

LEAF AREA INDEX AND CANOPY OPENNESS ESTIMATION USING HIGH SPATIAL RESOLUTION IMAGE QUICKBIRD¹

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ABSTRACT - The aim of this paper was to evaluate and propose a high spatial resolution image analysis method, for public managers, regarding to monitoring and observation of degraded areas recuperation success. The specific objectives were: i) to obtain leaf area index (LAI) and canopy openness data in field, ii) to calculate the relation between LAI and canopy openness data sampled in field, iii) to estimate canopy openness using the Quickbird high resolution image, iv) to use data sampled in field to obtain LAI values by image, and v) to analyze the residuals between data sampled in field and that obtained by image, of twelve species monitored in the Ecological and Multiple Use Olhos D'água Park, Brazil. The estimates of canopy openness and leaf area index of twelve Cerrado species using high resolution images were effective, as for the tolerable error of the adjustments obtained (6.9%) from the models, as for the image's practicality: it attends a larger area and larger timescale, and is efficient to evaluate the execution of revegetation projects.

Keywords: Environmental management. Public Management. Canopy openness.

ESTIMATIVA DE ÁREA FOLIAR E ABERTURA DE DOSEL ATRAVÉS DE IMAGEM DE ALTA RESOLUÇÃO ESPACIAL QUICKBIRD

RESUMO - O objetivo geral deste trabalho foi avaliar e propor a ferramenta da análise de imagem de alta resolução, para os gestores públicos, no monitoramento e observação do sucesso de recuperação de áreas degradadas. Os objetivos específicos foram: i) obter os dados de índice de área foliar (IAF) e abertura de dossel em campo, ii) calcular a relação entre o IAF e a abertura de dossel mensurados em campo, iii) estimar a abertura de dossel através de imagem de alta resolução QuickBird, iv) aplicar a relação dos dados mensurados em campo para se obter os valores de IAF através da imagem, e v) realizar a análise de resíduos dos dados obtidos em campo com os obtidos na imagem, de doze espécies monitoradas no Parque Olhos Ecológico e de Uso Múltiplo D'água. As estimativas da abertura de dossel e do índice de área foliar em doze espécies de Cerrado, utilizando imagens de alta resolução mostraram-se eficazes, tanto pelo erro tolerável obtido (6,9%) a partir dos modelos, quanto pela praticidade que a imagem fornece: atende uma área maior e em uma escala temporal, sendo eficientes para avaliação da execução de projetos de revegetação.

Palavras-chave: Gestão ambiental. Gestão Pública. Abertura de dossel.

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INTRODUCTION

Conservation Units were legally established in order to assemble biodiversity preservation, native ecological processes maintenance and social-economic sustainability (SNUC, 2000). There is an environmental recovery public policy in these units, specially related to recovery of degraded or previously disturbed areas (SPRINZ, 2009).

An index that could be applied to time and spatial monitoring would be the leaf area index (LAI), which is the leaf area per ground surface area unit, m^2/m^2 , thus dimensionless (WATSON, 1947). It is important to evaluate this index because it may indirectly indicate growth rate, nutrients accumulation, water deficit seasonality and biomass yield of an ecosystem, whereas the leaves are the primary plant tissue for exchanges of water, gases, carbon dioxide and energy with the atmosphere (ASNER et al., 2003).

Several methods to obtain this index are used in field, as: i) equipment for canopy analysis (SANTANA et al., 2010a), ii) leaf samples for scanning (HOFFMANN et al., 2005), iii) destructive sampling of individual plants within an area unit (SBRISSIA; SILVA, 2008) and iv) photos of a fish-eye camera (MACFARLANE et al., 2004). However, indirect methods, such as the remote sensing using satellite images, were proposed, as it covers a larger sampling area and deduces the deforestation or revegetation process within a timescale (SANTANA et al., 2010b; JENSEN et al., 2009; HOFFMANN et al., 2005).

Optical remote sensing techniques and high spatial resolution images, of around 0,6 m pixel resolution degree of detail were used in order to estimate leaf area data set, with a smaller sampling standard error in relation to medium spatial resolution images (10 to 30 m), (YANG; YANG, 2009; ZHAO; POPESCU, 2009).

