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CLASSIFYNG SUCCESSIONAL FOREST STAGES USING IKONOS IN ATLANTIC FOREST OF RIO DE JANEIRO

CLASSIFICAÇÃO DE ESTÁGIOS SUCESSIONAIS FLORESTAIS ATRAVÉS DE IMAGENS IKONOS NA MATA ATLÂNTICA DO RIO DE JANEIRO

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RESUMO
Devido ao avanço dos espaços urbanos sobre a Mata Atlântica se faz necessário um monitoramento constante deste bioma, principalmente de suas Unidades de Conservação. Este trabalho foi realizado no Parque Estadual da Pedra Branca, região metropolitana do município do Rio de Janeiro. O objetivo do estudo foi diferenciar estágios sucessionais florestais por meio de interpretação visual de uma imagem orbital de alta resolução. A classificação da imagem obedece a uma hierarquia de classes a partir de um nível geral (Nível I) a um nível específico (Nível II). As formações florestais foram classificadas de acordo com a legislação florestal brasileira em diferentes estágios sucessionais secundários, como estágios inicial, médio e avançado, além de floresta primária. Verificou-se que 83% da área total da bacia do rio Camorim é coberta por floresta em diferentes estágios de sucessão ecológica. As áreas em estágio mais avançado de sucessão (estágio avançado e floresta primária) empataram em extensão com as áreas em estágio inicial (estágios médio e inicial), ocupando 336 ha (42%) e 328 ha (41%), respectivamente. Isto significa que, apesar da grande pressão antrópica que sofre em seu entorno, o local de estudo ainda guarda remanescentes importantes para a conservação da Mata Atlântica.

Palavras-chave: Mata Atlântica, cobertura do solo, sucessão florestal, imagens de alta resolução, interpretação visual.

ABSTRACT
Due to the advancement of urban areas on the Atlantic Forest, it is needed constant monitoring of this biome, particularly concerning the Conservation Units. This work was conducted in the Pedra Branca State Park, metropolitan area of the municipal district of Rio de Janeiro. The goal of the study was to differentiate forest succession stages through visual interpretation of a high resolution orbital image. The image classification obeys a hierarchy of classes from a general level (Level I) to a specific level (Level II). The forest formations were classified according to the Brazilian forest law in different secondary successional stages, as early, middle, and advanced stages, besides primary forest. It was verified that 83% of the total area of the basin of the Camorim river are covered by forest in different stages of ecological succession. The areas in more advanced stage of succession (advanced stage and primary forest) had equalized in extension to the areas in early stage (middle and early stages), occupying 336 ha (42%) and 328 ha (41%), respectively. This means that despite the great human pressure that it suffers in its neighborhood, the study site still keeps important remnants for the Atlantic Forest conservation.

Keywords: Atlantic Forest, land cover, forest succession, high resolution images, visual interpretation.

1. INTRODUCTION

The Atlantic Forest biome, located on the Brazilian coast, represents one of the top five hotspots for biodiversity on the planet (Myers *et al.*, 2000). It therefore constitutes one of the five priority areas for biodiversity conservation worldwide. This forest is being drastically reduced since the arrival of Europeans due to economic cycles, highlights being the exploitation of the “pau-brasil” (*Caesalpinia echinata*) and the replacement of forests by spaces destined to agricultural activities, such as growing of coffee, sugar cane (Dean, 1997) and pastures. As a result of this historical process, there is a lack of various environmental services such as the regulation of water resources, the maintenance of soil quality, the supply of forest resources and the improvement of weather conditions (Pielke *et al.*, 1997), and the stock of carbon in their biomass (Schneider, 1995). This level of devastation can be explained both by the economic value of the forest species and by the use of the soil and the intense human occupation, which implies every kind of human pressure (Thomas *et al.*, 1998; Sips 1999). This form of occupation has generated an intense process of forest fragmentation and the formation of a mosaic of forest remnants in different successional stages. Despite the devastation to which it was submitted, the Atlantic Forest still harbors extremely high levels of biological richness and endemism (Conservation International do Brasil *et al.*, 2000). Hence the importance of performing, with minimum intervals, the mapping and monitoring of these forest remnants, aiming to diagnose their spatial distribution, for the conservation and recovery of the Atlantic Forest ecosystem (Vieira *et al.*, 2003; Silva and Ferreira, 2004; Cintra *et al.*, 2009).

