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Identification and mapping by remote sensing of native forests of the Atlantic Forest Biome in Rio Grande do Sul, Brazil

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Abstract. Management initiatives aiming on the conservation of tropical rain forest in southeastern Brazil ask for mapping and long term monitoring. The mapping of the Atlantic Forest in Rio Grande do Sul State, Brazil, was done through a set of ten images taken from August 2002 to April 2003 by the HRG sensor aboard SPOT-5 satellite. Images were geocoded using control points extracted from topographic maps at scale 1:50,000. Five forest subclasses were identified, based on analysis of images classified by the Gaussian Maximum Likelihood (GML) algorithm. Classification results were validated by ground truth surveyed at field trips. Besides the native forest classes, twelve other land-cover classes were implemented into the classification process. Final results include a set of 45 maps of the region, area delineation, and surface quantification for all forest classes. Botanical descriptions of native forest classes are given. The characteristic botanical composition of each class is the main factor to give for each one its characteristic spectral signature. Another separation parameter is geographical localization and resulting shadow effects. In a longer perspective, this project aims to monitor alterations of conditions across the forested areas, like additional deforestation and/or re-growth, aided by new imagery to be taken at five-year intervals

Palavras-chave: tropical rain forest, forest monitoring, GML classifier, SPOT images, land cover classification, floresta tropical, monitoramento de florestas, classificador MVG, imagens SPOT,classificação de uso do solo.

1. Introduction

Remote Sensing and Geoprocessing techniques are being used since 1990 by several Brazilia agencies, both governmental and non-governmental, to assess the spatial distribution of the Atlantic Forest Biome; this information is crucial to the environmental management of this fragile ecosystem, and, specifically, to monitor current impacts acting there. The Atlantic Forest can be found in a latitude of 7º and 30º South, from Rio Grande do Norte State, to northeast of Rio Grande do Sul State (Figure 1). It covers an Atlantic coastal strip, some tens of kilometers wide (Silva, 1985) in east Brazil, expanding to West in southeast and south Brazil, where it crosses both the Argentinean and Paraguayan borders, and finally expanding over the Southern Plateau to Rio Grande do Sul State. Atthe northern part of this State it is limited to a geomorphological feature called Serra Geral, occupying also the morpho-structural domain of the sedimentary deposits in the coast, the so-called Planície Costeira (Coastal Plains). The region presently has a fairly high population density, which has a continuous impact on this biome, formerly characterized by a very rich biodiversity. Now, it is reduced to remnants, a situation that asks for constant monitoring.In Rio Grande do Sul State, the first map showing the distribution of the Atlantic Forest remnants was made by the first author and collaborators in 1990, at scale 1:100,000. Even if having a few printed exemplars, it became the reference for scientific research on the field, and as well to political actions aiming to the biome conservation and management. This initiative was the starting point to the mapping, at scale 1:250,000, of the biome in 10 Brazilian states, concluded in 1993. The result was the Atlas of the Forest Remnants and Associated Ecosystems of the Atlantic Forest (UFRGS/FEPAM 1992). Since then, conservation initiatives by official and non-governmental movements were intensified, for which the constant evaluation of the biome conditions is of upmost importance. That mapping was followed by others, concerning the Atlantic Forest in Rio Grande do Sul, including: Jarenkow, 1994; Falkenberg & Voltolini, 1995; Brack & Ruschel, 1997; Jarenkow & Waechter, 2001; Wagner, 2004; Wagner & Ducati, 2004. These investigations were conducted using several methodologies, like the visual interpretation of printed Landsat-TM images (1988/89 summer) at scale 1:100,000; supervised classification of ASTER images, and field trips intended to survey ground truth.

Those works provided valuable information for more extensive investigations, and this paper reports on the first results of a long-term project calling for new imagery capture at five years intervals. The present database is formed by images collected by sensor HRG of SPOT-5 satellite, restricted to the part of the Atlantic Forest within Rio Grande do Sul State. The terrain's morphological features, along with local climate variations, are factors determinant to the introduction of variations and differences in forest composition at biotype level. The main focus of this project is the production of environmentally sensitive information, by an academic, independent group, performing the identification and mapping of the various existent biotypes, from automatic supervised classification of remote sensing derived images. Besides of being a result in itself, the biotype map will also be used to assess future changes in the biome, as new images become available. This information is crucial to defining management policies for this biome, which presents some unique ecological features, including one the world's richest biodiversity.

