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# Spectral Response and Limnological Characteristics of the Nhecolândia Pantanal Lakes

## Características Espectrais e Limnológicas dos Lagos do Pantanal da Nhecolândia

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**Resumo**

Dentre as sub-regiões do Pantanal destaca-se a Nhecolândia, caracterizada por sua peculiar paisagem com mais de 20.000 lagoas, sendo algumas de água salobra (salinas) e outras de água doce (baías). Para a melhor compreensão deste ambiente é muito importante a realização de estudos físico-químicos das lagoas, porém o levantamento dessas variáveis em campo torna-se dispendioso e praticamente impossível, já que exige tratamento em laboratórios adequados e por ser uma região muito extensa. Nesse sentido, com o intuito de facilitar o trabalho de caracterização de regiões extensas e de difícil acesso como neste caso, buscaram-se aplicar as geotecnologias de modo a auxiliar os estudos dos fatores físicos, químicos e biológicos dos alvos estudados. Sendo assim, neste trabalho, além de amostras de água coletadas em 32 pontos de coleta, também foram empregadas imagens de satélite e índices de vegetação para identificar as baías e as salinas da Nhecolândia. Como variáveis analisadas, têm-se a Clorofila a e o Material em Suspensão Total, os quais também podem ser medidos através de imagens de satélite. Como resultado, baseando-se nas variáveis analisadas em campo e nos critérios estabelecidos, detectaram-se 21 baías e 11 salinas. Comparando-se os resultados, verificou-se a eficácia do uso de imagens de satélite para a avaliação de corpos aquosos distribuídos em grandes áreas, com baixo custo e agilidade, pois os resultados apresentados por elas são tão precisos quanto os de análise em laboratório.
**Palavras-chave:** Clorofila a; resposta espectral; NDVI; baías; salinas

**Abstract**

Among the Pantanal sub-regions, Nhecolândia is unique in that it is characterized by a peculiar landscape with more than 20,000 lakes, including ones with brackish water (saline lakes) and others of fresh water (freshwater lakes). For a better understanding of this environment it is important to carry out physico-chemical studies of the lagoons; however, data surveys in the field become expensive and almost impossible due to the vast area and the fact that samples require treatment in appropriate laboratories. Accordingly, in order to facilitate the characterization of large, inaccessible areas such as these, we applied geotechnologies to aid research into the physical, chemical, and biological factors in the study area. Thus, in this work, in addition to water samples collected from 32 locations, satellite images and vegetation indices were also used to identify the freshwater and saline lakes of Nhecolândia. The analyzed variables were chlorophyll *a* and total suspended solids, which can also be measured through satellite images. As a result, based on the variables analyzed in the field and the established criteria, 21 freshwater lakes and 11 saltwater lakes were identified. By comparing results, we found that our results are as accurate as laboratory analyses, therefore, satellite images can be effectively used for low cost and flexible evaluation of aqueous bodies distributed over large areas.
**Keywords:** chlorophyll a; spectral response; NDVI; freshwater lakes; saline lakes

## 1 Introduction

Pantanal is considered one of the richest regions of biodiversity on Earth and has been designated a National Heritage site by the Brazilian Constitution (Brazil, 1988), and a Natural Heritage site and Biosphere Reserve by UNESCO. Although all the Pantanal plains have a common regional origin and are characterized by flooding during the wet season, each area has some distinctive characteristics that allow subdivision of the Pantanal into several wetlands (Mioto et al., 2012). Of these, perhaps the most intriguing is the Nhecolândia Pantanal, mostly because it contains tens of thousands of lakes that can be differentiated by their spatial distribution and their chemical, physical, and biological diversity.

In these lakes, the diversity of phytoplankton and the proportion of cyanobacteria in relation to other phytoplankton organisms is generally correlated to the different class of lake i.e. either freshwater lakes or saline lakes, in accordance with their pH and alkalinity (Almeida et al., 2010). Phytoplankton is responsible for the capture of electromagnetic energy from the Sun and its transformation into chemical energy through photosynthesis. The molecules that capture and transform this energy are photosynthetic pigments, such as chlorophylls a, b, and c, and carotenoids.

It is generally accepted that the trophic level of a body of water can be indicated by factors such as the concentration of chlorophyll a, the primary production of phytoplankton, the presence of algae species, the transparency of the water, and the concentration of nutrients and dissolved oxygen (Toledo et al., 1983). An increase in the concentration of nutrients, especially phosphorus and nitrogen in aquatic ecosystems, causes excessive growth of aquatic macrophytes and/or algae, leading to eutrophication (Esteves, 1998).

For the process of trophic classification, one of the variables used is chlorophyll a, a type of classification typically applied to the management of reservoirs. Accordingly, this study uses chlorophyll a to differentiate between freshwater and saline lakes in the region solely by the amount of existing phytoplankton and the absence of macrophytes in saline lakes. Furthermore, freshwater lakes have clear water and a large amount of macrophytes on the surface, some of which are endemic.

However, carrying out studies based on field surveys of physicochemical variables is costly, as they require appropriate treatment in properly equipped laboratories. When applied to large areas like the Nhecolândia Pantanal, where there are more than 20,000 lakes, they become virtually impossible. In this context, in order to facilitate the characterization of large, difficult to access areas such as these, technologies such as remote sensing can be employed, allowing a more comprehensive spatial analysis in less time and with smaller costs.

Using satellite imagery analysis, the spectral signature and land cover type of an area can be identified by its specific spectral response (Paranhos Filho et al., 2016). It can also characterize the physical, chemical, and biological factors of a study area. Thus, molecules such as chlorophyll a, present in phytoplankton and in organic and inorganic material suspended in water bodies, can be measured using these images.

In this paper we use the satellite ALOS-2 AVNIR, in which the bands with higher reflection and absorption of chlorophyll a are, respectively, band 3 (red) and band 4 (near infrared). The concentration and spatial distribution can be estimated directly from the reflectance values of these bands or through vegetation indices such as NDVI (Normalized Difference Vegetation Index) (Coelho et al., 2011). Therefore, the purpose of this study is to test different analysis techniques for the following variables: chlorophyll a and total suspended solids (TSS) dissolved in the water, and verify which of these techniques is more efficient at distinguishing freshwater and saline lakes. Our results contribute to the development of a technique that will allow for effective characterization of not only the survey sites, but also all environments within Nhecolândia Pantanal.

## 2 Materials and Methods

The Nhecolândia Pantanal (Figure 1) is located between the basins of rivers Taquari and Negro, and forms the largest Pantanal sub-region, with an area of 20,210 km2, 14% of the entire region, occupying the southern half of the Taquari fluvial fan (Mioto et al., 2012). It can be divided into two compartments (Fernandes et al., 2005): the Upper and Lower Nhecolândia, where the latter is characterized by a wealth of lakes (freshwater and saline).

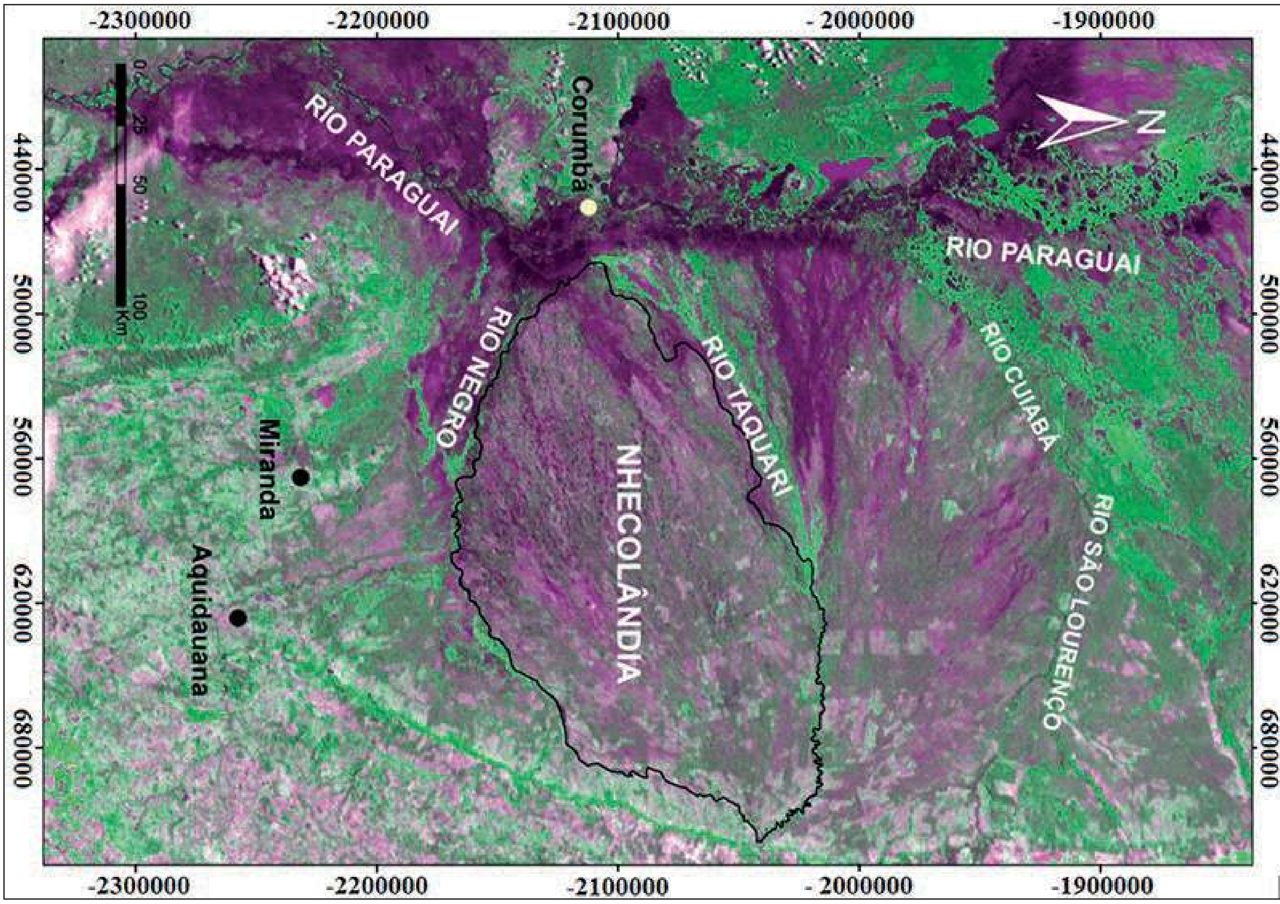


Figure 1 Location of Nhecolândia, sub region of the Pantanal and the Upper Paraguay River Basin (BAP).

