ESTIMATION OF LEAF AREA INDEX IN A MIXED OMBROPHILOUS FOREST USING REMOTE SENSING DATA

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ABSTRACT

This study was conducted to estimate leaf area index (LAI) in a fragment of Mixed Ombrophilous Forest, in São João do Triunfo, Brazil, using remote sensing techniques. The LAI was generated from orbital images from the Pleiades sensor, based on the relationship with vegetation indices (VI). On the ground, LAI was estimated from the CI-110 Plant Canopy Analyzer, assumed to measure actual LAI. The data obtained by the remote sensing techniques were correlated with the data obtained from the field, using the Pearson's correlation coefficient. The Normalized Difference Vegetation Index (NDVI) correlation with LAI (r = 0.32) was greatly surpassed by the Soil-Adjusted Vegetation Index (SAVI) correlation with LAI (r = 0.78). Meanwhile, the model proposed by SEBAL was moderately correlated with LAI (r = 0.66).

Key Words *— Hemispherical photographs, Mixed Ombrophilous Forest, Pleiades, Vegetation Index.*

1. INTRODUCTION

The Leaf Area Index (LAI) is considered a most sensitive forest structure parameter, since canopy leaves regulate fundamental processes of forest productivity. LAI is considered an important parameter to describe the canopy structure and its close relationship with biophysical processes such as photosynthesis, respiration, transpiration, and carbon and nutrient cycling. LAI is used in physiological and ecological studies, being an indicator of the vitality of trees and reflecting rates of assimilation and transpiration of canopies, as well as gas exchange, water balance, among others ([1]HU et al. 2018; [2] Tian et al. 2015; [3] Galvani, 2010).

Although critically important for ecological studies, LAI modeling in forests is considered inaccurate, so it is necessary to establish improved regional scale estimates. LAI estimation methods based on remote sensing have received prominence and are being widely used. There are two main methods of estimating the LAI from remote sensing: 1) through empirical relationships between vegetation indices (VI) generated from satellite images, and 2) based on radiation transfer models that use optical sensor inputs ([4] MA et al., 2014).

Current remote sensing data are being revolutionized with a new era of high Earth observation satellites having higher spatial, temporal, and spectral resolutions, resulting in more data to process ([5] MA et al., 2015). However, in Brazil, there are still few LAI estimation studies that make use of high resolution satellite images, such as the images of the Pleiades sensor. Another possible approach to understanding forest structure are with hemispherical photographs, which are considered a short-range remote sensing technique. Hemispherical photographs characterize solar radiation intercepted by the forest canopy from through a fisheye lens ([6] GONSAMO et al., 2011).

In this context, this study was conducted to estimate LAI in a fragment of Mixed Ombrophilous Forest, located in Brazil, using remote sensing techniques.

2. MATERIAL AND METHODS

The study area is located at the Experimental Station Rudi Arno Seitz of the Federal University of Parana, located in the city of São João do Triunfo-PR, Brazil (Figure 1). The study area comprises a fragment of the Mixed Ombrophylous Forest (FOM), object of the Long Duration Ecological Research Program (PELD), Araucaria Forest and its transitions.

Data collection was performed in permanent plots measuring 100x100m, divided into subplots measuring 10x10 m. The samples were the vertices of the subplots. The subplots located at the ends of the plots were not used to avoid border effect.

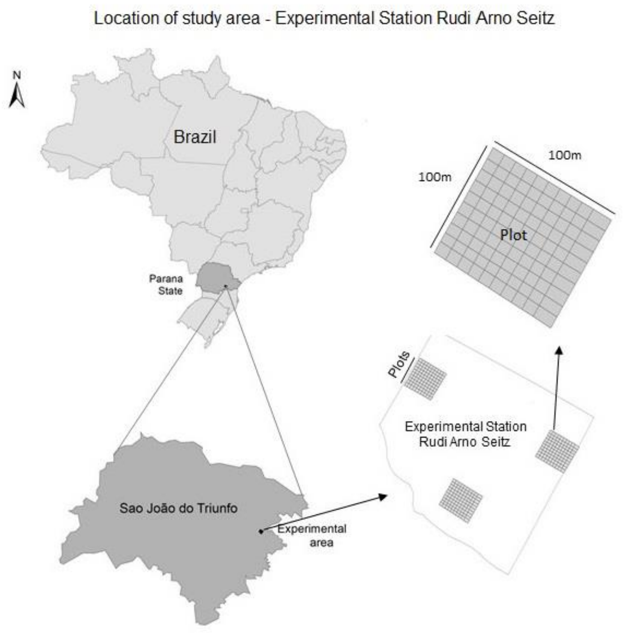

Figure 1. Location of study area and plots

The study utilized two datasets, orbital and terrestrial. LAI Orbital was estimated through VI, which are mathematical formulas developed to evaluate vegetation cover qualitatively and quantitatively, using spectral measurements. Initially the atmospheric and radiometric correction of the Pleiades image was performed, using Envi 5.2 software. The Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI) were generated, which estimated LAI by the models of [7] SEBAL (2002) and [8] Duchemin (2006). The acquisition of terrestrial data, called LAI Terrestrial was estimated using the CI-110 Plant Canopy Analyzer sensor, considered as ground truth. The CI-110 Plant Canopy Analyzer is a passive ground sensor used to measure the amount of incident solar radiation in the visible spectrum. It consists of a rod with 24 sensors, and at the tip of the rod is the fish eye lens that allows LAI calculation based on the transmission coefficient for diffuse penetration, the mean leaf angle, and the canopy extinction coefficient

Pearson correlation analysis was performed between the LAI Terrestrial and VI obtained from LAI Orbital.

