

HIGH-RESOLUTION IMAGE TO MAP BAMBOO-DOMINATED GAPS IN THE ATLANTIC RAIN FOREST, BRAZIL

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ABSTRACT:

This study presents the results referring to the analysis of QuickBird high resolution satellite images to establish patterns associated to the landscape dynamics in bamboo forests at the Intervales Park (São Paulo State, Brazil), considering its ecologic aspects. The methodology was based on visual image interpretation, as a preliminary step for digital processing. The results show the possibilities for the use of these high resolution data to map forests with bamboo dominance as well as for monitoring phenologic cycles of these dominant species. The visual interpretation was an adequate technique for our study, emphasizing that the knowledge of the ecological aspects from these forest typologies was of fundamental importance to understand the patterns mapped with this image.

1. INTRODUCTION

Presently remote sensing data are fundamental tools to survey natural resources, being of fundamental importance for decision taking in several areas of public policies. In Brazil, several methodologies using orbital data were developed and applied exclusively to map and monitor vegetation including several Brazilian biomes such as presented at the “Atlas of forest remnants from the *Mata Atlântica*” (SOS Mata Atlântica, INPE 2002).

At Atlantic Forest (*Mata Atlântica*), composed presently by fragments distributed along the Brazilian coast, the region known as “Continuous of Paranapiacaba” is considered one of the most important remnants of this biome. Located at southern São Paulo State and formed by the junction of Parks *Intervales, Turístico do Alto Ribeira and Carlos Botelho* and the Ecologic Station of *Xitue*, the Continuous includes approximately 150 thousand ha of vegetation composed almost completely of Ombrophilous Dense Forest (BIOTA/FAPESP, 2008). Recent diagnostics in the field however, associated with the analysis of aerial photographs, present extensive forest areas with dominance of bamboos (São Paulo, 2007), which were not detected on previous surveys (BIOTA/FAPESP, 2008; SOS, INPE, 2002). This fact evidenced the need to map the distribution and monitor the possible expansion of these forest formations at a compatible scale with this landscape.

The bamboos belong to the family of the Poaceae and are typical components of the humid forest from *Mata Atlântica* (Rizzini, 1979). Due to its’ characteristics of fast colonization from the rhizomes and of its’ invasive habits, they are frequently related to disturbed environments (Wong, 1991), to clearings of natural and human origin, interfering on both forest structure and regeneration (Griscom & Ashton, 2003). Besides that, they have a long life cycle between 20 and 60 years, culminating at a phase of sexual reproduction with a high production of seeds and massive mortality of population (Janzen, 1976), restricting the knowledge of the life cycle from these plants to a few species. These associated propagation characteristics allow its dominant establishment which results in differentiated landscape patterns, of fundamental importance to

understand the ecological aspects associated to these bamboo sites in studies of forest dynamics.

In Brazil studies of bamboo formations with remote sensing techniques were performed in the SW Amazon, where there are extensive areas dominated by the genus *Guadua* (Nelson et al., 2006). Using a series data from 28 years of Landsat-MSS, Landsat-TM and MODIS/TERRA, Nelson & Bianchini (2005) monitored the life cycle of the bamboo population of genus *Guadua* in Acre State, during two population mortality events in 1976 and 2003-04, learning on the reproductive cycles of these species. Despite differences in structure and floristic composition, forest classes with and without bamboo were not well discriminated with JERS-1 (Santos et al., 2000) and ASTER/Terra (Mendoza et al., 2004) image data in sections of the Amazon.

In Acre State, bamboo forests occupy large areas, with one or two dominant species. At Intervales Park, in the Continuous of Paranapiacaba, field observations show clearings occupied by different bamboo species occurring jointly with sections of dense forest. This landscape mosaic and the extremely mountainous topography of the region, make mapping of these areas difficult with medium resolution data. Being so, high resolution images become an additional information source for these studies on bamboo, with similar resolution of aerial photographs, but with distinct spectral characteristics which allow detailed mapping of forest features using automatic classification procedures.