Collection of water samples was performed in 32 different locations during field campaigns in August, 2012 and September, 2013, that is, the dry season of the region, which is the only time of year when access by land is possible (Figure 2), and the best time to distinguish between freshwater and saline lakes. During flood seasons, the lakes are interconnected, making it difficult to perform individual analyses of the lakes (Figure 3). Besides, there is no access by land at that time, so the field campaigns were performed during the dry season.

To differentiate freshwater and saline lakes, analytical techniques using physicochemical variables and remote sensing were tested (Table 1).

## 2.1 Chemical Analysis

A polyethylene bucket hoisted to a rope was used to collect water samples at random locations in the lakes, at a depth from the surface of approximately 40 cm. For each location, the samples were stored in two 1-liter vials made of sterile polyethylene, and then stored in an insulated box for preservation during collection.

Two analytical techniques were used to determine the level of chlorophyll a and total suspended solids (TSS). The first, based on Nusch (1980), consisted of spectrophotometry with hot extraction using 80% ethanol and subsequent thermal shock. The second, also spectrophotometric, although without chemical treatment, involved taking direct readings at wavelengths of 435 nm and 645 nm for chlorophyll a and 665 nm for TSS.

For TSS, methodology from the Standard Methods for Examination of Water and Wastewater was also applied (APHA, 2012), wherein for each sample, the volume of water was determined, and it

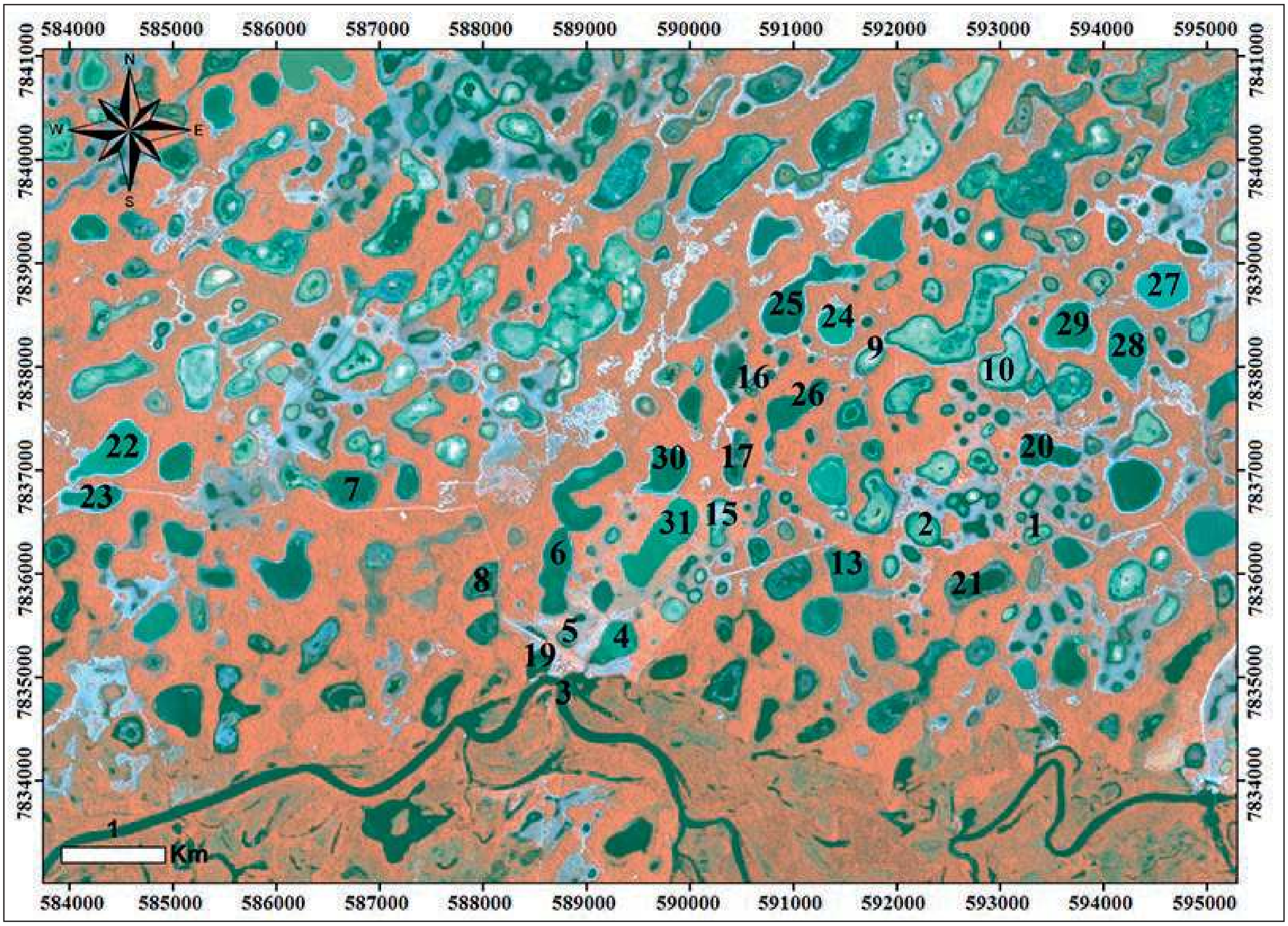


Figure 2 Location and id number of the sampled lakes in the field during 2012 and 2013. In an ALOS satellite image, AVNIR-2 sensor, the water has a blue-green color and the vegetation appears in red. In the white color are the outcrops of the sandy substrate.

was then filtered through filters previously calcinated in a muffle furnace at 460 °C for one hour and weighed (P0) on a digital scale. After the samples were filtered, they were placed in a stove at 65 °C and then kept in a desiccator. When the moisture was removed, the filters (P1) were reweighed and the new weight was subtracted from P0 to give the total suspended solids (organic and inorganic material - P2) (Equation 1):

TSS (P2) = filters with moisture (P0) - filters without moisture (P1) (1)

For more accurate results, the first stages of analysis were carried out in the field the same day that the samples were collected, at the headquarters of the farm where devices for initial analyses had been assembled. Water samples were filtered through gravimetry by vacuum onto glass fiber filters (0.45 µm) in order to determine the range of TSS and chlorophyll a. After filtration, the filters were placed in paper envelopes and stored in the dark until the time of extraction.

We carried out further spectrophotometry readings of the samples without chemical treatment, both for chlorophyll a and the TSS. The wavelengths were 435 nm and 665 nm for chlorophyll a, and 645 nm for the TSS. These wavelength values cover the range of blue and red in multispectral images. This choice was based on the fact that, within the blue range, absorption occurs by different types of chlorophyll and photosynthetic pigments; while the red range shows significant absorption by chlorophyll, commonly used to identify different types of vegetation (Paranhos Filho et al., 2016). Therefore, one can associate the identified physicochemical values with the satellite images.