The Atlantic Forest is more appropriately described as a mosaic of different forest communities, which will be presented in Section 3. Therefore, a high heterogeneity of the spectral signals is to be expected. Differentiation through spectral signatures has been successfully done over tree species and tree communities. Tropical biomes were studied, using Landsat data, by Singh (1987), and by Hill and Foody (1994). Airborne, high spectral resolution techniques were used by Martin et al. (1998) over 11 types of temperate forest cover, with 75% accuracy. Van Aardt and Wynne (2001) performed radiometric measurements of various tree species of temperate climate, showing their separability. Specific spectral signatures are effective to characterize a vegetation species or variety, as, for example, reported by Ducati and Silva (2006) for grape varieties, using ASTER satellite imagery. In the case of SPOT-5 images, its spectral resolution of four bands comes along with a spatial resolution of 10 meters. This is ensemble of resources that can lead to more accurate mappings, and is the one presently adopted.

2. Data and Methodology

The study area is limited by approximate coordinates 27º 30′ S to 30º S and 50º W to 52º W, depicted as an inset in Figure 1. It contains, besides several classes of forests, other classes related to land use and cover. Classification took as data source a set of ten multispectral images from the HRG (High Resolution Geometric) sensor aboard SPOT-5 satellite, collected in 2002 and 2003. All four spectral bands (visible, near infrared (NIR), short wave infrared (SWIR)) were acquired, and used through the study, at 10 m spatial resolution. Each image covers 3600 km^2, with georeferencing made with respect to datum WGS 84 and UTM projection, using control points extracted from Brazilian Army topographic maps at scale 1:50,000. In the process to produce thematic maps on classes of land use and cover, images were subsetted and adjusted to the geographical boundaries of the Brazilian Army charts, which cover 15′ x 15′ areas. A low-pass filter, sized 3x3 pixels, was also applied as a pre-processing step, reducing the salt and pepper noise. This process produced a set of 45 charts ready for classification, covering a total imaged area of about 23,000 km^2. All image processing was made through ERDAS Imagine software. Classification of forest types was done after their four-bands spectra, extracted from values of digital numbers of winter images, dated Aug. 28, 2002, with no atmospheric correction. From the set of 45 charts, the one for the region around Aratinga area is shown in Figure 2.

Figure1. Study area (inset)

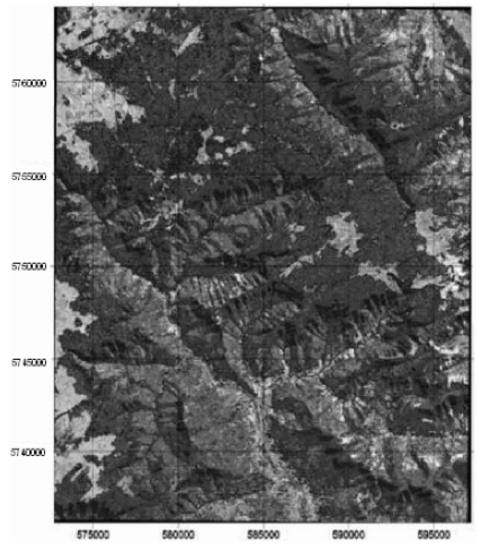

Figure2. Example of a chart (Aratinga area)

Classification was made from pixel sampling for each class, the criterion being that samples have to contain at least 100 pixels. Simultaneous to classification, field trips were made to collect and refine data on ground truth, making possible the characterization of specific vegetation types (phytophysiognomy) of the various botanical units at the region. Five forest types (classes 1 to 5 from list below) were identified on field. Data from pixel sampling lead to the spectral signatures for each class (shown in section 3); from this file every class is characterized by its statistical attributes (vectors of averages, and variance and covariance matrices), used to estimate the decision functions to be used in the classification process.