The remotely-sensed leaf-area values estimates are obtained by leaf-area spectral reflectance, whereas the presence or absence of leaves, is the main factor in order to obtain the leaf area index (JENSEN et al., 2009). Visual interpretation of the images and manual delimitation of forested and deforested areas are also used, with a higher precision compared to automatic delimitation (SANTANA et al., 2010b). The vegetation monitoring adjustment and a leaf-area estimated data were more precise after the species composition was obtained; the most frequent species and the individuals' leaf architecture were known in field (PINHEIRO et al. 2010; HOFFMANN et al., 2005).

Public managers have used remote sensing and visual interpretation within several fields, evaluating: i) agriculture (SANTANA et al., 2010b); ii) land and water degradation (KAUR et al., 2009); iii) erosion (RAHMAN et al., 2009); iv) air pollution (HU; RAO, 2009); v) urban expansion (GOLDEN et

al., 2009); vi) rural property size (TAN et al., 2009); vii) fire and biomass burning (RESSL et al., 2009); among others.

The general objective is to evaluate and propose a high spatial resolution image analysis method, for public managers, with respect to future monitoring and observation of degraded areas recuperation success, with the subsequent specific objectives: i) to obtain LAI and canopy openness data set in field, ii) to calculate the relation between LAI and canopy openness data sampled in field, iii) to estimate the canopy openness through high resolution image, iv) to apply the data set obtained in field in order to obtain LAI values by image, and v) to analyze the residuals between the data obtained in field and that obtained through the imagery, of twelve species monitored in the Olhos D'água Park, Brazil.

MATERIALS AND METHODS

The Olhos D'água Park or Ecological and Multiple Use Olhos D'água Park is situated at *Asa Norte*, a neighborhood of *Brasilia Plano Piloto*, Federal District, Brazil, which covers an area of 21 hectares (Figure 1A). With a 2.1 km jogging track, a playground, an exercise station and its trails, it is daily visited by *Asa Norte* and surrounding communities. The park was inaugurated in 1994, and the Federal District Government has invested around 350 thousand dollars (US\$) to urbanize, protect, revitalize and recover the area. In the inauguration year, degraded areas in the park were revegetated with native species from the park and with other Cerrado Biome (Brazilian savanna) native species (IBRAM, 2009).

The vegetation in the park is typical of the Gallery Forest phytophysiology with tree heights reaching 35 m, surrounding the Sapos Lagoon, which arises from the *Talvegue* stream. The soils are poorly drained, mesotrophic and classified as gleisol next to the lagoon (660 m), and as red oxisol in more elevated areas (> 680-720 m). The climate is the tropical semi-humid with annual average temperature of 19 °C and annual precipitation of approximately 1,400 mm (IBGE, 2009).

To estimate the leaf area index (LAI) of the selected plant individuals, through the high resolution satellite image, the following steps were considered: i) the first was the obtainance of LAI and canopy openness data in field; ii) afterwards, it was used the regression analysis between the LAI and the canopy openness, with the purpose of obtaining the equation of this relation; iii) the next step was to delimit canopy openness through the satellite image and then to obtain the residual error between canopy openness data sampled in field and by image; and iv) lastly, the adjusted equation was used to obtain the LAI values estimated by image and the residual error between LAI data sampled in field and by image.

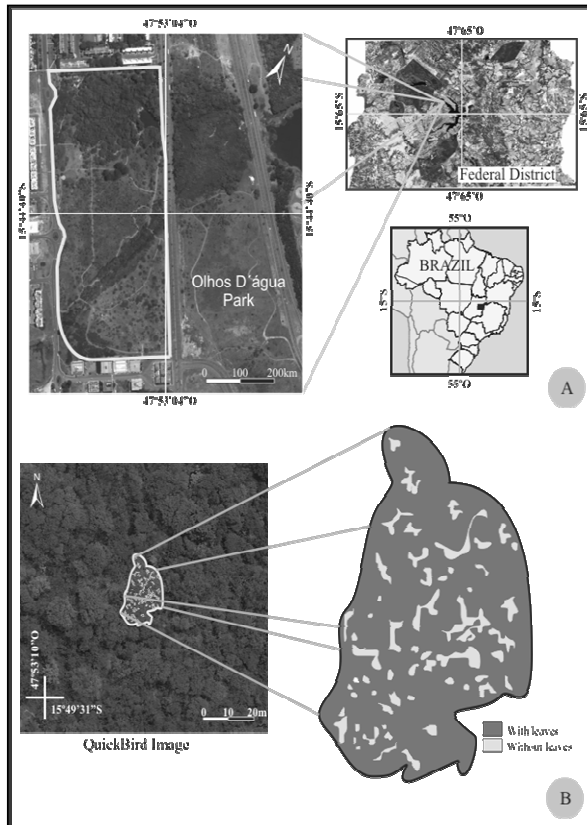


Figure 1. A) Localization of the study area and B) Method of collecting canopy openness data (% of polygon) obtained through the Quickbird satellite high resolution image.