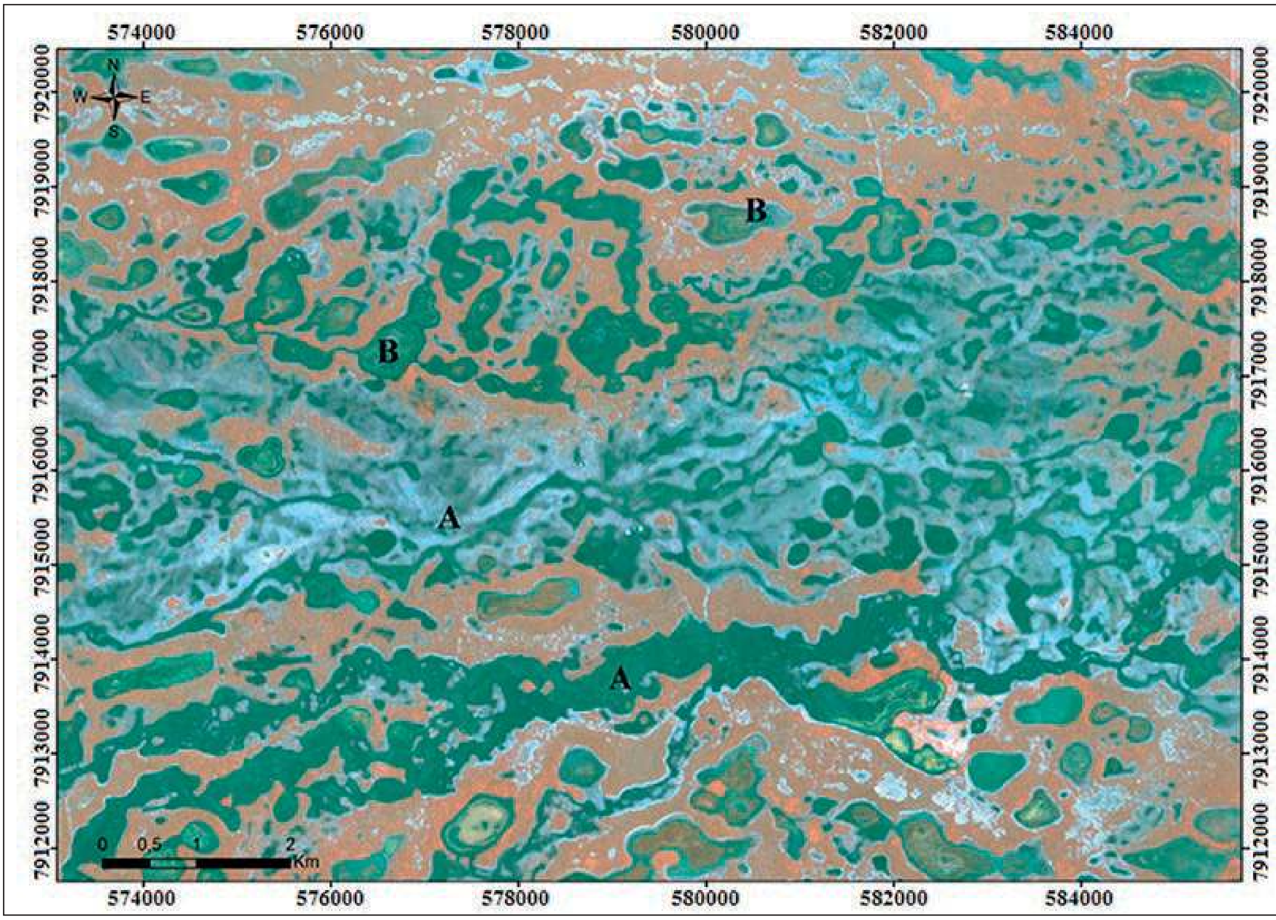


Figure 3 Image of a flooded area an AVNIR scene from february, 2 of 2011. “A” represents the ‘vazante’ (temporary streams) and “B” the ‘baia’ (fresh water lakes), where it is possible to observe connections between ‘vazantes’/’baia’ and ‘baia’/’baia’.The water has a blue-green color and the vegetation appears in shades of orange. In the white color are the outcrops of the sandy substrate.

| Analysis | Physico-Chemical | | Remote Sensing |
|---|---|---|---|
| Material | Clorofila a | Total Suspended Solids | ALOS AVNIR - 2 |
| Analytical Techniques | Nusch (1980) | Nusch (1980) | Spectral response |
| | Direct reading spectrophotometer | Direct reading spectrophotometer | Vegetation index (NDVI) |
| | | Standard Methods (APHA, 2012) | |

Table 1 Type of analysis and the applied techniques.

## 2.2 Image Processing

To analyze the lakes for their spectral response and vegetation index (NDVI), we used an image from the ALOS satellite, AVNIR2 sensor (Advanced Visible and Near Infrared Radiometer type 2), from February 2010. These images have a radiometric resolution of 8 bits per pixel and a swath width of 70 km, thus requiring only one scene to cover the study area. The satellite has a multispectral sensor with 4 spectral bands covering the region of visible colors and near infrared, with a spatial resolution of 10 m, ensuring a good visual interpretation of the sampled lakes.

The ALOS images come in CEOS format. Thus, for the extraction of bands in GeoTIFF format, it is necessary to process them in ASF MapReady 3.0.6 software (2008). After this procedure, the bands were joined in one file in QGIS 2.2.0 software (QGIS Development Team, 2014).

The next step was the atmospheric correction, using the algorithm "i.atcorr" (which "performs atmospheric correction using the 6S algorithm") of the free software GRASS GIS 6.4.3 (2013). For the atmospheric correction, a linear equation was used with offset and gain to convert the digital number for the corresponding sensor. These coefficients can change with time and geographical position, as included in the image metadata file (Richter, 2008). To execute the algorithm, it was necessary to create an input file, in .txt format, with some properties of the image, as listed in Table 2.

The parameters described herein are in the AVNIR ALOS-2 image metadata file (IBGE, 2008), linked with the help file of the algorithm, which list the options according to the chosen alternative. Band correction was performed individually, in this case for bands 3 and 4, as these were the bands used to generate the NDVI. Subsequently, the NDVI was applied, using the red and near infrared bands, and calculated according to Equation 2:

$$NDVI = \frac{(NIR-R)(NIR-R)}{(NIR+R)(NIR+R)} \quad (2)$$

where NIR = reflectance in the near infrared band and R = reflectance in the red band (Rouse et al., 1974). The red and near infrared bands correspond to bands 3 and 4 from the AVNIR ALOS-2 sensor, respectively. Thus, the equation was applied through the QGIS 2.2.0 software (QGIS Development Team, 2014) using the raster calculator, resulting in a raster file with the values of the index. As the targets of this study are the lakes, they were deleted individually from the generated file, thereby creating a raster file with the NDVI values for each lake sampled in the field.

To analyze the spectral response of the lakes from the ALOS AVNIR-2 image (IBGE, 2008), each sampled lake was cut and their frequency histograms were analyzed individually, without radiometric enhancement and maintaining the original digital number. The enhancement was in order to improve the detail view, thus aiding with interpretation (Paranhos Filho et al., 2008). For the photo-interpretation of these lakes, we opted for the false-color composition R4G2B3, which was more suitable for the distinction between freshwater and saline lakes.

### 2.3 Statistical Analysis

Statistical analysis was carried out using R 2.15.2 software (R FSC, 2012) and the sampling values of freshwater lakes and saline lakes obtained during the fieldwork in 2012 and 2013. Several tests have been determined in pursuit of a variable that could differentiate freshwater lakes from saline lakes. The Kolmogorov-Smirnov test, which determines which sample sets follow a normal distribution, was used in this study. To compare the sets of samples that had normal distributions, we applied the unpaired t-test with a Welch correction (parametric). As for those that did not follow a normal distribution, we used the Mann-Whitney-Wilcoxon test (nonparametric) for independent samples.

## 3 Results and Discussion

The analytical techniques using physicochemical parameters detected 21 freshwater lakes and 11 saline lakes, among the 32 sampled lakes (Figure 4). Individual lakes were chosen by accessibility criteria combined with available resources during the fieldwork, which resulted in a random spatial distribution according to the collection sites.

Table 3 presents the concentration results of chlorophyll a, sorting the resulting values according to the collection location. High absorbance values for chlorophyll a are observed (Nusch, 1980) (Table 4). This method determines the biomass of phytoplankton organisms, even though the concentration of this substance (chlorophyll a) may vary depending on the physiological state of the cells and the species composition, allowing for rapid and direct assessment (Santos, 2003). We notice this difference mainly in locations 1 and 17, corresponding to freshwater lakes, and locations 26 and 27, corresponding to saline lakes.

The effectiveness of the distinction between saline lakes and freshwater lakes lies in the fact that saline lakes have high phytoplankton density, since