The quantification of classes in images was made after classification through the Gaussian Maximum Likelihood (GML) classifier. The total of identified classes was 17, following criteria defined by official environmental agencies. These classes (along with abbreviations used in Table 1, Section 3) are: 1) Dense Ombrophile Forest (dod); 2) Mixed Ombrophile Forest (mof); 3) Seasonal Deciduous Forest (sdf); 4) Seasonal Semi-Deciduous Forest (ssf); 5) Secondary Forest (sf); 6) Highlands Prairies (hp); 7) Lowlands Prairies (lp); 8) Pioneer Coastal Vegetation (pcv); 9) Marshes (mar); 10) Water wt); 11) Sand Dunes (sd); 12) Artificial Forests (af); 13) Cultivated Areas (ca); 14) Other Areas for Agriculture (oaa); 15) Clouds (cl); 16) Shadows (sh); 17) Urban Areas (ua). Regions of occurrence and description of all five forest types are given in Section 3. Visually defined vectors generated boundaries of areas of this last class. In present days, these native forest types do not cover extensive, continuous areas; on the contrary, their remnants are distributed in patches between fields and agriculture land. This situation makes difficult to present the whole study area in a single image, where forests are mixed with other classes. However, out of the final set of 45 classified images, a example is given at Figure 3 for the area around Aratinga; as it's the case for most images, not all of the 17 classes previously defined are present in this example.

3. Forests Description

Spectral differentiation of the five forest classes presented at this section arises from their respective floristic compositions. Description of the dominant species at each class is given along with additional environmental information.

The Dense Ombrophile Forest, also called Tropical Rain Forest, originally occupied most of Brazilian coast. Its southern limit is about 30º South, corresponding to the northern half of Rio Grande do Sul State. There, besides the Coastal Plains, this forest is present on the slopes of the geomorphologic features called Serra do Mar and Serra Geral. It is the vector for the introduction of tropical species in the State (Rambo 1951), the migration path being the coast, which links the south of Santa Catarina State to northeast of Rio Grande do Sul.

Regarding the composition of tropical forests in Brazil, besides the three more specifically rich tree families – Fabaceae, Myrtaceae e Lauraceae, others, essentially tropical, are important, like Arecaceae, Annonaceae, Melastomataceae, Moraceae, Meliaceae, having a marked presence also in the flora of the subtropical zone. In view of its geographic position and climate, the Brazilian South, and in Rio Grande do Sul specially, does not present centers of endemic tree species, being on the contrary, thephytogeographic boundary to many tropical species (Rambo 1950). Differences at biotype level are present, mostly on an east-west gradient, where a succession of forest classes occurs as the terrain goes up to the west.

Field trips to the northern part of the coast confirmed that the Coastal Plains suffered a strong loss of its original landscape, especially regarding original forest formations, which were replaced by crops, grazing fields, and urban occupation by beach resorts. Going inland, however, a better preservation was observed at the Serra Geral slopes, which are the eastern rim of the Araucaria Plateau. Even there, it was verified that both forest fragmentation, and anthropic influence, have contributed to the dissemination of exotic species, like *Hovenia dulcis* (Japanese raisin tree).

With respect to the Seasonal Deciduous Forest, and Seasonal Semi-Deciduous Forest, their occurrence in the State is due to the temperate climate barrier. Their difference comes from the fact that, in the deciduous forest, more than 50% of trees have canopies with senile leaves at cold season, while the semi-deciduous has that proportion between 25% and 50%. These subtropical forests expand to south and southwest through the basins of Uruguay and Parana rivers. The Seasonal Forest occurs where distances to sea, or the continentality, are greater. That happens at the western and northwestern parts of the State, where it occupies valleys, going as high as 600 meters to the Meridional Plateau; it is replaced there by the Mixed Ombrophile Forest, also called Araucaria Forest.

Several tree species form the characteristic elements of the Seasonal Deciduous Forest, with origin at the basins of Paraná and Uruguai rivers. Their names, along with local name, are: *Apuleia leiocarpa* (grápia), *Parapiptadenia rígida* (angico-vermelho), *Luehea divaricata* (açoita-cavalo), *Cordia trichotoma* (louro-pardo), *Ocotea puberula* (canela-guaicá), *Eugenia involucrata* (cerejeira-do-mato), *Nectandra lanceolata* (canela-amarela). At the Seasonal Semi-Deciduous Forest, present at the basins of Sinos and Gravataí rivers, species like *Machaerium stipitatum, Fícus organensis* (figueira-de-folha-miúda), *Cupania vernalis* (camboatá-vermelho), *Cabralea canjerana* (canjerana), *Patagonula americana* (guajuvira), *Ocotea puberula* (canela-guaicá), *Solanum mauritianum* (fuma-bravo), are observed, between others. On field studies performed at the region, it was observed the high complexity of the mosaic formed by native forests, in many succession stages, from bushes to primaryforest, spatially mixed with artificial woods *(pinus elliottii,* eucalyptus, and acacia). This complexity makes difficult their identification in satellite images.