Taking into account the complexity of these high resolution data and consequently of the associated processing, the visual interpretation is still a quite frequently used procedure, as an alternative or in parallel to digital procedures (Buchanan et al., 2008; Tottrup et al., 2007). Based on parameters such as color, texture, shape and pattern (Lillesand & Kiefer, 1994), this technique allows the direct inclusion of knowledge from the analyst in the field during the mapping process, fundamental to understand this forest dynamics in areas with bamboos.

In this context, the objective of this paper is to evaluate the potential of high-resolution images to establish patterns

associated to the dynamics of landscape in bamboo forests at Intervalles Park, considering the ecologic aspects of this forest physiognomy. The methodology was based on the visual interpretation of images, as a preliminary step for the application of digital processing. The results obtained integrate a databank of a project for the analysis of the spatial and temporal distribution of bamboo forests from Intervalles, subsidizing the discussion on the monitoring of such areas.

2. STUDY AREA

This study was performed in the Intervalles Park (Figure 1), a conservation unit of the Continuous of Paranapiacaba region, located at southern São Paulo State, between geographic coordinates S 24° 12' - 24° 32' and W 48° 03' - 48° 32'. The section selected for analysis, with an area of 2,300 ha is located between the administrative office from this Park and the control bases Carmo and Capinzal, that are characterized by a history of intense natural and human disturbances during the time before the constitution of this conservation reserve.

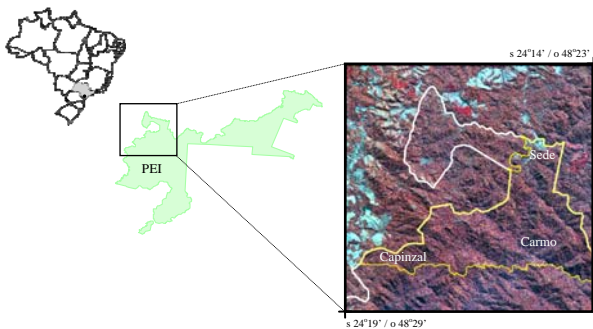


Figure 1. Localization of Intervalles Park (PEI) in São Paulo State/Brazil and the area under study within PEI (in yellow) at Quickbird image (R4G2B1).

3. METHODOLOGY






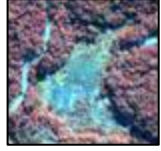


This study was done using a QuickBird image, radiometric resolution 11 bits (2048 gray levels), type Standard 2A, with five spectral bands, namely 1 panchromatic, spatial resolution of 0,6 m and 4 multi-spectral (blue, green, red and infrared), spatial resolution of 2,4 m. The data-take was May 19th 2006, with an area of 8,000 ha, including part of the park and a section of its surroundings. A sample area was selected based on more detailed knowledge in the field survey.







The mapping activity with the QuickBird image was supported by a databank with historical records from the area (1962-2000) and a set of field survey data with the description of dominant landscapes, referring to four years of monitoring (2004-2008). Taking into account that the use of high-resolution images aimed to generate data to be integrated into a databank of the project, an ortho-rectification of the image was not done. Nevertheless the image was registered, considering as a base a mosaic of aerial photographs from 2000 (scale 1:35.000). Afterwards an image fusion procedure was undertaken, using the principal components method (Pinho, Rennó & Kux, 2005), and the result was a fused image with a resolution of 0,6 m. Image processing at the QuickBird scene was done using the software package ENVI 4.1.

Based on information from the databank, an interpretation key was established, considering different patterns found in the field as a function of the QuickBird image bands that are best suited for this mapping. The definition of mapping classes was based on parameters of visual interpretation like texture and color, associated to structural vegetation information such as height and canopy density, besides information on the dominance of bamboo. This information directed the visual interpretation of the image, done in ArcView 3.2, at an approximate scale of 1:5,000, and the generation of a land cover map. Additionally the thematic mapping classes were discussed as a function of spectral responses of targets of interest.