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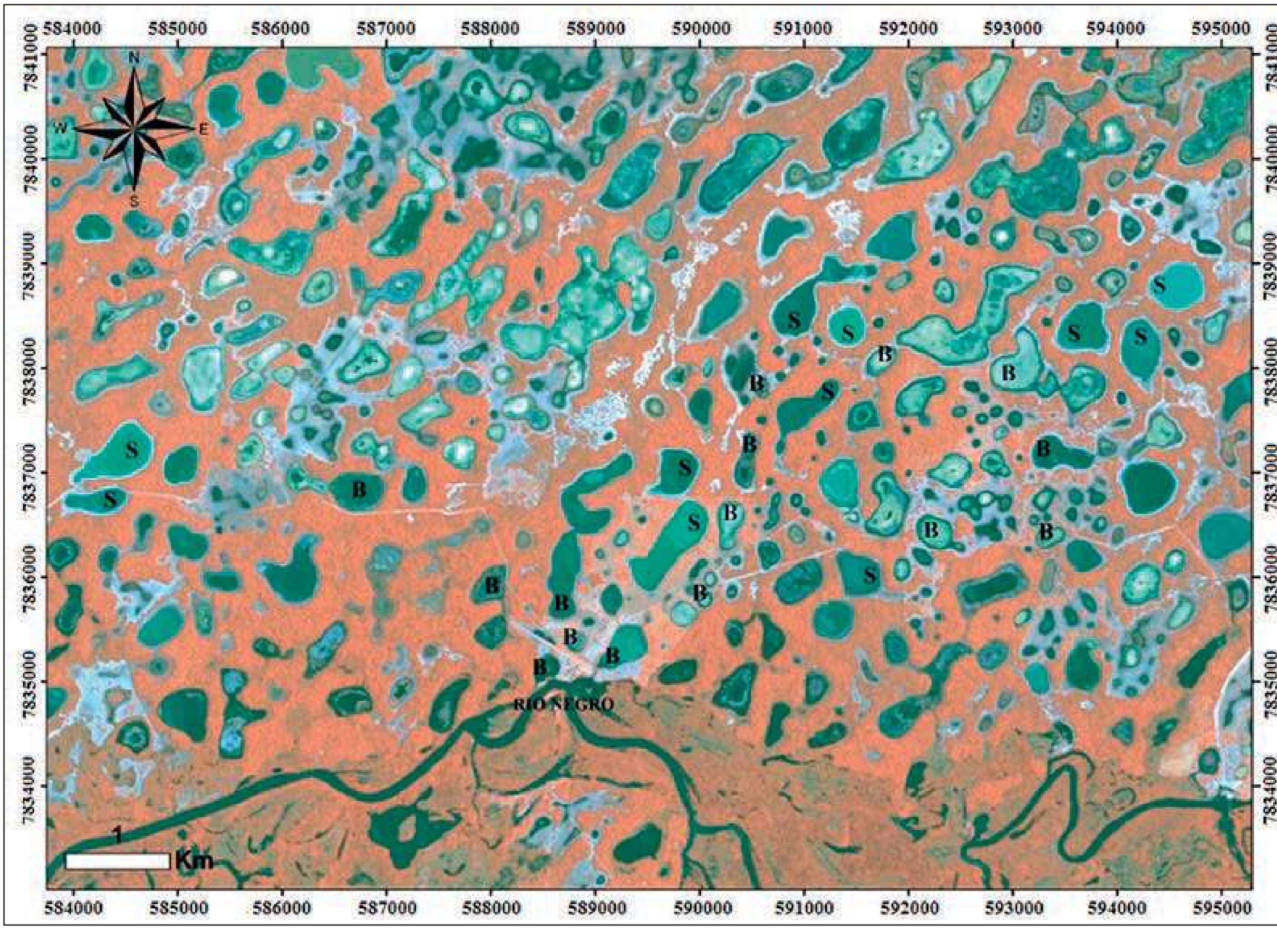


Figure 4 Sampled lakes, where B represents ‘baias’ (freshwater) and S ‘salinas’ (brackish water) in an ALOS AVNIR-2 image, false-color composite R4G2B3, February, 2 of 2010.

they have high pH and salinity, which limits the survival of macrophytes but permits a considerable variety of microscopic aquatic algae species (Santos, 2005).

The absorbance values of chlorophyll a concentration in wavelengths of 435 nm and 665 nm (Table 4) for samples collected in 2013 are also very significant. The direct reading on the spectrophotometer, without chemical treatment, allows for the identification of freshwater and saline lakes, indicating that there is no need for analysis less than 24 hours after collection, since samples kept for days under refrigeration are sufficient for determining the type of lake.

The fact that the direct reading at wavelengths of 435 nm and 665 nm is very significant is due to the fact that all absorptions of solar radiation that reach a water body are assigned to four components of the aquatic medium: the water itself, dissolved compounds, photosynthetic biota (phytoplankton and macrophytes), and particulate matter (organic and inorganic fractions, Kirk, 1980). It is also noteworthy that the absorption peak of chlorophyll a is located in the wavelengths of 435 nm and 665 nm (Blackmer et al., 1996).

The effectiveness of chlorophyll absorption depends on its concentration, shape, size, and stage of the cells or colonies (Esteves, 1998). Based on this principle, the variable absorption/concentration of chlorophyll a is significant for distinguishing lakes, probably due to the relationship between the biota and the environment. In the Nhecolândia region this process is very common in both saline and freshwater lakes, with different stages of eutrophication taking

| Parameter | | CHLOROPHYLL 2012 | | | | | | CHLOROPHYLL 2013 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ABSORBANCE | | | TRANSMITTANCE | | | ABSORBANCE | | |
| Technique | | Nusch (1980) | Spectrum | | Nusch (1980) | Spectrum | | Nusch (1980) | Spectrum | |
| Locations | | Chlorophyll a mg/L | 435 nm | 665 nm | Chlorophyll a mg/L | 435 nm | 665 nm | Chlorophyll a mg/L | 435 nm | 665 nm |
| 1 | B | 7,69 | 0,07 | 0,037 | 7,696 | 9,319 | 9,635 | 20,128 | 0,066 | 0,059 |
| 2 | B | 0 | 0,074 | 0,029 | 0,000 | X | X | -65,12 | 0,084 | 0,046 |
| 3 | R | X | X | X | X | X | X | 5,92 | 0,045 | 0,042 |
| 4 | B | X | X | X | X | X | X | 0 | 0,109 | 0,058 |
| 5 | B | X | X | X | X | X | X | 11,84 | 0,12 | 0,051 |
| 6 | B | X | X | X | X | X | X | 3,55 | 0,10 | 0,047 |
| 7 | B | X | X | X | X | X | X | 2,36 | 0,099 | 0,050 |
| 8 | B | 0 | 0,069 | 0,040 | 0,000 | X | X | -2,36 | 0,067 | 0,046 |
| 9 | B | X | X | X | X | X | X | 0 | 0,078 | 0,047 |
| 10 | B | 20,01 | 0,057 | 0,036 | 20,010 | 9,437 | 9,640 | 4,93 | 0,066 | 0,045 |
| 11 | B | 0,0 | 0,033 | 0,042 | 0,000 | X | X | 8,88 | 0,10 | 0,060 |
| 12 | B | X | X | X | X | X | X | 5,92 | 0,091 | 0,053 |
| 13 | B | X | X | X | X | X | X | 5,92 | 0,106 | 0,078 |
| 14 | B | 21,54 | 0,073 | 0,043 | 21,540 | 9,290 | 9,576 | 68,08 | 0,089 | 0,064 |
| 15 | B | 16,93 | 0,116 | 0,066 | 16,930 | 8,902 | 9,361 | 0 | 0,105 | 0,065 |
| 16 | B | X | X | X | X | X | X | 1,18 | 0,122 | 0,052 |
| 17 | B | 35,45 | 0,081 | 0,034 | 35,450 | 9,213 | 9,658 | 56,24 | 0,093 | 0,050 |
| 18 | B | X | X | X | X | X | X | X | X | X |
| 19 | B | X | X | X | X | X | X | X | X | X |
| 20 | B | X | X | X | X | X | X | X | X | X |
| 21 | B | X | X | X | X | X | X | 0 | 0,136 | 0,078 |
| 22 | S | 38,480 | 0,054 | 0,038 | 38,480 | 9,479 | 9,631 | 0 | 0,066 | 0,053 |
| 23 | S | 13,850 | 0,064 | 0,045 | 13,850 | 9,380 | 9,562 | -2,277 | 0,136 | 0,079 |
| 24 | S | X | X | X | X | X | X | 14,800 | 0,433 | 0,162 |
| 25 | S | 58,490 | 1,509 | 0,830 | 58,490 | 2,212 | 4,362 | 0 | 1,174 | 0,656 |
| 26 | S | 3,078 | 0,137 | 0,079 | 3,078 | 8,723 | 9,242 | 148,000 | 0,113 | 0,071 |
| 27 | S | 129,300 | 0,136 | 0,073 | 129,300 | 8,728 | 9,295 | 167,733 | 0,161 | 0,073 |
| 28 | S | X | X | X | X | X | X | 47,360 | 0,390 | 0,148 |
| 29 | S | 0 | 0,631 | 0,234 | 0,000 | X | X | 35,520 | 0,123 | 0,061 |
| 30 | S | X | X | X | X | X | X | 438,080 | 2,155 | 0,717 |
| 31 | S | 76,960 | 0,047 | 0,033 | 76,960 | 9,539 | 9,676 | 0 | 0,000 | 0,000 |
| 32 | S | 13,850 | 0,055 | 0,044 | 13,850 | 9,469 | 9,567 | 17,760 | 0,082 | 0,058 |

Table 3 Absorbance values and transmittance of the concentration of chlorophyll a, obtained by different analytical techniques.B represents 'baias' (freshwater); S - 'salinas' (brackish water); R - Negro River; 0 - underscale value.

place and with an immense diversity of species of algae and macrophytes.

However, the transmittance of the concentration of chlorophyll a (mg/L) from the 2012 field campaign does not correspond to a variable of differentiation, as its values are not significant.

TSS values from the 2012 and 2013 field campaigns are shown in Table 5. The statistical analysis, displaying analytical techniques proposed by Nusch (1980) and by the Standard Methods for Examination of Water and Wastewater (APHA, 2012) for distinguishing freshwater lakes from saline lakes, is shown in Table 6.

Unfortunately, the direct reading from the spectrophotometer was not effective at identifying the type of lake, indicating that traditional methods are preferable.