On a macro scale, coastal areas of Rio de Janeiro state have a high structural variability due to the numerous gradients such as altitude, soil classes, temperature, and orientation of slopes (Costa *et al.*, 2009). The remote sensing techniques have been considered valuable and low-cost tools for the implementation of continuous forest inventories (Kayitakire *et al.*, 2006). There is wide use of medium-resolution images such as Landsat TM / ETM for this purpose (Almeida-Filho and Shimabukuro, 2002; Helmer *et al.*, 2002; Hernandez-Stefanoni and Ponce-Hernandez, 2004; Ingram *et al.*, 2005).

In many cases, however, limiting the spatial resolution prevents the generation of more accurate data on a local scale. The high-resolution images acquired by commercial sensors such as IKONOS and QuickBird have shown potential for the mapping and monitoring of the forest dynamics, including studies on ecological succession (Clark *et al.*, 2004; Mehner *et al.*, 2004; Kayitakire *et al.*, 2006). In Brazil, studies on the determination of successional stages by means of satellite images are concentrated in the Amazon region (Ponzoni and Rezende, 2002; Vieira *et al.*, 2003; Asner *et al.*, 2004; Salovaara *et al.*, 2005; Lu, 2005), while very few focus on ranking or monitoring the Atlantic Forest biome (Araújo *et al.*, 2008, Cintra *et al.*, 2009).

Regarding the technique used, most studies employ automated techniques for classification (Song and Woodcock, 2002; Rego and Koch, 2003; Mehner *et al.*, 2004; Kayitakire *et al.*, 2006; Couturier *et al.*, 2009) that provide a fast method of data extraction from satellite image. Few studies adopt the technique of visual interpretation (Ulbricht and Heckendorff, 1998; Clark *et al.*, 2004; Araujo *et al.*, 2008; Cintra *et al.*, 2009), since it is a slower and more subjective process. On the other hand, this method is classically regarded as more accurate, but the main advantage, the high accuracy of results and contextual interpretation (Schmitt *et al.*, 1998).

This work aims to use the Geographic Information System (GIS) and remote sensing as tools to differentiate the successional stages of the forest remnants and other types of land use on a portion of the Atlantic Forest in Rio de Janeiro, through an IKONOS image. Information from phytosociological surveys carried out in field and analysis of satellite images are correlated.

2. MATERIALS AND METHODS

2.1. Study Area

This study was conducted at Pedra Branca State Park (PEPB), located in a stretch of urban forests in the western zone of Rio de Janeiro (Figure 1). This conservation unit occupies 12,500 ha, including all the slopes located above the elevation of 100 m (SMAC, 1998), between 22°50'S to 23°15'S and 43°20'W to 43°40'W.

In the State of Rio de Janeiro, changes in land use over the past 400-500 years led the area of forest cover to be reduced to less than 20% compared to the original one (Fundação CIDE, 2003), of which 30% are in protected areas (Solórzano *et al.*, 2007).

The area of PEPB is in the way of an urban expansion, which encroaches on the park area, leading to the reduction of local biodiversity, either by removing the forest, or by the contamination of rivers and groundwater due to the lack of basic sanitation (Oliveira, 2005).

The region climate is Aw by Köppen's classification (Peel *et al.*, 2007), subhumid, with little or no water deficit, megathermic, with heat well distributed throughout the year and rainfall ranging from 1,500 mm to 2,500 mm (Oliveira, 2005). The predominant vegetation is the tropical ombrophilous submontane forest (Solórzano *et al.*, 2007).

2.2. Satellite Sensor Data Characteristics

For this study, a cloud-free shot from the IKONOS satellite to 11.5 km for 13.5 km, from February 16th, 2001, has been used, with radiometric resolution of 11 bits containing the multispectral bands with spatial resolution of 4 m and panchromatic band with a spatial resolution of 1 m.