4. RESULTS

Taking into account the different patterns found in the field, the key for the interpretation of the QuickBird image (Table 2) was elaborated with 9 classes of land cover: (1) water bodies, (2) bare soil, (3) grass, (4) bush, (5) secondary succession with dominance of bamboo in vegetative or reproductive stage, (6) secondary succession with senescent bamboos, (7) secondary succession with spaced bamboo sections, (8) advanced secondary succession and (9) primary forest. These classes were defined considering bands R4G2B1 of the fused image, an image composition which was most adequate for this mapping effort because it allows the distinction of different forest categories. The result of the image interpretation was a thematic map of land cover from a section of the PEI (Figure 3), including the quantification of the respective areas by class (Table 4), and by the analysis of spectral response of targets (Figure 5).

Class	Ground Survey	IMAGE (R4G2B1)
1		
2		
3		
4		

Class	Ground Survey	IMAGE (R4G2B1)
5		
6		
7		





Class	Ground Survey	IMAGE (R4G2B1)
8		
9		

Table 2. Landscape elements and corresponding QuickBird image composition.

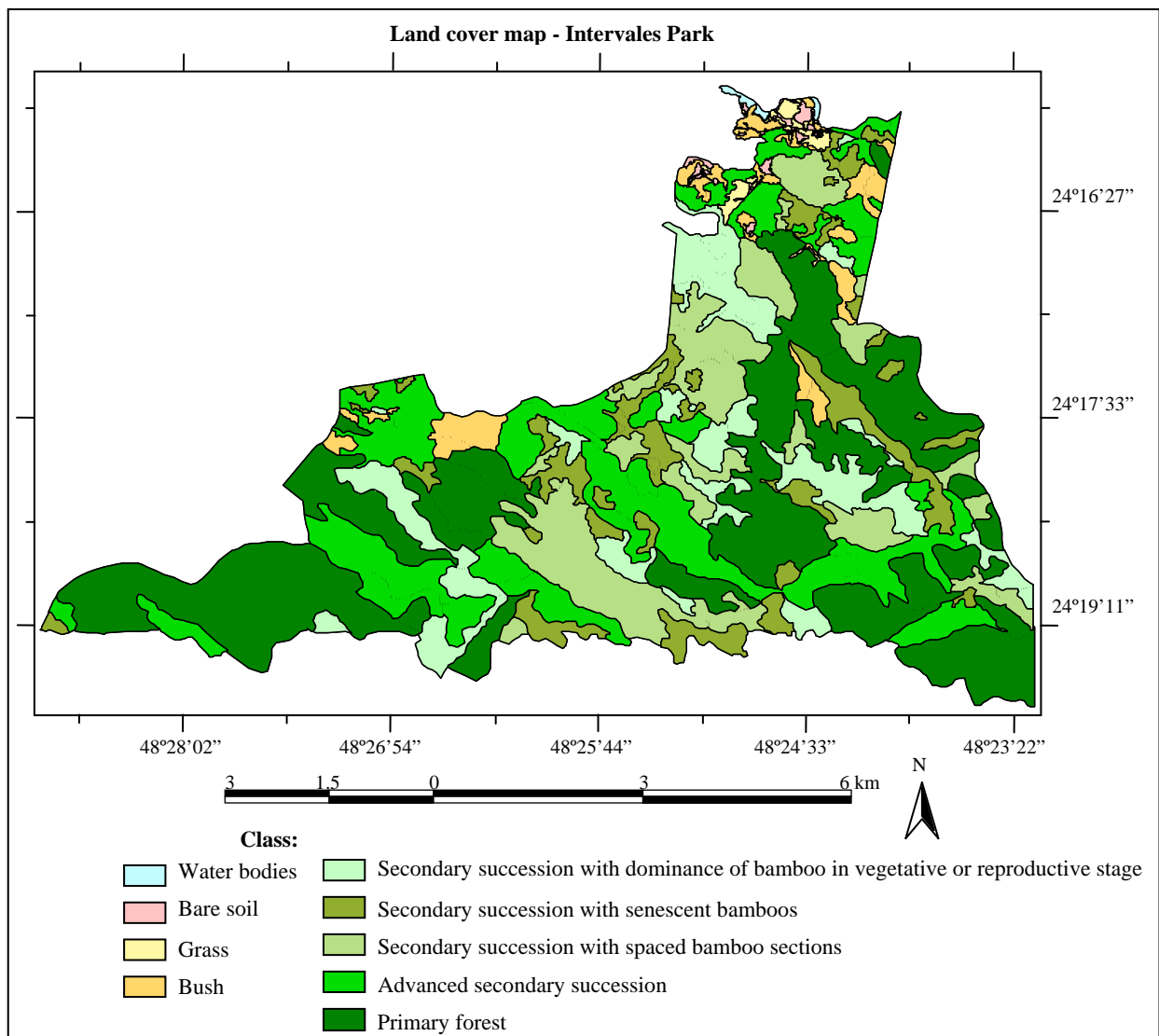


Figure 3. Land cover map of a section from PEI, as a result from visual interpretation at 1:5,000 scale, of the QuickBird image dated from May 19th 2006.

Class	Area	
	hectare	%
Water bodies	4.09	0.18
Bare soil	12.42	0.54
Grass	17.37	0.75
Bush	87.56	3.80
Secondary succession with dominance of bamboo in vegetative or reproductive stage	215.63	9.36
Secondary succession with senescent bamboos	272.82	11.85
Secondary succession with spaced bamboo sections	353.83	15.37
Advanced secondary succession	496.88	21.58
Primary forest	841.95	36.57
Total	2302,55	100

Table 4. Areal distribution of land cover classes.

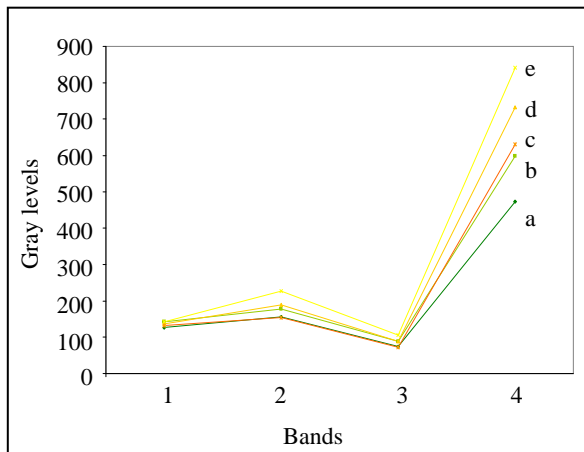


Figure 5. Spectral responses in gray levels of targets corresponding to thematic mapping at the 4 original bands of the QuickBird scene (a) Primary forest, (b) Advanced secondary succession, (c) secondary succession with dominance of bamboo in vegetative stage, (d) secondary succession with dominance of bamboo in reproductive stage, (e) secondary succession with senescent bamboos.

5. DISCUSSION