According to the study of Medina Jr. and Rieltzer (2005) in a saline lake from the Nhecolândia Pantanal, the concentrations of solids in suspension, nutrients, chlorophyll a, and pheophytin are directly related to

| Parameter | CHLOROPHYLL 2012 | | | | | | CHLOROPHYLL 2013 | | |
|---|---|---|---|---|---|---|---|---|---|
| | ABSORBANCE | | | TRANSMITTANCE | | | ABSORBANCE | | |
| Analytical Techniques | Nusch (1980) | Spectrum | | Nusch (1980) | Spectrum | | Nusch (1980) | Spectrum | |
| | mg/L | 435nm | 665nm | mg/L | 435nm | 665nm | mg/L | 435nm | 665nm |
| Average Baías | 16,544 | 0,07095 | 0,04232 | 16,544 | 9,237 | 9,553 | 5,480 | 0,09115 | 0,05445 |
| Average Salinas | 47,715 | 0,32890 | 0,1719 | 47,715 | 8,218 | 8,762 | 108,37 | 0,4834 | 0,2077 |
| Median Baías | 18,470 | 0,07058 | 0,04096 | 18,470 | 9,304 | 9,605 | 5,920 | 0,09557 | 0,05159 |
| Median Salinas | 38,480 | 0,10000 | 0,05897 | 38,480 | 9,380 | 9,562 | 41,440 | 0,1486 | 0,07573 |
| Standard Deviation Baías | 6,202 | 0,02459 | 0,01151 | 6,202 | 0,2321 | 0,1311 | 27,785 | 0,02164 | 0,009678 |
| Standard Deviation Salinas | 44,719 | 0,51520 | 0,2738 | 44,719 | 2,672 | 1,947 | 147,38 | 0,6757 | 0,2553 |
| Standard Error Baías | 3,101 | 0,009293 | 0,004351 | 3,101 | 0,1161 | 0,06557 | 7,706 | 0,005410 | 0,002419 |
| Standard Error Salinas | 16,902 | 0,1821 | 0,09680 | 16,902 | 1,010 | 0,7361 | 52,106 | 0,2137 | 0,08074 |
| Test | MWW | MWW | MWW | MWW | MWW | MWW | MWW | MWW | MWW |
| P | 0,5273 | 0,6126 | 0,0721 | 0,5273 | 0,9273 | 0,3152 | 0,0099 | 0,0050 | 0,0012 |
| Difference between Baía e Salina. | NS | | NMS | NS | NS | NS | MS | MS | MS |

Table 4 Result of the statistical analysis of the values of the chlorophyll a concentration in the different analytical techniques. MWW: Mann-Whitney-Wilcoxon Test (no normal distribution samples). TnpW: t Test no binded with Welch correlation (normal distribution samples).

| Material | | MST 2012 | | | MST 2013 |
|---|---|---|---|---|---|
| | | ABSORBANCE | | TRANSMITTANCE | ABSORBÂNCIA |
| Method | | Nusch (1980) | Spectrum | | APHA (2012) |
| Location | | MST mg/L | 435 nm | 645 nm | MST mg/L |
| 1 | B | 0 | 0,039 | 9,622 | mg/L |
| 2 | B | 0 | 0,030 | 9,703 | 0,001 |
| 3 | R | X | X | X | 0 |
| 4 | B | X | X | X | 0 |
| 5 | B | X | X | X | 0,006 |
| 6 | B | X | X | X | 0,001 |
| 7 | B | X | X | X | 0,001 |
| 8 | B | 0 | 0,042 | 9,585 | 0,004 |
| 9 | B | X | X | X | 0,003 |
| 10 | B | 0 | 0,037 | 9,635 | 0,003 |
| 11 | B | 0 | 0,039 | 9,617 | 0,002 |
| 12 | B | X | X | X | 0 |
| 13 | B | X | X | X | 0,001 |
| 14 | B | 0 | 0,045 | 9,562 | 0,003 |
| 15 | B | 0,003 | 0,069 | 9,333 | 0 |
| 16 | B | X | X | X | 0 |
| 17 | B | 0,003 | 0,069 | 9,975 | 0,004 |
| 18 | B | X | X | X | X |
| 19 | B | X | X | X | X |
| 20 | B | X | X | X | X |
| 21 | B | X | X | X | X |
| 22 | S | 0,006 | 0,040 | 9,603 | 0,001 |
| 23 | S | 0,006 | 0,047 | 9,544 | 0,005 |
| 24 | S | X | X | X | 0,001 |
| 25 | S | X | X | X | 0,014 |
| 26 | S | 0,016 | 0,081 | 9,223 | 0,001 |
| 27 | S | 0,006 | 0,075 | 9,938 | 0,011 |
| 28 | S | X | X | X | 0,002 |
| 29 | S | X | X | X | 0,013 |
| 30 | S | X | X | X | 0,021 |
| 31 | S | 0,002 | 0,034 | 9,984 | X |
| 32 | S | 0,003 | 0,047 | 9,544 | 0,004 |

Table 5 Total suspended solids (MTC) in water obtained by three different methods of physico-chemical analysis. B represents ‘baias’ (freshwater); S - ‘salinas’ (brackish water); R - Negro River; 0 - underscale value.

| Material | MST (2012) | | | MST (2013) |
|---|---|---|---|---|
| | ABSORBANCE | | TRANSMITTANCE | ABSORBANCE |
| Técnica Analítica | Nusch (1990) | Spectrum | | APHA (2012) |
| | mg/L | 645 m | 645 m | mg/L |
| Average Baías | 0,0004429 | 0,0432 | 9,580 | 0,0006571 |
| Average Salinas | 0,006450 | 0,05398 | 9,639 | 0,007200 |
| Median Baías | 0,0001 | 0,03905 | 9,617 | 0,0007000 |
| Median Salinas | 0,006150 | 0,04672 | 9,573 | 0,004350 |
| Standard Deviation Baías | 0,0009071 | 0,01237 | 0,1175 | 0,002624 |
| Standard Deviation Salinas | 0,005110 | 0,01933 | 0,2833 | 0,007163 |
| Standard Error Baías | 0,0003429 | 0,004674 | 0,04440 | 0,0007012 |
| Standard Error Salinas | 0,002086 | 0,007892 | 0,1157 | 0,002265 |
| Test | MWW | TnpW | MWW | TnpW |
| P | 0,0066 | 0,2662 | 0,8357 | 0,0107 |
| Difference between Baía e Salina. | MS | NS | NS | S |

Table 6 Results of the statistical analysis from the concentration values of the dissolved suspended material in water, from the field surveys made in 2012 and 2013. MWW: Mann-Whitney-Wilcoxon Test (no normal distribution samples). TnpW: t Test no binded with Welch correlation (normal distribution samples).

the hydrological regime, with values almost always higher during the dry season. The suspended material is mostly organic, corresponding to more than 90% in both periods. Several genera of planktonic algae in saline lakes are also related to the regional water dynamics (Malone et al., 2007).

Some genera of algae, such as Anabaenopsis sp., may be useful as potential indicators of saline lakes in the Nhecolândia Pantanal (Santos, 2005). Thus, the presence of chlorophyll a and suspended material is probably due to the presence of these chlorophyll organisms in the water and of organic matter originating from their decomposition during the dry season.

Regarding the data obtained by remote sensing, the atmospheric correction technique using model 6S contributed to the removal of turbidity and more precise reason adjacency effects in the case of clouds (Richter, 2008).

The NDVI results of the sampled lakes are shown in Table 7, which lists the minimum, maximum, and average values for each lake. The NDVI is scaled to 0-255 (8 bits), which means that the image has different shades of gray, ranging from -1 to +1. Higher values (lighter gray) are linked to photosynthetically active vegetation and lower values (darker shades) represent areas with less vegetation (Ponzoni and Shimabukuro, 2010) (Figure 5). According to Coelho et al. (2011) this index has a high correlation to chlorophyll a concentration because of its spectral characteristics that absorb light in the red region and reflect light in the green region.

NDVI data from the lakes are extremely significant, as shown in Figure 5 and Table 8, and therefore the best variable for differentiation of water bodies. It is important to stress that it was possible to analyze an entire scene, which demonstrates high applicability of this tool for monitoring aqueous bodies, saving time and financial resources in terms of excessive field activities. The macrophyte and phytoplankton communities have a large influence on this result.

Water bodies containing macrophytes have a lighter shade, which indicates a high vegetal density of the surface. Conversely, saline lakes have a darker and more homogeneous color, since they have no macrophytes on the surface, but a large amount of phytoplankton. This community can also produce a large quantity of chlorophyll a, since they are dissolved in the water at various depth levels. Therefore, surface vegetation values differ.