2.3. Classification of Image

For the classification of the different types of land cover, the visual interpretation method has been used. Firstly, general classes have been defined (Level I) which include all types of land cover present in the PEPB. Secondly,

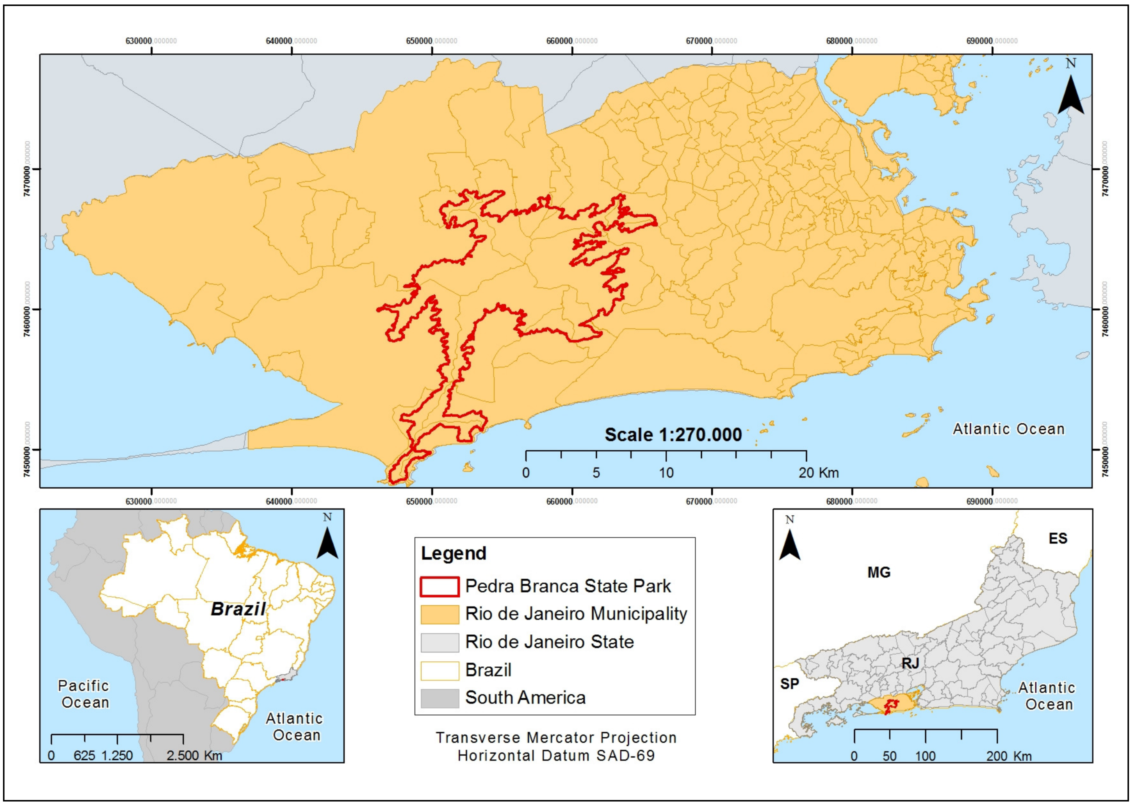

Figure 1 - Location of the study area, Pedra Branca State Park. Brazilian states: RJ - Rio de Janeiro; ES – Espírito Santo; MG – Minas Gerais; SP – São Paulo.

Level II classes were defined by separation of the forest class and vegetation in rocky outcrops. From the data collected in the field in the study area and the transfer of the image data obtained in the field using Global Position System (GPS), a key for interpretation has been defined. The aspects of color, hue and texture have been taken into account to differentiate the different successional stages as well as other classes of land cover. Likewise, data from declivity, orientation face and hydrography also assisted in the classification process. The image was placed in the NRG composition (bands 4-1-2), which best shows the differences of vegetation.

2.4. Classes

The forest formations have been classified according to specific legislation on the subject (CONAMA resolution No. 06 of May 4th, 1994) as early stage, middle stage, advanced stage and primary forest (CONAMA, 1994). Because this legislation does not cover all vegetation types in the area, the class 'Eucalyptus' has been created, since the high resolution image allowed this differentiation. The vegetation in rocky outcrops has been classified, according to Firme *et al.* (2001), as rupicolous (rock-dwelling) or saxicolous (rock-crevice-dwelling). The classes ‘shadow’, as an indication of the shadow of relief, and ‘unclassified’ were also included. Both represent situations in which the type of land use could not be determined. The classes of land cover are:

Level I classes

Forest: it has been defined as a broad formation that extends from an open or closed shrubland to a forest with no sign of anthropogenic change, or with minimal changes. It presents different levels of roughness and uniformity of texture, representing the successional stages.