The region under study, between the administrative office and Capinzal and Carmo bases, concentrates the largest area of public use from PEI and the analysis of the QuickBird image allowed the discrimination of these different classes of land cover.

The classes of bare soil and grass vegetation are related to those areas of predominant actual use, such as streets and buildings, which are concentrated almost exclusively in the area of the administrative offices, characterized by a smooth texture and tonal variation between blue and green. The class of bush vegetation with fine texture and orange-like color, includes low

size vegetation surrounding the streets (initial regrowth) and the bushy-herbaceous vegetation associated to the hilltops.

Referring to those classes with forest structure, the history of human disturbance at PEI, related to small scale slash-and-burn plantations and palm tree (*Euterpe edulis*) exploitation, seems to reflect at the physiognomic-structural characteristics of actual vegetation. Such activities, when performed intensively and recurrently in the past in this region, may have affected the natural succession process, easing the colonization and the establishment of bamboo. In this area, different stages of secondary succession, sometimes with dominance of bamboo, occur together with dense forest, causing tonal variations and specially texture changes in the image. The mapped classes were defined as a function of canopy dominance, considering specially the degree of coverage from the area analyzed by bamboo or arboreal individuals.

The areas of dense forests are those regions without human interventions in the past, located mainly on hilltops or slopes and associated mainly to Dense Ombrophilous Mountain Forests (São Paulo, 2008). This class presents at the QuickBird image a rough texture due to different vegetation strata and the presence of emergent individuals and darker red tones, with intensity variations related to shadowing, caused by the positioning of mountainous topography and by the heterogeneity of the canopy. The class advanced secondary succession, in spite of similar floristic characteristics of dense forests, presents a slightly more homogeneous canopy due to the absence of emergent individuals with less rough texture and more clear tones, located in areas with better access than the forest remnants.