Twelve woody species were selected for this study, because they were used in the park revegetation and they have the highest density among species present in the study area (with tree density of 20 individuals by 0.5 hectares). Twenty individuals of each species were identified for data collection. The selected species and their respective botanical families were: 1) *Anadenanthera macrocarpa* (Benth.) Brenan (Fabaceae); 2) *Aspidosperma subincanum* Mart. ex A. DC (Apocynaceae); 3) *Bauhinia rufa* (Bong.) Steud. (Fabaceae); 4) *Caesalpinia peltophoroides* Benth. (Fabaceae); 5) *Diospyros burchellii* Hiern (Ebenaceae); 6) *Guazuma ulmifolia* Lam (Sterculiaceae); 7) *Inga marginata* Willd. (Fabaceae); 8) *Luehea grandiflora* Mart (Tiliaceae); 9) *Peltophorum dubium* (Spreng.) Taub. (Fabaceae); 10) *Tabebuia impetiginosa* (Mart. ex DC.) Standl. (Bignoniaceae); 11) *Tabebuia serratifolia* (Vahl) G. Nicholson (Bignoniaceae); and 12) *Tipuana tipu* (Benth.) Kuntze (Fabaceae).

The leaf area index data (LAI – m^2/m^2) were obtained in field through a LAI-2000 Plant Canopy Analyzer (LI-COR, 1992) and the canopy openness (%) with a GRS Densitometer (GRS, 2009). These data were registered in 20 random points under the canopy of each individual of the selected species (without overlapping individuals of other species), adding up to a sampling n of 400 per species (20

individuals X 20 points), at a height of 1.30 m below the photograph camera base, where the equipment and the GPSmap 76CSx (Garmin) were put, in order to mark the geographical points and the individuals spatially. Photographs were taken with the use of fisheye lenses (Peleng 8 mm f3.5 fisheye lens), in order to observe the differences in canopy openness among the selected species.

Canopy openness data (% of polygon) was obtained through the Quickbird satellite high spatial resolution image and was determined by MapWindow GIS Open Source 4.7 software (MAPWINDOW, 2009), by visual classification: i) with leaves and ii) without leaves (Figure 1B), within the selected individuals. The satellite and images specifications are described in Table 1. Geometric and radiometric corrections were carried out according to Wu et al. (2008). Control points: i) $15^{\circ}44'29.06''S$ $47^{\circ}53'12.00''W$; ii) $15^{\circ}44'26.27''S$ $47^{\circ}53'03.72''W$; iii) $15^{\circ}44'49.51''S$ $47^{\circ}53'05.03''W$; iv) $15^{\circ}44'44.92''S$ $47^{\circ}52'58.06''W$; v) $15^{\circ}44'37.73''S$ $47^{\circ}53'04.59''W$; were used to rigorous geometric modeling and correction (ROBERTSON, 2003). Data collection was on March, 2009, and the satellite image was acquired on March 17, 2009.

Table 1. The specifications of satellite and images Quick-Bird (SPOT, 2009).

Specifications QuickBird: satellites and images	
Date	March 23, 2009
Orbit	97.2 degree, sun synchronous Polar orbit
Speed on Orbit	7.1 km / second
Orbit Time	93.5 minutes
Altitude	450 kilometers
Sensor	Push-broom
Pointing	Forward, backward, right, left $\pm 30^{\circ}$
Pixel Resolution	Nadir:
	0.61 meters panchromatic
	2.44 meters multispectral
	25° Off-Nadir:
	0.72 meters panchromatic
	2.88 meters multispectral
Type	ORStandard – 2A
Target	9.7° off-nadir; -5.7° in track; -7.4° across track
Image Swath	16.5 kilometers at nadir
Time	01:13 p.m. (descending node)
Revisit Time	1-3.5 days depending on latitude (30° off nadir)
Dynamic Range	11 bits per pixel
Image Bands	Panchromatic, blue, green, red, near, infrared

RESULTS AND DISCUSSION

The leaf area index (LAI) and canopy openness values varied according to the selected species (Figure 2 A and B). The LAI values varied less ($\pm 55\%$) than the canopy openness values ($\pm 0.63\%$), due to the fact that most of the canopy openness data sampled in several points in the woody individuals

presented extreme values, 0 or 100%, in accordance with the literature (MACFARLANE et al., 2004). Figure 3 presents this heterogeneity among species and the amount of areas with and without leaves.