Rocky outcrop: presence of exposed rock.

Field: anthropogenic grazing fields (pastures) dominated by grasses, shrub and tree sparse vegetation or bare soil.

Water body: includes lakes and dams. Does not include rivers.

Urban occupation: any building types.

Anthropogenic activity: includes activities such as quarrying, agriculture and electricity pylons and its serving tracks.

Shadow: only those caused by relief have been classified as such, excluding the shadows of trees and buildings.

Level II classes

Early Stage: open or closed shrublands. Usually shows the dominance of a single species, observed by rather homogeneous texture and spectral pattern (color). Furthermore, the dominant species has a clumped distribution, which can also be observed through the similar texture and reflectance.

Middle stage: closed woodlands. There is an early differentiation into strata, observed in the differences in the height of trees in different parts of the image. Some species with clumped distribution are still observed, but the texture reveals a trend toward heterogeneity.

Advanced Stage: tree-covered closed facies, forming a canopy relatively uniform in size. The texture becomes rougher and there are more signs of dominance of species with clumped distribution. The texture is heterogeneous, with spectral pattern (color) more diversified, which shows an increase in diversity.

Primary forest: Forest with no sign of anthropogenic change, or minimal anthropogenic change. Great diversity reflected by the very rough texture. Maximum diversity of spectral pattern.

Eucalyptus: Cluster of trees of the genus *Eucalyptus*, with a homogeneous texture and usually with different in height from the others. Texture markedly differentiated because of the lack of roughness.

Rupicolous vegetation: vegetation that develops directly on rock outcrops.

Saxicolous vegetation: vegetation that grows over cracks and cavities found in rocky outcrops, where soil accumulates.

2.4. Field Inventories

To perform the field inventory, a qualitative and quantitative assessment was adopted, using criteria in legislation (CONAMA, 1994). Typical areas of occurrence of each of the successional stages (early, middle, advanced and primary) have been selected within the Camorim river basin.

The early stage area has been identified in the field. The species most characteristic of this stage of succession are the pioneers: Red Cecropia (*Cecropia glaziovii*), Cambará (*Gochnatia polymorpha*), Alecrim-do-campo (*Baccharis dracunculifolia*); Pau-jacaré (*Piptadenia gonoacantha*) and Purple Glory Tree (*Tibouchina granulosa*).

To define the area of primary forest transects were made in a pre-selected area without any evidence of past human use. Each transect measured 50 m x 6.66 m (333 m^2), and was repeated twice, which amounted to approximately 1,000 m^2. The inclusion criterion used was diameter at breast height (DBH) greater than or equal to 5 cm. Trees with branching stems and standing dead trees were also recorded, following the same inclusion criterion. The stems were considered branched when branching occurred below 1.3 m. The parameters obtained were: total basal area; mean diameter; greater diameter; the coefficient of variation of diameter; average height; greater height; the coefficient of variation of height; standing dead trees, multiple trunks; total density, and living biomass above ground (LBAG). To obtain these data, except the last, the recommendations contained in Vuono (2002) have been observed. To calculate the LBAG, the formula of Chave *et al.* (2005) has been used, as suggested by Vieira *et al.* (2008) to be the most suitable for this purpose in the Atlantic Forest. The percentages of diameter and height distributions of all sampled individuals have been made using histograms with defined classes every 5 cm.

All forest classes (Level II) and the classes 'Field' and 'Water body' (Level I) had their coordinates obtained in the area, through the use of a Promark 2.0 GPS with external antenna. Only items with values of Position Dilution of Precision (PDOP) of less than 6.00 were accepted (Thenkabail *et al.*, 2003). The sampled areas have been used as standards for the classification of other areas in the image.

3. RESULTS AND DISCUSSION

3.1. Field Inventories

The results collected in the field are summarized in Table 1. It can be observed that the analyzed parameters of height, DBH, basal area and biomass increase with the maturity of the forest. In contrast, the parameters of percentage of dead trees and multiple trunks tend to decline (Table 1, Figures 2 and 3).