Remote sensing provides two independent groups of information: spectral responses of the lakes, indirectly associated with alkalinity/salinity and the

| Remote Sensing | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NDVI ALOS AVNIR2 | | | | | | | | | |
| Location | | Min | Max | Average | Location | | Min | Max | Average |
| 1 | B | -0,595 | 0,527 | -0,358 | 18 | B | -0,200 | 0,257 | 0,056 |
| 2 | B | -0,299 | 0,405 | 0,126 | 19 | B | -0,136 | 0,546 | 0,105 |
| 3 | B | -0,564 | 0,555 | -0,387 | 20 | B | -0,589 | 0,340 | -0,208 |
| 4 | B | -0,092 | 0,355 | 0,122 | 21 | B | -0,477 | 0,384 | -0,060 |
| 5 | B | -0,239 | 0,374 | 0,105 | 22 | S | -0,622 | 0,509 | -0,464 |
| 6 | B | -0,375 | 0,303 | 0,022 | 23 | S | -0,575 | 0,280 | -0,431 |
| 7 | B | -0,158 | 0,240 | 0,083 | 24 | S | -0,470 | 0,347 | -0,293 |
| 8 | B | -0,167 | 0,307 | 0,118 | 25 | S | -0,431 | 0,015 | -0,351 |
| 9 | B | -0,300 | 0,492 | 0,047 | 26 | S | -0,564 | 0,555 | -0,367 |
| 10 | B | -0,222 | 0,363 | 0,056 | 27 | S | -0,434 | 0,266 | -0,347 |
| 11 | B | -0,564 | 0,546 | 0,297 | 28 | S | -0,519 | 0,189 | -0,405 |
| 12 | B | -0,500 | 0,564 | 0,009 | 29 | S | -0,550 | 0,139 | -0,444 |
| 13 | B | -0,437 | 0,290 | -0,200 | 30 | S | -0,328 | 0,507 | -0,249 |
| 14 | B | -0,556 | 0,451 | -0,364 | 31 | S | -0,546 | 0,277 | -0,391 |
| 15 | B | -0,588 | 0,391 | -0,362 | 32 | S | -0,604 | 0,080 | -0,483 |
| 16 | B | -0,528 | 0,188 | -0,362 | | | | | |
| 17 | B | -0,437 | 0,585 | -0,073 | | | | | |

Table 7 NDVI values for each sampled point.B represents 'baias' (freshwater); S - 'salinas' (brackish water).

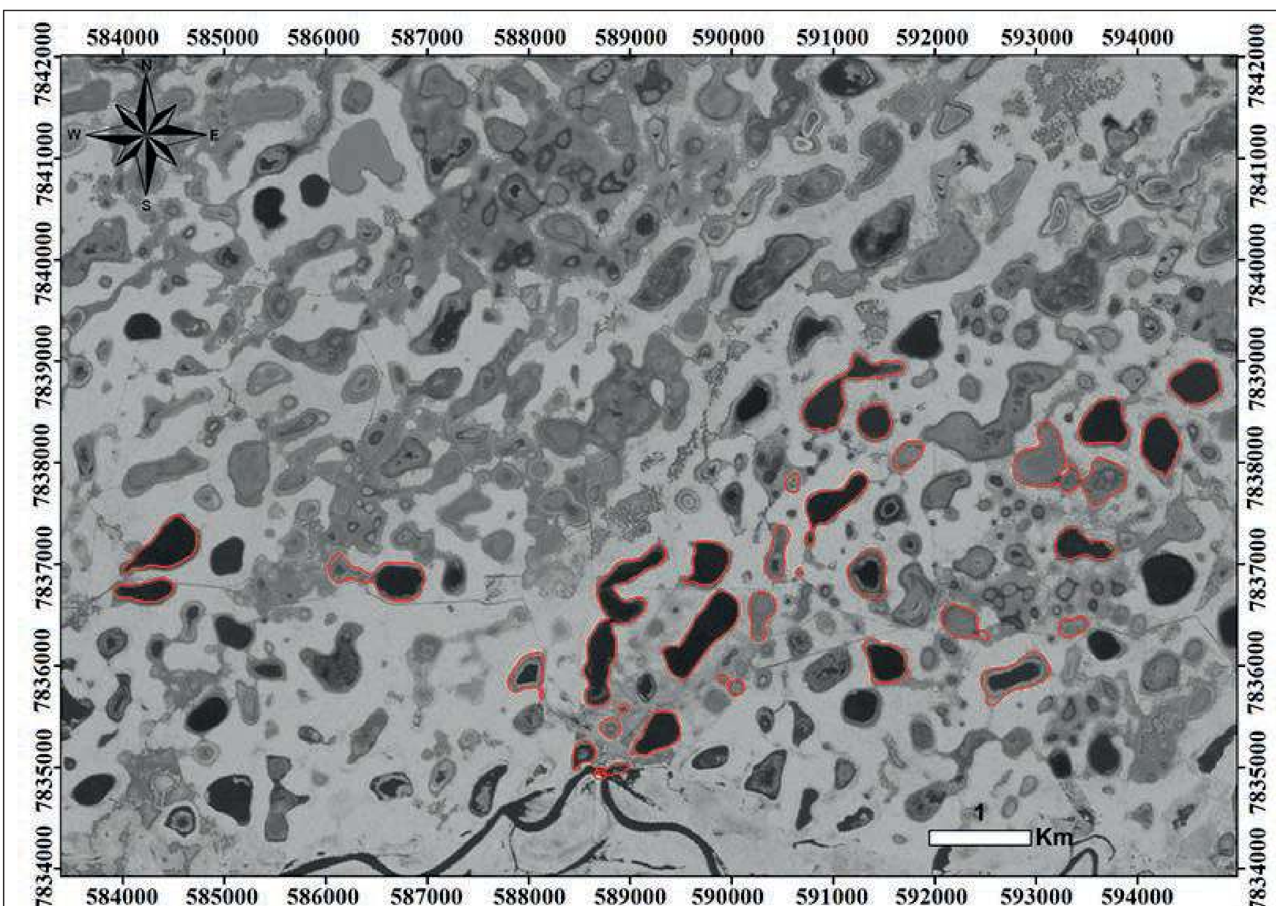


Figure 5 NDVI from ALOS AVNIR-2 scene, highlighting the lakes sampled in the campaigns of 2012 and 2013. The areas with black color has the value 0 (zero) and the white ones are 255 (8 bit amplitude).

| Remote Sensing | |
|---|---|
| | NDVI |
| Average 'Baías' | -0,05770 |
| Average 'Salinas' | -0,3841 |
| Median 'Baías' | 0,03415 |
| Median 'Salinas' | -0,3915 |
| Standard Deviation 'Baías' | 0,2132 |
| Standard Deviation 'Salinas' | 0,07188 |
| Standard Error 'Baías' | 0,04767 |
| Standard Error 'Salinas' | 0,02167 |
| Test | MWW |
| P | <0,0001 |
| Difference Between B. e S. | ES |

Table 8 Results of statistical analysis with the NDVI values. MWW: Mann-Whitney-Wilcoxon Test (no normal distribution samples). TnpW: t Test no binded with Welch correlation (normal distribution samples). NS: no significant. S: significant. MS: very significant. ES: extremely significant.

direct, spatial relationship of the mountain ranges with the lakes and permanent streams or corixos (Almeida et al., 2003). However, we note that application of the NDVI allows for the identification of different shades in the lakes, wherein the lighter the lake, the greater the density of vegetation on its surface. This may be related to the concentration of chlorophyll a, a key variable for the biotic activity of a lentic environment.

Figure 6 displays field photographs illustrating some of the water collection locations. Note the difference between freshwater and marine lakes. In the same figure is presented how these lakes appear on the NDVI index raster file and also in the ALOS satellite, AVNIR-2 sensor image (IBGE, 2008) in false-color RGB composition 423, which displays the vegetation in red. In the NDVI file, we observe