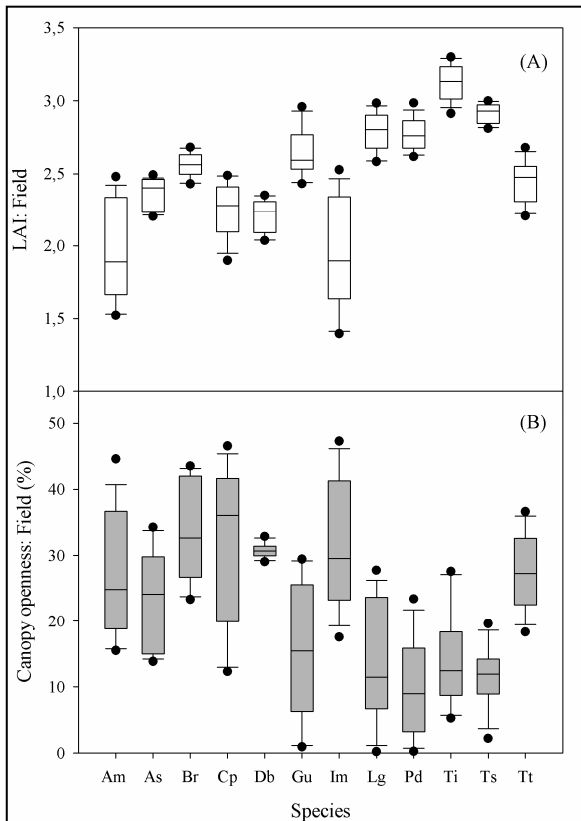


Figure 2. Average and standard deviation of LAI and canopy openness sampled in the study area, of the twelve tree species sampled in Olhos D'água Park, Brasília, DF: Am = *Anadenanthera macrocarpa* (Benth.) Brenan (Fabaceae); As = *Aspidosperma subincanum* Mart. ex A. DC (Apocynaceae); Br = *Bauhinia rufa* (Bong.) Steud. (Fabaceae); Cp = *Caesalpinia peltophoroides* Benth. (Fabaceae); Db = *Diospyros burchellii* Hiern (Ebenaceae); Gu = *Guazuma ulmifolia* Lam (Sterculiaceae); Im = *Inga marginata* Willd. (Fabaceae); Lg = *Luehea grandiflora* Mart (Tiliaceae); Pd = *Peltophorum dubium* (Spreng.) Taub. (Fabaceae); Ti = *Tabebuia impetiginosa* (Mart. ex DC.) Standl. (Bignoniaceae); Ts = *Tabebuia serratifolia* (Vahl) G. Nicholson (Bignoniaceae); and Tt = *Tipuana tipu* (Benth.) Kuntze (Fabaceae).

In Figure 2, it is also observed an apparent inversely proportional relation between LAI and canopy openness data collected in field, corroborated by the significance of the linear regression analysis values (Figure 4A), and by the linear adjustment, calculated between these two variables ($R^2 > 0.90$; Error < 0.05; and $p < 0.0001$). From the variables relationship data set, the LAI and canopy openness averages were separated and the data dispersion was repeated, observing, in Figure 4B, that each species contributes to the regression line data set, presented in Figure 4A, showing the necessity of sampling a higher number of species and individu-

