of São Paulo state (that allowed us to use one of their image).

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