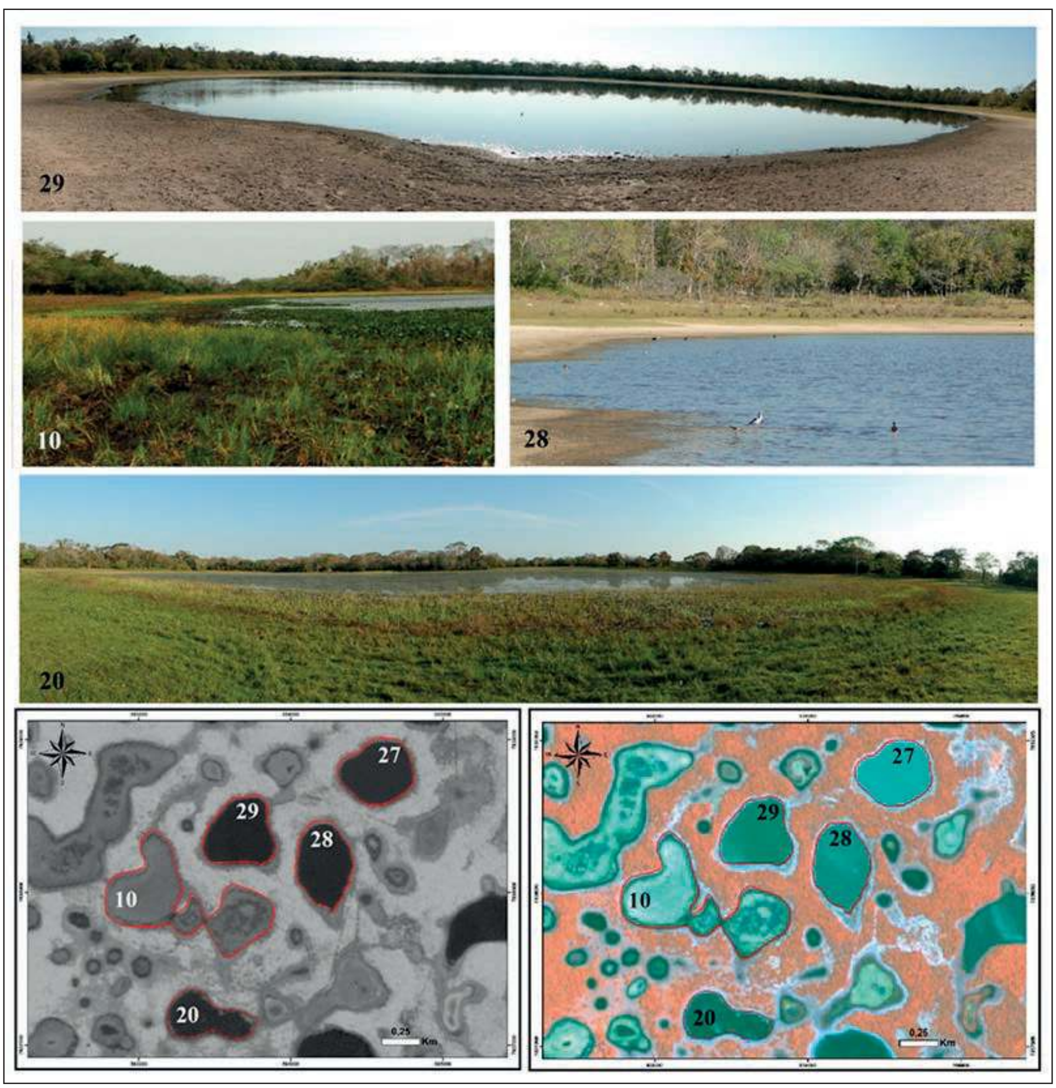


Figure 6 Field photographs and ALOS AVNIR-2 scene (NDVI, on left, and false-color composite R4G2B3, on right) illustrating the collection points 10, 20, 28 and 29. The points 10 and 20 demonstrate 'baias' (freshwater lakes) with different types of vegetation on the surface and edge. The points 27, 28 and 29 show a saline lake without macrophytes and no vegetation on the beach.


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the surrounding vegetation in a light gray color. For example, freshwater lake location 10 has a light gray color, with darker shades in some areas. The reason for this variation is the surface vegetation.

This is more evident in the satellite image due to the spectral response of this vegetation. It is easy to determine the distribution of this vegetation in the freshwater lake area, since it is floating and not rooted in the sediment (Figure 6). One exception is location 20, which corresponds to a freshwater lake, yet the NDVI shows a darker shade (Figure 6 right). This might be explained by the occurrence of macrophytes, which are submerged with floating leaves in this bay, that is, rooted in the sediment and with leaves floating on the water surface.

It is important to note the dynamic nature of aquatic vegetation, i.e., the variation in the amount of certain species from one year to the next, which is influenced by conditions of flood and drought, whose intensities vary significantly in the Pantanal (Pott and Pott, 2000). This explains the difference in the types of species, as some lakes are permanent and others dry out for an amount of time in the dry season.

When exploring the saline lakes using the NDVI, their black color is evident (locations 27, 28, and 29 in Figure 6). Such a color is attributed to a low concentration of chlorophyll a dissolved in the water, which can be associated with physical and chemical parameters. Since the saline lakes have high salinity, alkalinity, and pH, the survival of aquatic biota is restricted. Given the fact that chlorophyll a is a determining factor in phytoplankton biomass, it is interesting that saline lakes have such a low concentration, despite an abundance of phytoplankton.

It is possible to clarify this by correlating the availability of nutrients and chlorophyll a, since higher levels of nitrates + nitrites, phosphates, and ammonia correspond to lower chlorophyll a values (Franco, 2007). However, this should be restricted to the absence of emerged vegetation, which can be seen in Figure 6 at locations 28 and 29.

Another interesting result is the spectral analysis of ALOS AVNIR-2 images by means of frequency histograms (Figure 7) without radiometric enhancement. The AVNIR ALOS-2 image (IBGE, 2008) in false-color R4G2B3 can be used to highlight the saline lakes. The individual saline lake histogram is well defined, that is, the frequency of the RGB channels that make it up are concentrated around a narrow range of pixel shades, unlike the histogram of the freshwater lake (Figure 8), where the spectrum is quite varied, with no clear pattern.

Galvão et al. (2003) used AVIRIS hyperspectral images to demonstrate that there is great variability

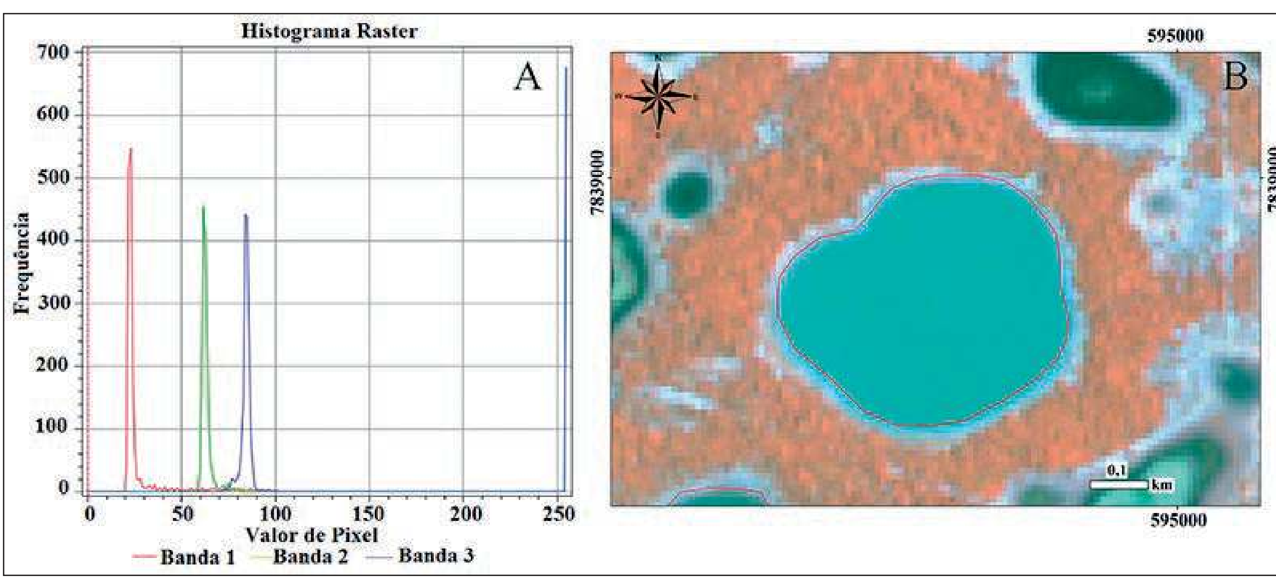


Figure 7 Frequency histogram (A) of the ALOS AVNIR-2 image, false-color composite R1G2B3 (B) without stretching, representing a 'salina' (brackish water lake). And in the right side, the same lake in false-color composite R4G2B3, with stretching.

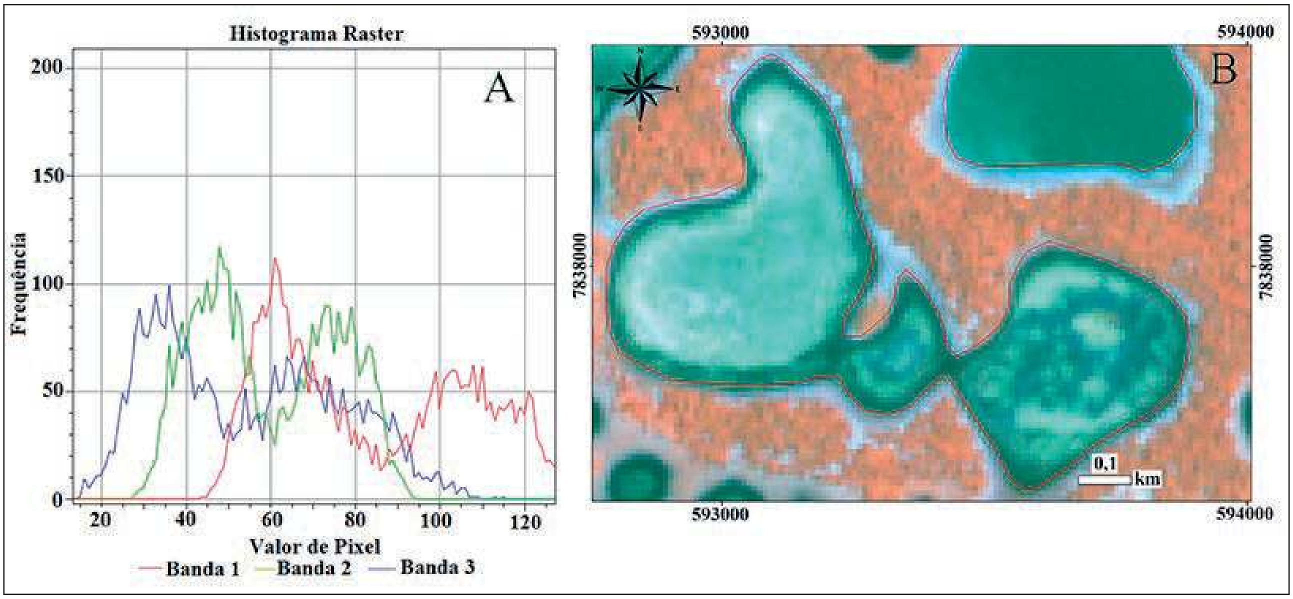


Figure 8 Frequency histogram (A) of the ALOS AVNIR-2 image, false-color composite R1G2B3 (B) without stretching, representing a 'baias' (freshwater lake). And in the right side, the same lake in false-color composite R4G2B3, with stretching.

in the spectral responses of lakes due to the ratio between reflectance and optically active constituents of the water. The multispectral sensor for photo-interpretation of the freshwater and marine lakes requires a combination of bands that best favors the user, based on characteristics such as homogeneity, greenish, yellow, or bluish color, and the presence of a beach, in order to recognize a saline lake.