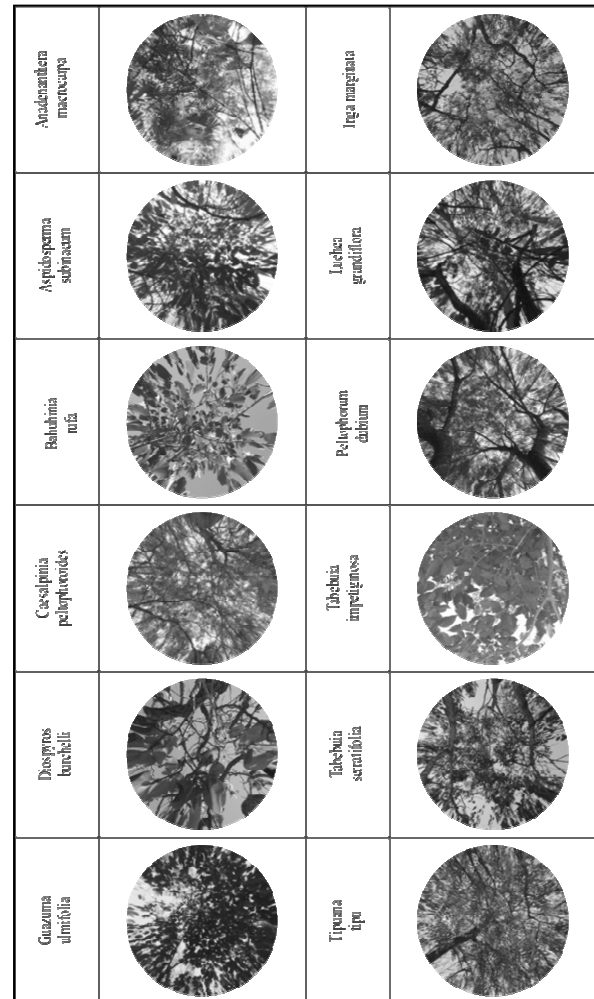


Figure 3. Representative canopy openness of the twelve studied species in Olhos D'água Park. Photographs taken with fisheye lens, at 1.30 m above soil level.

als, preferentially spatially scattered, according to bibliographic references (HOFFMANN et al., 2005; LIMA et al., 2008; MOREIRA et al., 2003). Another highlight point was that species data followed the inversely proportional pattern of its data set, which means that the highest was the canopy openness the lowest was the LAI (HOFFMANN et al., 2005; ASNER et al., 2003).

The canopy openness estimate through the satellite image was close to the data collected in field (Figure 5A). This was confirmed in the residual analysis, whereas the average residual error, between the twelve species canopy openness data, was 2.7% (Figure 5B). The species *P. Dubium* presented the highest residual error among the isolated species, 4.8% below the regression line, therefore, overestimating the data collected in the field. Regarding data under or overestimation, all the errors were added up, negatively and positively, and the value 0.11% was obtained, which means that the canopy openness data obtained through satellite image overestimated the data in -0.11%.

From the adjusted equation in Figure 4A, it was estimated the LAI data, from canopy openness

obtained by the satellite image (Figure 6A). LAI data were also close, confirmed by the residual analysis, with an average error of 4.2%, where the species *I. marginata* presented the highest error (Figure 6B), 8.2% below the line, with an overestimated data. At large, adding up every error value, it was found the value of -1.5%; therefore, the final LAI estimated data from the satellite image was overestimated in 1.5%.