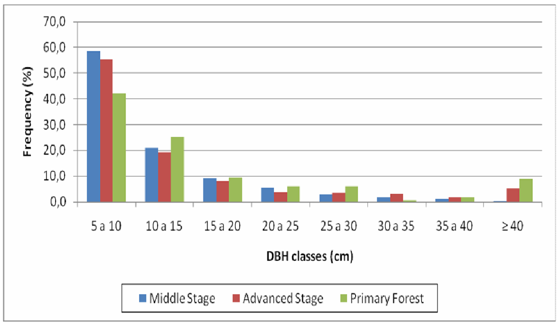

Figure 2 - Comparison of the trees diameter distribution by the forest successional stage, on the Camorim river basin, Pedra Branca State Park, RJ.

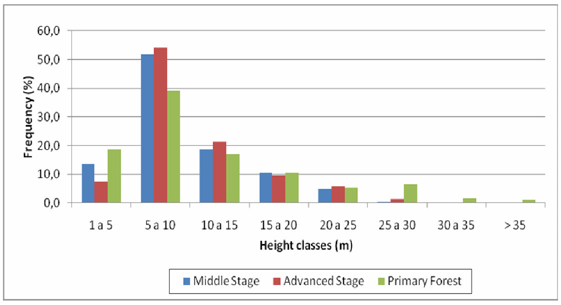

Figure 3 - Comparison of the distribution of the trees height classes by the forest successional stage, on the Camorim river basin, Pedra Branca State Park, RJ.

3.2. Visual Interpretation of the Image

The most expressive classes of land cover at Level I were Forest, with 67.2% of the analyzed area and Field with 27.8%. The other classes take up less than 1% of the area each, except for Rocky Outcrop (3.2%) (Figure 4). The field areas are abundant in the northern edges of the massif and its spots are scattered through the interior of PEPB, permeating the forest areas. It is believed that these areas are a consequence of the farming system of slash-fallow carried out before the creation of the PEPB. Many of these areas being predominantly located on the northern slope, where there is high occurrence of fires and because of the lack of nearby matrices are no longer able to follow the natural process of ecological succession and remain infertile. Instead, on the southern slope of the massif this type of activity was almost extinct after the creation of PEPB, and over time the ecological succession promoted the healing of gaps (Oliveira, 2005). Because of this, it is observed that most areas of the forest stretch across the southern portion of PEPB and its interior, with some fragments remaining in the northern portion.

Table 1 - Parameters for the classification of vegetation in the study area.

Class	*Density ind.ha^{-1}*	*Maximum height (m)*	*Maximum DBH (cm)*	*Death trees (%)*	*Multiples trunks (%)*	*Basal area (m².ha-1)*	**Biomass (Mg ha^{-1})**
Middle Stage	1.800	30	43	9.5	10.6	26.2	132
Advanced Stage	1.244	32	108	4.5	9.9	34.2	265
Primary Forest	1.820	38	121	2.2	0.0	90.1	593

