

SÃO PAULO STATE NATURAL VEGETATION MONITORING
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The present study consists on natural vegetation monitoring, using remote sensing, to support control and administration natural resources of São Paulo State, Brazil. At the stage, it was done a survey based on the Landsat-5 satellite images that resulted on the elaboration of the "São Paulo State Natural Vegetation Mapping", formed of 408 maps on a scale of 1:50000 and 9 vegetation's themes. It was verified that 13,7% of the state, which has 24.379.900 ha, is covered with natural vegetation. The continuity of this study has been done using the Image Treatment System associated with an Geographic Information System to update the mapping superimposing thematic maps with actual images. The results obtained have been a significant contribution for the State forest control activities.

KEY WORDS: Geografic Information System, Global Monitoring, Image Interpretation, Landsat, Remote Sensing Application, Renewable Resource, Mapping.

INTRODUCTION

The DEPRN - Natural Resources Protection State Department is part of the Secretary for the Environment of São Paulo State responsible for the natural resources control, mainly the fauna and flora. In its action, this Department has been looking for better technics to the forest control activities and consequently to do a more efective protection of the natural vegetation of São Paulo State.

Considering the size of the area of its activity, 24 millions of hectares, the DEPRN decided for the use of remote sensing to mapping and to posterior monitoring the natural vegetation in a scale and a frequency compatible with the details possibility and disponible images.

After these definitions, the DEPRN contracted the FUNCATE - Spacial Science, Aplication and Tecnology Foundation to ensure this work introducing the necessary technics to the use of remote sensing in the routine of the forest control works.

METHODOLOGY

Figure 1 MAP OF BRASIL WITH SÃO PAULO STATE LOCALIZATION (WITHOUT SCALE)

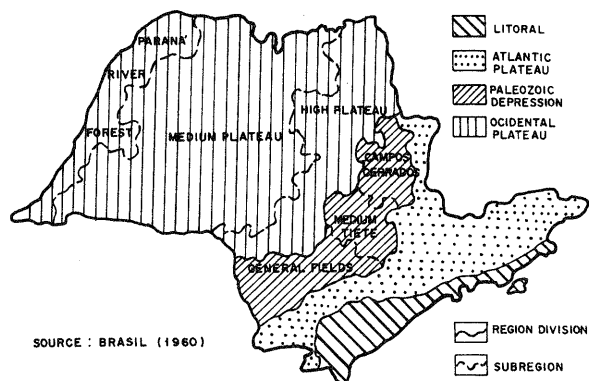


Study Area Characterization

The São Paulo State has an area of 24.379.900 ha, located between 19°45' and 25°10' latitud south and 44°05' and 53°10' longitude west. See Figure 1, map, without scale, of Brazil with São Paulo State localization.

Monbeig (1954) cited in Brasil (1960) divided the State in four regions: Litoral, Atlantic Plateau, Paleozoic Depression and Ocidental Plateau (Figure 2).

Figure 2 THE FOUR REGIONS OF SÃO PAULO STATE



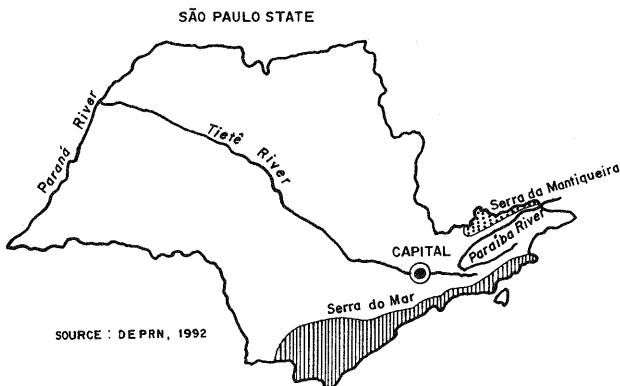
The Litoral goes from North to South and is characterized for the sedimentary prairies, with several hills and isolated massifs and is limited by the "Serra do Mar" (a sierra). The prairies are very extensives by the South side, until 80 km long. By the North side they are reduced, and in many places the "Serra do Mar" or the isolated massifs go directly in to the sea.

In the climatic classification of "Koeppen" there is in this region mainly two climatic subtypes: the tropical wet, without a dry season, with rain in the dryest month over 60 milimeters and the temperature of the warmest month over 18°C (climatic subtype Af); and the wet mesothermic climate, without a dry season, with the rain in the dryest month over 30 milimeters and the temperature of the warmest month over 22°C (climatic subtype Cfa).

The natural vegetation, according the Kuhlmann (1956) classification, there is a predominance of four formations: the tropical perene broadleaved forest, with trees until 30 meters high with a great variety of epiphytes and climbing plants; the "restinga" vegetation, xeromorphique, with dachshund formations near the tide line, shrubland and arboreal formations; the mangrove, the halophyc vegetation presents in the areas of the tide influence; and the meadow along river beds, that remains under the water during some periods of the year.

Because of the soil declivity and the low fertility, the natural ecosystems of the region are well preserved. This is the region of the State with more legaly protected area.

The Atlantic Plateau begins in the end of the Litoral band, through the abrupt slopes of "Serra do Mar" It is a region constituted by high lands and with some hills. The subltoraneous slopes and ridges of "Serra do Mar", the blocks of Plateau as the Bocaina and "Campos do Jordão" in the "Serra da Mantiqueira" (a sierra), and great extentions of hills in the Paraíba do Sul river basin with their valleys are in the region.