The Mixed Ombrophile Forest, also known as the Araucaria Forest, occurs continuously from south and southeast in São Paulo State, to Rio Grande do Sul, where it is present in smaller patches sparsely distributed, going further south. These formations in Rio Grande do Sul are in higher altitudes (800 to 1200 m), at the geomorphologic feature Meridional or Araucaria Plateau, associated to the highlands prairies. These grasslands are dominant at higher lands and water divides, while forests are more concentrated to the plateau's south border, at valleys and rivers. Rambo (1950) states that the plateau's austral/antartic floristic ensemble is older than the tropical forest, which arrived from the north. At present climatic conditions, the Araucaria Forest would be giving place to a forest of tropical origin; this process is suggest by the present discontinuity of the Araucaria Forest at its northern border, at Rio de Janeiro and Minas Gerais states, where it occurs only at higher altitudes sierras (Rambo 1956).

Climatic conditions at the Meridional Plateau are harsh, due to the altitude. Over one average year, freezing or even sub-zero temperatures are reached in about 20 to 30 days. Tropical plants, like the large-leaved of the Dense Ombrophile Forest, are often sensible to temperatures below 5° C, and in general do not resist to the rapid slowing of metabolic processes. Cell damage, associated to physiological drying by cold, leads to severe dysfunction and to plant death, in a few hours (Fitter & Hay, 1987). Therefore, variations in vegetation are place-related, to altitude and latitude; at sea level, mean temperatures fall 2ºC to every 10º increase in latitude; this variation is even more intense at the Subtropical Zone, with changes of 1º C to 100 m or 150 m increases in altitude (Veloso *et al.,* 1991).

The description of leave features at the Mixed Ombrophile Forest is marked by structural and functional traces, like small size and dense pilosity on leave's lower side *(Piptocarpa angustifolia, P. axilares, Vernonia discolor, Baccharis uncinella),* strong scleromorphism (ex. *Schinus polygamus),* hardiness (ex. *Drimis brasiliensdis, Quillaja brasiliensis, Myrsine lorentziana)* (Cain & Castro, 1959). Other features for this forest include stems with thick ritidome, besides a lower abundance of lianes.

Even if much damaged by lumbering, these woods still keep a fair amount of its original composition. At higher places in the plateau these forests are dominated by *Araucaria angustifolia* and have a variate canopy, composed by broad-leaved (latifolia) species like *Tabebuia Alba* (ipê-da-serra), *Parapiptadenia rigida* (angico-vermelho), *Ocotea pulchella* (canela-lageana), *Luehea divaricata* (açoita-cavalo), and many Myrtaceae like *Eugenia uniflora* (pitanga). At hill slopes, woods 7 to 12 m high have *Mimosa scabrella* (bracatinga), *Piptocarpa angustifolia (vassourão), Vernonia discolor* (cambará-da-serra), *Schinus terebinthifolius* (aroeira-vermelha), *Lithraea brasiliensis* (aroeira brava), *Quillaja Brasiliensis* (sabão de soldado), and others.

During field trips, it was observed that the Araucaria Forests, starting from altitudes of 700 to 800 m, at the plateau's south and east, have a profile different from those of the Seasonal and Atlantic Forests; this is due to the fact that agriculture was not developed in these regions, leaving many formations in a still pristine condition, even if, in a considerable extent, extraction of native trees for their high quality timber took place.

The class Secondary Forests includes formations of secondary growths, new and old, in natural regeneration process, after being partially cut, or severely changed by fire or by the introduction of exotic species.