In situations where bamboo reaches the height and dominates the forest canopy, the latter presents a more homogeneous aspect with distinct spectral characteristics, allowing the identification of vegetation sections with bamboo, amid dense forest. As mentioned earlier, the bamboo is a typical component of this environment from Atlantic Forest, of natural occurrence within the PEI vegetation. The class secondary succession with spaced bamboo sections, considers those areas with small sections of bamboo that are distributed within the dominant vegetation of forest structure, where a rough texture and shadowing by several strata predominate.

Those forests with predominance of bamboo correspond to the clearer tones and especially to a smoother texture, due to this homogeneous surface of the canopy, dominated by bamboo and the sparse presence or arboreal individuals of a large size. The variations of tones and textures in these classes with bamboo are related mainly to its phenologic phase.

The areas dominated by bamboo in the vegetative stage, i.e. at a time before the reproduction stage, represent the most critical class for mapping, because its characteristics sometimes are similar to vegetation classes without bamboo. At this stage, the bamboo frequently does not dominate completely the forest canopy, and there is an influence of arboreal individuals in its spectral response. Nevertheless the vegetative stage was included in the class secondary succession with bamboos, together with samples in reproduction stage, based on field survey data.

During this reproduction stage, i.e. the flourishing and fruiting period, the leaves of bamboo take a yellow color, being easily discriminated in the image by orange tones and a texture of low

roughness. With the end of the reproduction stage, several bamboo species are characterized by a massive mortality of population (Janzen, 1976), as observed in the dominant PEI species, and the results are extensive clearings with a large volume of dry biomass. Being so, the senescence period can be clearly identified by very clear tones due to the dominance of dry materials.

With the mass mortality of bamboo populations, many of these areas within the PEI are colonized again by other bamboo species, restarting the dominance cycle. In the area under study, two bamboo species predominate: *Guadua tagoara* (Nees) Kunth (popularly known as *taquaruçu*) and *Chusquea oxylepis* (Hack.) Ekman (popularly known as *criciúma*). Both species have associated occurrences at several points within PEI. *G. tagoara* presents characteristically developed trunks which use thorns to climb arboreal individuals and to establish itself at the forest canopy, while *C. oxylepis*, with a similar structure as a climbing plant, forms a closed cover over the canopy. In spite of the distinct strategies for its dominance, both species originate a similar structural pattern, characterized by a discontinuous canopy, low density of arboreal individuals of medium and large size. Additionally, the superposition of the reproduction cycles of these species masks its individual characteristics in the image. In May 2006, when the QuickBird image was taken, the populations of *taquaruçu* from the area under study were at the end of the reproduction cycle, while this time was the height of the reproduction period for *criciúma*. The structural similarity of vegetation together with the simultaneous flourishing of these species, makes it difficult to establish distinct patterns for them on a QuickBird scene.

The map of land cover generated from the visual interpretation of the QuickBird image (Kappa = 0.85) allows the evaluation of class extension, which forms a mosaic composed by vegetation in different succession stages, and many of them have a dominant occurrence of bamboos at different life phases. In the Amazon, each internally synchronized bamboo population, occupies extensive areas between 10^2 to 10^4 km², which can be detected with TM-Landsat and MODIS (Nelson et al, 2006) images during the massive mortality of these sections. At PEI however sections of bamboo dominance occupy areas between 0.15 to 0.30 km², which cannot be identified with medium resolution sensors (Araujo et al, 2005), independently of its phenologic stage.

From the land cover map it is also possible to evaluate the extension of the bamboo occupation at Intervales. In the region analyzed, despite the class forest still covers 36% of the total area, those classes with bamboo dominance come up to 21%. The class with spaced bamboo sections, due to the border contact with bamboo dominance, besides the extremely aggressive habits of these species, has a high chance to be progressively converted to the class secondary succession with bamboos. With this inclusion, the percentage of areas with bamboo is also 36%. A similar inference can be made for the class advanced secondary succession covering 21% of the area under consideration.