With the histogram analysis, the ability to spectrally differentiate freshwater and marine lakes can go beyond the photo-interpretation, therefore providing another useful tool to support the analysis of lakes by remote sensing, and expanding the possibilities for a better understanding of the Nhecolândia Pantanal.

## 4 Conclusion

The use of physical and chemical parameters has allowed the differentiation of freshwater and saline lakes in the Nhecolândia Pantanal. However, remote sensing data have shown the potential for distinguishing all the lakes on a regional scale due to the fact that, although physical-chemical methods are satisfactory, the Nhecolândia has more than 20,000 lakes. Furthermore, poor access and the high cost of fieldwork make it difficult to collect samples, and the Pantanal is governed by a regime of floods and droughts, making studies unviable at certain times of the year.

Therefore, this study proves the effectiveness of satellite images for the simple assessment of large areas at low cost, by delivering results as accurate as those of physical and chemical analyses. Thus, it demonstrates the capability of remote sensing for monitoring and identification of aqueous bodies.

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## 6 References

Almeida, T.I.R.; Sígolo, J.B.; Fernandes, E.; Queiroz Neto, J.P.; Barbiero, L. & Sakamoto, A.Y. 2003. Proposta de classificação das lagoas da Baixa Nhecolândia-MS com base em sensoriamento remoto e dados de campo. *Revista Brasileira de Geociências, 33*(2): 83-90.

Almeida, T.I.R.; Paranhos Filho, A.C. & Bertolo, R.A. 2010. Os Diferentes Graus de Isolamento da Água Subterrânea como Origem de sua Variabilidade: Evidências Isotópicas, Hidroquímicas e da Variação Sazonal do Nível da Água no Pantanal da Nhecolândia. *Revista do Instituto de Geociências - USP. Geologia USP, Série Científica, 10*(3): 37-47.

APHA. American Public Health Association. 2012. *Standard Methods for the Examination of Water and Wastewater*. Washington, American Public Health Association, 21 th Ed.

ASF Software. 2008. ASF Map Ready, Remote Sensing Toolkit ver. 2.1.9 (8468). Fairbanks/AK: University of Alaska Fairbanks, Alaska Satellite Facility.

Blackmer, T.M.; Schepers, J.S.; Varvel, G.E. & Walter-Shea, E.A. 1996. Nitrogen deficiency detection using shortwave. radiation from irrigated corn canopies. *Agronomy, 88*(1): 1-5.

Brasil. 1988. *Constituição da República Federativa do Brasil*. Diário Oficial da União, Poder Legislativo, Brasília, Distrito Federal, 5 jan. 1988.

Coelho, L.S.; Roche, K.F; Paranhos Filho, A.C. & Lemos, V.B. 2011. Uso de sensor CBERS/CCD na avaliação do estado trófico do reservatório do Lago do Amor (Campo Grande, MS). *Revista Brasileira de Cartografia, 63*(2): 221-232.

Esteves, F.A. (1998). Fundamentos de limnologia. 2. Ed. Rio de Janeiro: Interciência.

Fernandes, E.; Sigolo, J.B; Almeida, T.I.R; Capellari, B.; Melero, M.G. & Queiroz Neto, J.P. 2005. Identification et organisation spatial edesmilieux hydriques acides et. calins et leurs rapports avecles forms dureli ef dansle Pantanal de Nhecolândia (Brésil). *In:* INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY, 6 th, Zaragoza, 2005, p.123.

Franco, V.P.C. 2007. *Produtividade Primária da Zona Costeira Adjacente aos Estuários do Tejo e Sado*. Programa de Mestrado em Biologia e Gestão de Recursos Marinhos, Departamento de Biologia Vegetal, Universidade de Lisboa, Dissertação de Mestrado, 98p.

Galvão, L.S.; Pereira Filho, W.; Abdon, M.M.; Novo, E.M.L. M.; Silva, J.S.V. & Ponzoni, F.J. 2003. Spectral reflectance characterization of shallow lakes from the Brazilian Pantanal wetlands with field and airborne hyperspectral data. *International Journal of Remote Sensing, 24*(21): 4093-4112.

GRASS Development Team. 2013. Geographic Resources Analysis Support System, Software, Version 6.4.3. Open Source Geospatial Foundation, 2013. Disponível em: <http://grass.osgeo.org>. Acesso em: 10 de Abril de 2014.

IBGE. Instituto Brasileiro de Geografia e Estatística em parceria com ASF/AADN - Alaska Satellite Facility. 2008. Imagem de Satélite. ALOS (Advanced Land Observing Satellite) AVNIR-2 (Advanced Visible and Near Infrared Radiometer type 2) - JAXA Japan Aerospace Exploration Agency. Canais 1, 2, 3 e 4. Órbita 1086. CD-ROM. De 4 de fevereiro de 2008.

IBGE. Instituto Brasileiro de Geografia e Estatística em parceria com ASF/AADN - Alaska Satellite Facility. 2011. Imagem de Satélite. ALOS (Advanced Land Observing Satellite) AVNIR-2 (Advanced Visible and Near Infrared Radiometer type 2) - JAXA Japan Aerospace Exploration Agency. Canais 1, 2, 3 e 4. Órbita 1086. CD-ROM. De 2 de fevereiro de 2011.

Kirk, J.T.O. 1980. Spectral Adsorption properties of natural water: Contribution of Soluble and Particulate fractions to light absorption in some inland waters of South-eastern Australia. *Marine and Freshwater Research, 31*(3): 287-296.

Malone, C.F.S.; Santos, K.R.S.; Neto, M.J. & Sakamoto, A.Y. 2007. Gêneros de Algas no Plâncton de Lagoas Salinas Situadas na Fazenda Nhumirim, Pantanal da Nhecolândia, MS. *Revista Brasileira de Biociências, 5*(2): 588-590.

Medina-Júnior, P.B. & Rietzler, A.C. 2005 Limnological study of a Pantanal saline lake. Brazil Journal. *Biology, 65*(4): 651-659.

Mioto, C.L.; Paranhos Filho, A.C. & Albrez, E.A. 2012. Contribuição à caracterização das sub-regiões do Pantanal. *Revista Entre-Lugar, 3*(6): 165-180.

Nush, E.A. 1980. Comparison of different methods for chlorophyll and phaeopigments determination. *Arch. Hydribiol. Beih.*, *14*: 14-36.

Paranhos Filho, A.C.; Mioto, C.L.; Marcato Junior, J. & Torres, T.G. 2016. *Geotecnologias em Aplicações Ambientais*. Campo Grande, Editora UFMS. 398p.

Ponzoni, F.J & Shimabukuro, Y.E. 2010. *Sensoriamento Remoto no Estudo da Vegetação*. São José dos Campos, SP: A. Silvia Viera Ed.

Pott, V.J. & Pott, A. 2000. Macrófitas Aquáticas do Pantanal. Embrapa, Centro de Pesquisa Agropecuária do Pantanal, Corumbá, MS. Brasília: Embrapa Comunicação para Transferência de Tecnologia, 404p.

QGIS Development Team. 2014. Quantum GIS Geographic Information System, Version 2.2.0. Open Source Geospatial Foundation. Disponível em: <http://qgis.osgeo.org>. Acesso em: 10 abr. 2014.

R Foundation for Statical Computing. 2012. R 2.15.2 (2012.10.26). Disponível em: < http://www.r-project.org/>. Acesso em: 5 dez. 2012.

Richter, R. 2008. Classification Metrics for Improved Atmospheric Correction of Multispectral VNIR Imagery. *Sensors, 8*(11): 6999-7011.

Rouse, J.W.; Hass, R.H.; Deering, D.W. & Schell, J.A. 1974. Monitoring the vernal advancement and retrogradiation (green wave effect) of natural vegetation. Texas, 120p. Disponível em: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19730017588_1973017588.pdf. Acesso em: 5 abr. 2014.

Santos, A.C.A.; Calijuri, M.C.; Moraes, E. M.; Adorno, M.A.T.; Falco, P.B., Carvalho, D.P.; Debert, G.L.B. & Benasi, S.F. 2003. Comparison of three methods for Chlorophyll determination: Spectrophotometry and Fluorometry in samples containing pigment mixture ans spectrophotometry in samples with separate pigments through High Performance Liquid Chromatography. *Acta Limnol. Bras., 15*(3): 7-18.

Santos, K.R.S. 2005. Gêneros de algas de seis lagoas (quatro salinas, uma salitrada e uma baía) do Pantanal da Nhecolândia, MS, Brasil. Curso de Ciências Biológicas, Universidade Federal de Mato Grosso do Sul, Monografia.

Toledo Jr., A.P.; Talarico, M. & Chinez, S.J. 1983. A aplicação de modelos simplificados para a avaliação de processo de eutrofização em lagos e reservatórios tropicais. *In:* CONGRESSO BRASILEIRO DE ENGENHARIA SANITÁRIA, 12, Camboriú, 1983. Associação Brasileira de Engenharia Sanitária, *Anais*, Camboriú, 34p.