4. Results and Conclusions

Spectral signatures of all five native forest types and for the exotic forest class are given in Figure 4. Values for the green band tend to be high, due to atmospheric interference. In general terms, forest classes display spectral differentiation, an exception being classes Deciduous and Semi-Deciduous. As mentioned in Sec. 3, these formations have similar composition, the difference being the percentage of deciduous species. In this case, distinction for mapping purposes comes from spatial criteria. It is noted that the Dense Ombrophile Forest has a lower albedo. This is partially due to illumination conditions, since this class has its remnants concentrated at the eastern part of Meridional Plateau, where the anthropic action, besides being more intense, was concentrated at the northern slopes, more exposed to sunlight; therefore, preserved forests tend to be located at southern slopes, which are less illuminated. The Secondary Forest is considered as a unique botanical unit, even if being composed by several regeneration stages of the primary classes. However, spectral differentiation comes from its high reflectance at the near-infrared band, due both to the lack of canopy stratification and to the fact that, frequently, this class is located at illuminated slopes, formerly used in agriculture.

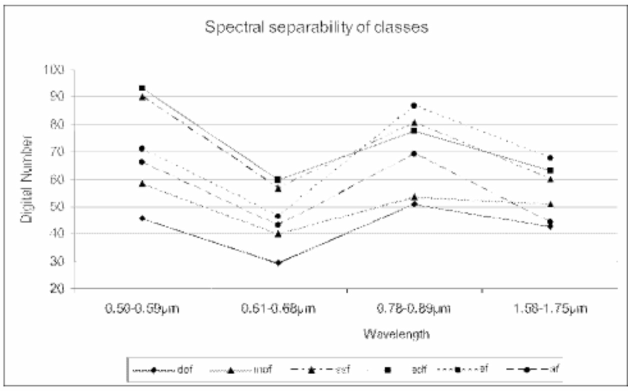

Figure 3. Chart for the Aratinga area.

Figure 4. Spectra for the native forest classes

The results derived from this survey were evaluated with respect to their accuracy through estimates of the statistical reliability of classification process. The contingency matrix given in Table 1 for the region illustrated in Figs. 2 and 3 shows an estimate of the probability of an exact classification of any pixel at the image, allowing an evaluation of the confidence level of the thematic image issued from the classification. Inspection of Table 1 shows that classification is fairly reliable. This assessment gave the necessary confidence to proceed to the quantification of forest classes, with respect to the total imaged area. Results are given in Table 2. These numbers are set as a reference for future studies, one crucial aspect being the possible advance of artificial forests over areas of grasslands and even native woods. This information will be important for government policies concerning environment and landscape protection.

Table 1. Contingency matrix from classification of image of area around Aratinga, from the set of 45 images covering the region. Out of 17 defined classes, 11 are present in this image. Abbreviated class names are given in full length in Section 2. Numbers in Table refer to quantity of pixels selected within each sampling area.

Classes	dod	mof	sf	hp	mar	wt	af	ca	oaa	cl	sh	Total
dod	113	4	50	0	0	0	9	0	0	0	0	176
mof	3	100	6	0	0	0	6	0	0	0	0	115
sf	7	0	246	0	0	0	4	0	0	0	0	257
hp	0	0	0	913	0	0	0	5	0	0	0	918
mar	0	0	0	0	46	0	0	0	0	0	0	46
wt	0	0	0	0	0	734	0	0	0	0	0	734
af	0	0	3	0	0	0	600	0	0	0	0	603
ca	0	0	0	14	0	0	0	522	0	0	0	536
oaa	0	0	2	0	0	0	0	0	220	0	0	222
cl	0	0	0	0	0	0	0	0	0	710	0	710
sh	0	0	0	0	0	0	0	0	0	0	347	347
Total	123	104	307	927	46	734	619	527	220	710	347	4664

Table 2. Surfaces of native forest classes, measured on all 45 images covering the study area.

Class	Area (ha)	Area (%)
Dense Ombrophile Forest	28,117	1.2
Mixed Ombrophile Forest	322,177	13.7
Seasonal Deciduous Forest	32,346	1.4
Seasonal Semi-Deciduous Forest	70,728	3.0
Secondary Forest	274,014	11.7
Other Classes	1,616,554	69.0
Total Imaged Area	2,343,936	100

As a conclusion, the use of high-resolution satellite images proves to be an effective tool to a precise and quantitative monitoring of wooded areas, given that classification techniques can distinguish between different kinds of forests. The mapping and monitoring of forests in the biome being the prime objective of this project, the methodology presently developed will be used on a new set of images, from the same sensor, collected in 2007.

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