Despite the relative restricted number of bands at the QuickBird image, when compared with other products of remote sensing, the analysis of the spectral responses from different targets evidences the discrimination between classes of interest, as observed at Figure 5. Generally the classes present a typical spectral behavior of vegetation, with low values at bands 1, 2 and 3, referring to the visible section of the electromagnetic

spectrum and high values at band 4, corresponding to the near-infrared section, which is more adequate for the discrimination of these forest targets. Similarly to what was observed in other scales of work (Nelson et al, 2006; Mendoza et al. 2004), the layer formed by bamboo leaves in the forest canopy reflects more intensively, especially when considering the near-infrared band. We emphasize again the difficulty to discriminate the class with bamboo dominance in growing stage, which has a very similar spectral response as the class advanced secondary succession, despite the floristic and structural differences.

The adequate mapping of this secondary succession with bamboo dominance in vegetative stage and the understanding of the phenologic aspects of the dominant bamboo species, is an important aspect for studies of forest dynamics. These factors allow the planning to open new clearings, which is of fundamental importance to understand the landscape of this region. In this case, the use of a temporal series is fundamental for such studies, due to a very specific dynamic of this forest formation.

Figure 6a illustrates a section of bamboo at reproductive stage, mapped with aerial photography and the corresponding QuickBird image. The aerial photography was taken in 2000, probably at the growing stage. Figure 6b shows part of the phenologic cycle from the bamboo at an advanced decomposition stage in 2006.

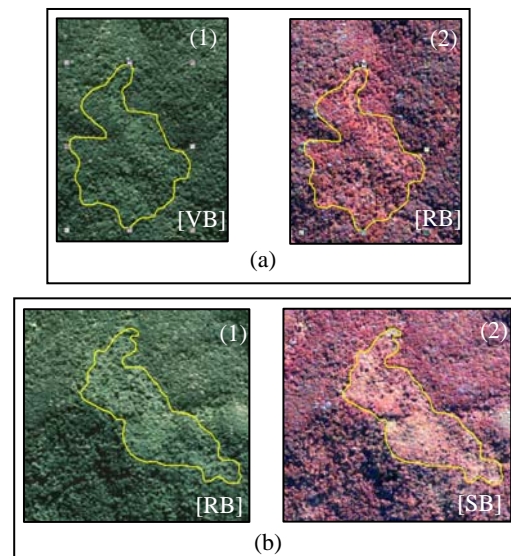


Figure 6. Examples of the phenologic phases of bamboo at aerial photography from 2000 (1) and QuickBird image from 2006 (2): [VB] bamboo during vegetative stage, [RB] bamboo during reproductive stage and [SB] bamboo after senescent stage.

In spite of a similar resolution, the QuickBird images have advantages when compared to aerial photographs, even considering only the visual interpretation. At the satellite image, the tonal variations in the near-infrared band, allows the discrimination of different phenologic phases of the bamboo that are not evident in the aerial photographs, even if the bamboo is at the early senescent stage. The temporal analysis using QuickBird images is of promising importance in this case to characterize the life cycles of these dominant bamboos

6. CONCLUSIONS

The results of this image analysis demonstrate the possibility of using these high-resolution satellite data to map bamboo forests, and also to monitor the phenologic cycles of the dominant species. The visual interpretation proved to be an adequate technique in this case, emphasizing that the knowledge of the ecological aspects of these bamboo formations was of fundamental importance to understand the patterns mapped on the image. Nevertheless there are still more detailed studies needed as far as the dynamics of this forest typology are concerned, considering the peculiarities observed in this area.

This study is part of a project aiming the analysis of the spatial and temporal distribution of forests with bamboos of Intervales. These results evidence the possibilities for the discrimination of different vegetation classes using digital processing procedures at these images during further steps of the work, considering the specific characteristics of this region, referring to climate and topography and the need of ortho-rectification, a geometric correction necessary to improve the precision of future maps.

Taking into account the results presented, QuickBird images are adequate products for mapping and monitoring at a compatible scale, the possible expansion of these bamboo forests, feeding a databank on the species of this region and contributing to better understand this landscape that was recently diagnosed within the Atlantic Forest domain.

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