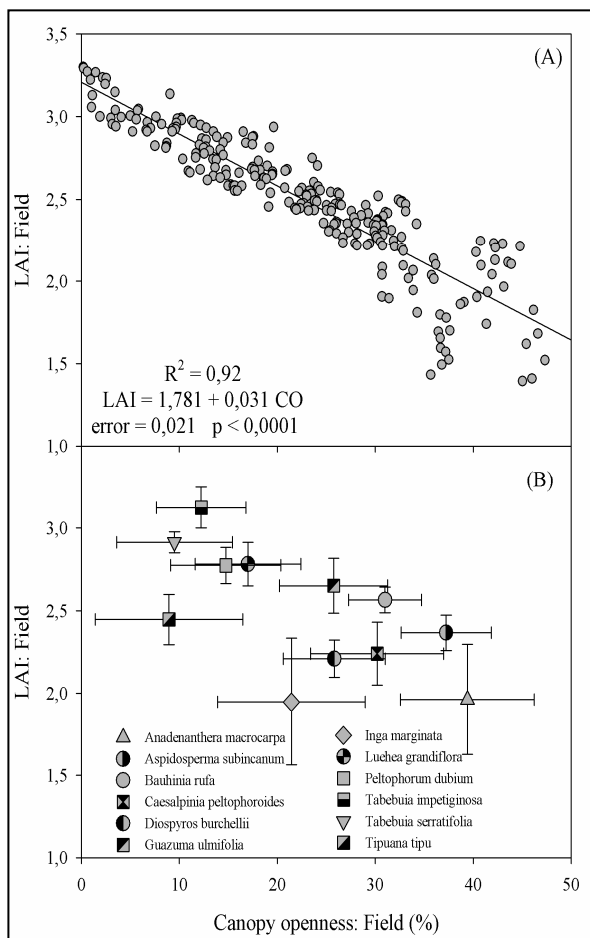


Figure 4. Relationship between leaf area index (LAI) and canopy openness - CO (%) sampled in field, (A) all sampled individuals and (B) sampled average of separated species, with the standard deviations. R^2 = coefficient of determination, error, equation and p = significance level, obtained through the regression analysis.

The total residual error was 6.9% (2.7% from canopy openness + 4.2% from LAI). In regulated-environment tests and experiments, the accepted accuracy of adjusted data are errors between 5 and 10%; however, in field data, which may have a non-normal distribution, mainly due to the external data variation, it is accepted an error ranging from 15 to 20% of the adjusted data set (DUFLOT; BORDAS, 2008). Therefore, it is possible to assert that satellite imagery estimated data was accurate, as its total error was within an accepted range.

Commonly, when an environmental recuperation is executed, revegetation in this case, the immi-

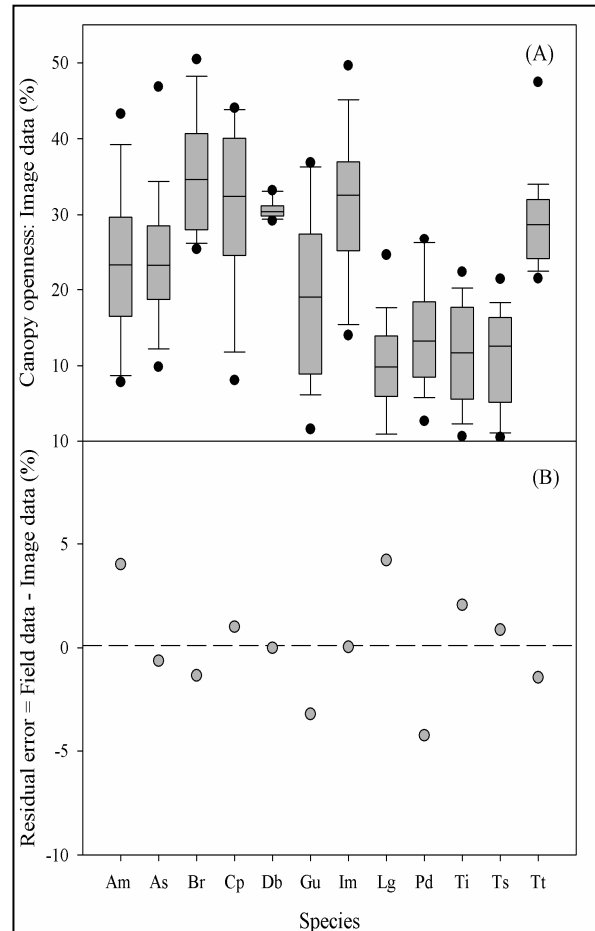


Figure 5. Average and standard deviation of canopy openness delimited with the QuickBird images (A) and Residual error (%) between the canopy openness data sampled in field and by image, of the twelve tree species sampled in Olhos D'água Park, Brasília, DF: Am = *Anadenanthera macrocarpa* (Benth.) Brenan (Fabaceae); As = *Aspidosperma subincanum* Mart. ex A. DC (Apocynaceae); Br = *Bauhinia rufa* (Bong.) Steud. (Fabaceae); Cp = *Caesalpinia peltophoroides* Benth. (Fabaceae); Db = *Diospyros burchellii* Hiern (Ebenaceae); Gu = *Guazuma ulmifolia* Lam (Sterculiaceae); Im = *Inga marginata* Willd. (Fabaceae); Lg = *Luehea grandiflora* Mart (Tiliaceae); Pd = *Peltophorum dubium* (Spreng.) Taub. (Fabaceae); Ti = *Tabebuia impetiginosa* (Mart. ex DC.) Standl. (Bignoniaceae); Ts = *Tabebuia serratifolia* (Vahl) G. Nicholson (Bignoniaceae); and Tt = *Tipuana tipu* (Benth.) Kuntze (Fabaceae).

grating species and the managed area are known. If a satellite image is obtained in the initial project, and then other images are acquired in a timescale, and the success of the degraded area recuperation may be effectively followed. This method enables not only the environmental monitoring, but also to check the efficiency of the project execution. Another important point was the possibility to evaluate species separately, as well as their contribution to the data set, which made it possible to show if the selected species were satisfactory or not in terms of leaf area growth.