3. RESULTS

The NDVI vegetation index correlations to LAI were between 0.82 and 0.97, with a mean of 0.89, presenting the lowest coefficient of variation and amplitude for all plots, so that it was not possible to distinguish differences between physiognomies in the study area.

The SAVI vegetation index presented values between 0.34 and 0.67, with an average value of 0.48.

From the generation of NDVI and SAVI vegetation indices, two models were generated for the orbital LAI, one proposed by Surface Energy Balance Algorithms for Land ([7] SEBAL, 2006), and the other proposed by [8] Duchemin (2002). LAI estimated by the orbital and terrestrial methods can be visualized in Table 1.

Table 1 - LAI Orbital and LAI Terrestrial

Data	Min	Max	Average	Standard Deviation	Coefficient Variation
LAI Duchemin	3.21	7.37	4.34	0.71	16.37
LAI Sebal	1.95	7.80	3.14	1.12	35.76
LAI Terrestrial	6.94	8.01	7.63	0.27	3.56

LAI for the Mixed Ombrophilous Forest fragment estimated by the CI-110 Plant Canopy Analyzer varied between 6.01 and 8.01. Figure 2 shows the maximum, minimum and mean LAI values obtained in the hemispherical photographs.

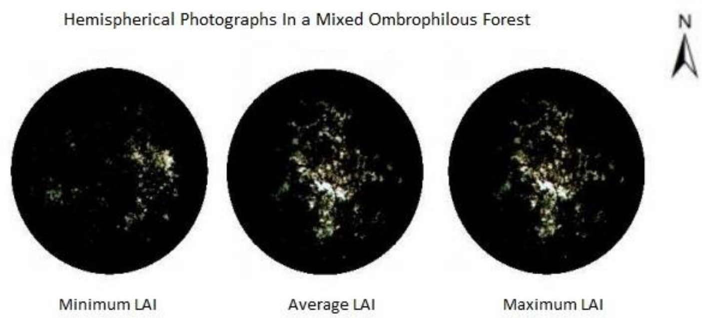

Figure 2. LAI obtained in the hemispherical photographs

The NDVI correlation to LAI Terrestrial was r = 0.32, while the SAVI correlation to LAI Terrestrial was r = 0.78.

Among LAI estimation models, SEBAL produced satisfactory results, with a moderate correlation (r = 0.66) with the LAI data obtained in the field. The model proposed by Duchemin et al. (2006), produced a linear correlation of 0.23, considered inadequate to characterize the LAI of the Mixed Ombrophilous Forest.

The experimental station Rudi Arno Seitz presents a large number of species, constituting high diversity. The analysis of floristic composition for the examined fragment identified 734 ind.ha^{-1} in total, distributed across 33 families and 80 species. The most represented families were Lauraceae, Auracariaceae and Myrtaceae, which corroborates the observed variation in estimated LAI.

4. DISCUSSION

The NDVI saturates quickly at values > 0.875, which makes it insensitive to variation in high plant biomass ([9] Rodrigues et al., 2013)

The relationship between LAI and SAVI or NDVI varies in different types of vegetation (pasture, undergrowth and coniferous forest). NDVI is only sensitive to LAI up to 5.0, SAVI had the strongest correlation over all LAI values, with an r of 0.94. The authors consider that these correlations between LAI and VI is directly related to the vegetation patterns analyzed and the characteristics of the sensor ([10] Turner et al., 1999).

NDVI is highly correlated with LAI, but this relationship may not be so strong when or where LAI is high, due to saturation of NDVI. For pastures, arid and semi-arid ecosystems, biomass is considered low, so NDVI is able to estimate LAI more accurately ([11] Jensen, 2009).

Research with VI for the Rudi Arno Seitz Experimental Station has the lowest values of the coefficient of variation for the NDVI, being 0.74% for the Aster sensor, 2.83% for the LISS III sensor and 1.26% for the TM sensor. The coefficient of variation for E for SAVI between 5.62 and 11.35% ([12] Cassol, 2013).

Estimated LAI shows great variability among the plots. This factor is related to the different forest types that predominate in the Rudi Arno Seitz Station. On-site studies show variations, where they are classified as predominantly hardwood, mixed with *Araucaria angustifolia* (Brazilian pine) and *Ocotea porosa* (Imbuia).

LAI estimates obtained through indirect methods are significantly correlated with LAI obtained from direct methods. However, when LAI is obtained by direct and optical methods, inferences are subject to seasonal variations, so the data should be collected at the same time of year ([13] LIU et al., 2015).

5. CONCLUSIONS

LAI obtained on the ground with a terrestrial passive sensor showed great variability, a factor that may be associated with the large number of species and structures present in the study area, characteristic of natural forests.

LAI estimation using orbital images showed great potential, since the 2 m spatial resolution of Pleiades images correctly represented the spectral/spatial characteristics of the vegetation. However, LAI estimated using the orbital data as input into the two models analyzed (SEBAL and Duchemin) presented distinct results. The SEBAL and Duchemin models underestimate the LAI values obtained in field, but the SEBAL model was considered efficient due to the strong correlation with the field data.

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