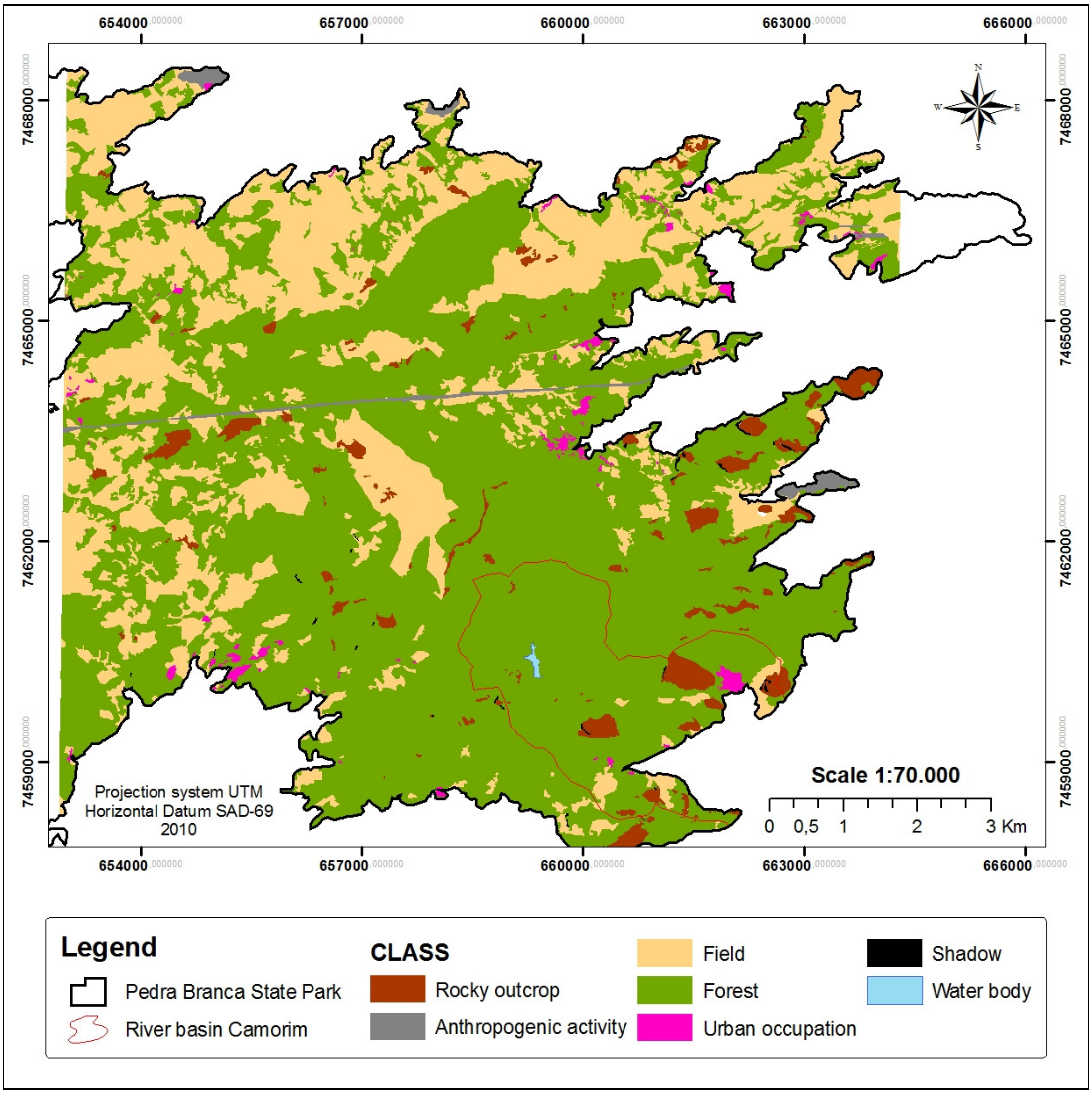

Figure 4 - Land cover of the Pedra Branca State Park, result of visual interpretation at Level I of the Ikonos image (multispectral, 4 m spatial resolution).

The same pattern can be observed on a larger scale of detail. In the analysis of data from the classification of Level II, it can be seen that in comparison to the northern slope, the southern slope houses the most conserved forests of the basin studied (Table 2). The slopes facing south receive more moisture from the convective sea winds and cold fronts and at the same time a lower incidence of sun heat. Thus, the recovery of the forest occurs in a relatively short time, being less susceptible to forest fires than the slopes facing north (Oliveira *et al.*, 1995).

Table 2 - Analysis of the area occupied by different successional stages by the north and south slope orientation.

Class	*North*		*South*	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**
Field	8,5	**10,9**	6,2	**3,5**
Early Stage	12,1	**15,6**	16,2	**9,2**
Middle Stage	26,3	**33,9**	43,6	**24,7**
Advanced Stage	17,8	**23,0**	56,3	**31,9**
Primary Forest	4,7	**6,0**	33,3	**18,9**

The class ‘Rocky Outcrop’ has been detailed in ‘saxicolous vegetation’ and ‘rupicolous vegetation’ at Level II. The limits of these classes are rather difficult to establish, because they lie on rocky outcrops, which in turn borders the forest areas. It is possible to mistake the vegetation of rocky outcrop for forest vegetation, as they sometimes look similar. One factor that helped at this stage was the information on declivity, with which it is possible to determine where this formation is actually located.