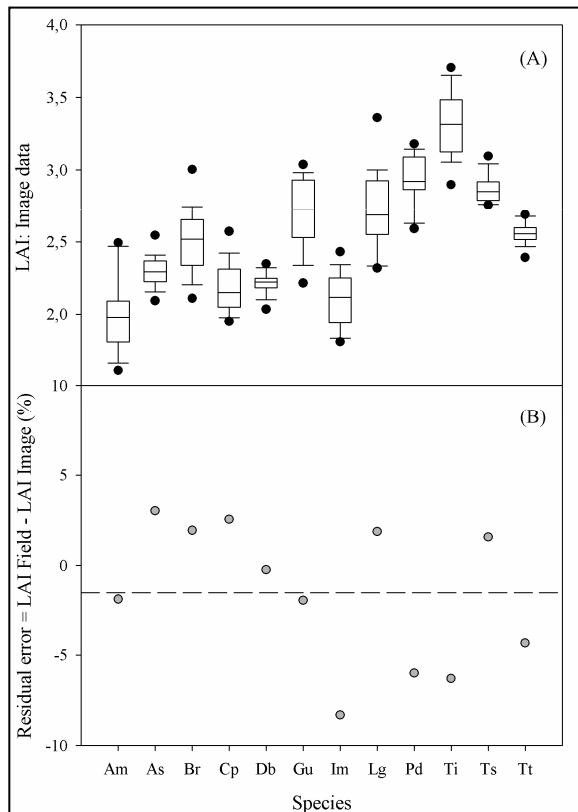


Figure 6. Average and standard deviation of leaf area index (LAI) delimited with QuickBird images (A) and Residual error (%) between the LAI data sampled in field and by image, of the twelve tree species sampled in Olhos D'água Park, Brasília/DF: Am = *Anadenanthera macrocarpa* (Benth.) Brenan (Fabaceae); As = *Aspidosperma subincanum* Mart. ex A. DC (Apocynaceae); Br = *Bauhinia rufa* (Bong.) Steud. (Fabaceae); Cp = *Caesalpinia peltophoroides* Benth. (Fabaceae); Db = *Diospyros burchellii* Hiern (Ebenaceae); Gu = *Guazuma ulmifolia* Lam (Sterculiaceae); Im = *Inga marginata* Willd. (Fabaceae); Lg = *Luehea grandiflora* Mart (Tiliaceae); Pd = *Peltophorum dubium* (Spreng.) Taub. (Fabaceae); Ti = *Tabebuia impetiginosa* (Mart. ex DC.) Standl. (Bignoniaceae); Ts = *Tabebuia serratifolia* (Vahl) G. Nicholson (Bignoniaceae); and Tt = *Tipuana tipu* (Benth.) Kuntze (Fabaceae).

CONCLUSIONS

The leaf area index (LAI) and canopy openness values varied according to the selected Cerrado species, varied by distinct architecture of species, and its data are in accordance with the literature data;

The relationship between LAI and canopy openness data, collected in field, showed an apparent inversely proportional relation, corroborated by the significance of the linear regression analysis values;

The canopy openness estimate through the satellite image was close to the data collected in field. This was confirmed in the residual analysis,

whereas the average residual error, between the twelve species canopy openness data, was 2.7%. The estimated LAI data were also close to the data collected in field, estimated through of adjusted equation results of relationship between LAI and canopy openness data collected in field, and confirmed by the residual analysis, with an average error of 4.2%;

Canopy openness and LAI estimates in twelve Cerrado species, using high spatial resolution satellite imagery, in the Ecological and Multiple Use Olhos D'Água Park, showed their effectiveness, as for the accepted error obtained (6.9% total), as for the practicality offered by the satellite image, since it comprises a larger area in a timescale, which is efficient to evaluate the execution of revegetation projects.

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