The classification at Level II (Figure 5) revealed that the forest in the middle stage of succession occupies most of the Camorim river basin (28.4%), followed by advanced stage (26.2%) and primary forest (15.1%). When only the data of the forest class are analyzed, it can be observed that the areas at more advanced stages of succession (advanced stage and primary forest) are comparable in size to the areas in the earlier stages (early and middle stage) together. The class of land cover *Eucalyptus* was excluded from this analysis because it presents a negligible percentage in relation to the area occupied (0.2%), besides not being the focus of this study.

The ‘early stage’ is easily distinguished from others by its uniformity of texture, which generally reflects the dominance of few species. Sometimes it might have been confused with rupicolous vegetation when it completely covered the rocky outcrop. In these cases, the panchromatic image and/or the declivity data were essential to decide to what type of land cover class the area belonged. Importantly, this class is the one that presents greater variability in time, because it is where the ecological succession occurs with the greatest speed, changing its facies, mainly the biomass allocation.

The ‘Middle Stage’ has been differentiated from the other classes mainly through the observation of a trend to heterogeneity of texture. Nevertheless, the dominance of some species with clumped distribution can still be seen through the similarity of architecture and texture of the canopy of some species. Among these, in the region studied Guapuruvú (*Schizolobium parahyba*) stands out, for its canopy architecture is unmistakable in imaging study.

The 'Advanced Stage' was more easily differentiated from the early and middle stages and more confused with the Primary Forest. This class is characterized by a lack of uniformity of texture. It was possible to detect the differentiation of forest strata by the difference between the heights of the trees and the increasing

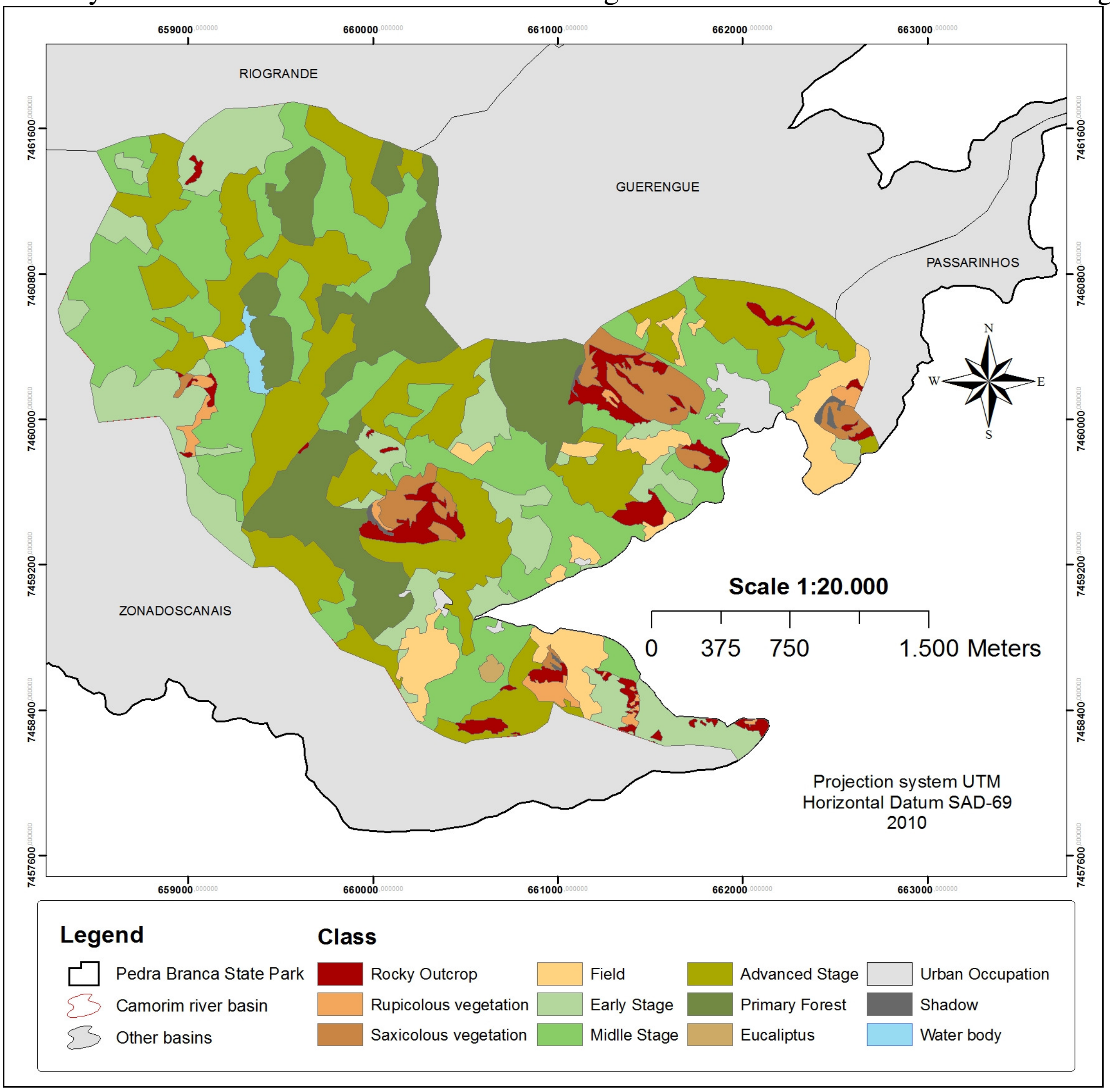

Figure 5 - Land cover of the Camorim river basin, result of visual interpretation at Level II of the Ikonos image (multispectral, 4 m spatial resolution).

diversity by the heterogeneous canopy architecture.

The 'Primary Forest' was differentiated from the other stages, especially the advanced stage, because a standard has been defined in the field that had a good match with the pattern observed in the image. This pattern was used as reference for maximum diversity and heterogeneity achieved in the area. It should be noted that the reference pattern generated in this work to the class 'primary forest' refers to a single topographic position (valley bottom). Possibly, this pattern changes in steeper areas or on top of hills.

Besides the primary forest there are formations in a local climax that generally have spectral patterns corresponding to less mature stages of succession. This is due to the particular soil features and can hinder the application of visual interpretation and possibly underestimate the area of a more preserved forest in the region. In Table 3, we observe the strong presence of early stage in areas with slopes above 37.5°. This is because with increasing slope, the soil layer becomes shallower, and there is more incidence of light. Therefore, the trees do not grow much, making it appear that they structurally and spectrally belong to a lower successional stage.

Table 3 - Analysis of the area occupied by different stages of succession in accordance with the change of slope.

Class	***Field***		***Early Stage***		***Middle Stage***		***Advanced Stage***		***Primary Forest***	
Slope	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
0° - 12,5°	1,1	**1,8**	6,5	**10,5**	21,9	**35,2**	16,2	**26,1**	8,5	**13,7**
12,5° - 25°	12,6	**4,9**	28,9	**11,3**	95,1	**37,3**	70,6	**27,7**	37,8	**14,8**
25° - 37,5°	26,5	**7,4**	51,2	**14,4**	92,7	**26,0**	95,1	**26,7**	63,2	**17,7**
37,5° - 45°	3,8	**5,0**	15,0	**19,6**	12,5	**16,3**	18,3	**23,9**	7,2	**9,5**
> 45°	2,6	**6,0**	7,7	**17,8**	3,5	**8,2**	7,5	**17,3**	2,9	**6,7**

5. FINAL CONSIDERATIONS

The data collected in the field were related to the data observed in satellite images, allowing an estimative of the forest structure. However, the variables that determine the successional stage of a forest are many and only through a comprehensive field study it would be possible reduce the uncertainty associated with local variability. The strategy of sorting by class hierarchy is a suitable method for visual interpretation of the classes that is systematic, therefore reducing the eventual subjectivity of the process.

The GIS and remote sensing techniques have proved to be very useful in the analysis and assessment of vegetation cover. Only with the combination of satellite images and field work it is possible to embrace the structural variability of the landscape in places of great heterogeneity. These constitute useful tools for improving the performance of regulatory agencies and managers in the region.

Considering the extent of forest in the region analyzed and the possibility of having underestimated the area of forest conserved, it is believed that despite the great human pressure on its surroundings, the study area still retains significant material for conservation of the Atlantic Forest.

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