The predominant climatic subtypes are: in the low and plane part of the meadow of the Paraíba river the mesothermic climate of wet winter, with the rain in the dryer month inferior to 30 milimeters, the average temperature of the coldest month inferior to 18°C and the warmest superior to 22°C (climatic subtype Cwa); in the upper lands between the "Serra da Mantiqueira" and the "Serra do Mar", the mesothermic climate of dry winter has temperature of the warmest month above 22°C (climatic subtype Cwb); in the hills of "Serra da Bocaina" and "Serra de Paranapiacaba" (two sierras) nearest the sea, the mesothermic climate is wet without a dry season, with the temperature of the warmest month above 22°C (climatic subtype Cfb); and in part of the region the subtype Cfa as previously described.

The tropical broadleaved evergreen forest occurs in this region, mainly in the "Serra do Mar" and neighbouring. The other vegetal formations in this region are: the tropical semideciduous broadleaved occurs mainly in the Paraíba river valley, with trees of 15 to 30 meters high in the superior stratum with a few epiphytes; the subtropical needleleaved forest or "Araucaria Forest", mainly in the "Campos do Jordão" region; it is characterized by the presence of *Araucaria angustifolia* in a simple superior stratum; the mountain fields, present in restricted area of "Serra da Bocaina" and "Campos do Jordão"; and the meadows along river beds.

This region, very industrialized, shelters great part of the State population and presents problems. In this region is the capital of the State.

The Paleozoic Depression is constituted by a band as an arcle of a circle between the highlands of

Atlantic Plateau and a scarp crossed by rivers as the Tietê river. This region can be divided in three subregions: the "Campos Cerrados", great plane surfaces at 600 to 700 meters high; the Medium Tietê, with tabular surface with basalt spots; and the general fields with great plane surfaces and over 700 meters high.

The predominant climatic subtypes are the previously described: Cwa, Cfa and Cfb.

In this region, besides the tropical semideciduous broadleaved forest and the meadows along river beds, there is the "cerrado", wich has a variable structure but has its own characteristic as the presence of trees and shrubs with crooked stems and branches with thick barks.

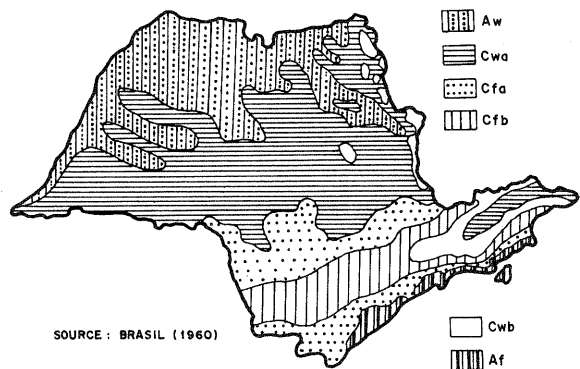
The Ocidental Plateau is characterized by a smooth relief. Its geographic delimitation is on the top of the "cuestas" around the Paleozoic Depression, between 800 to 1200 meters high and in the Parana river, between 30 to 250 meters. These smooth relief can be divided in three subregions: the High Plateau, the Medium Plateau and the Parana River Forest.

The predominant climatic subtypes are: in the North and Northwest of the State, the wet tropical climate with the rain season in the summer and the dry season in the winter (climatic subtype Aw); the Cwa climate occurs in a continuous band since the West, near the Parana river until the East of State, in the Paleozoic Depression region; and in some more high areas, distributed by the geographic region of climatic subtype Cwa, there is the subtype Cwb, previously described.

The vegetal formations in this region are the same described to the Paleozoic Depression region.

The Paleozoic Depression and the Ocidental Plateau regions have great part of their area ocupied with agriculture, siviculture and pastoral activities, mainly pastures, the sugar-cane culture, the Citrus culture, siviculture and annual crops as soyabeens and wheat.

THE CLIMATIC SUBTYPES OF SÃO PAULO STATE



1st Stage: Natural Vegetation Mapping

The mapping of the natural vegetation was divided in two phases. Preliminary was developed a pilot project, described by Hahn (1990) to test the methodology in determinated situations that represent the extention and the forecast diversity in the study area. The selected area represents 20% of the total area of the State (24,379,000 ha). The employed methodology was the visual interpretation of images in paper of bands 3 and 4 of the sensor Thematic Mapper (TM) of the Landsat-5 satellite in scale 1:100,000. In this phase the images utilized were relatif to 12 quadrants, with the Landsat passage between March 25th to September 10th of 1988.

During the pilot phase, the characterization of natural vegetation needed a selection of a system

based on the phisionomic-structural variations of the vegetal formations easier to be perceptible in the use of the remote sensing products (PONZONI, 1989). The adopted phisionomic classification follow, with small modifications that one utilized by CAMPOS (1926), AZEVEDO (1950), KUHLMANN (1956), SERRA FILHO (1975) and others, that is the one that presents the best adaptation to the utilized terminology in the ambiental legislation.

Forest: complex vegetal formation, constituted mainly by trees with great number of species. It has three distintive levels. The upper, relatively little dense, that is formed by individuals above 15 meters high, with cilinder stems and medium to high branches. The intermediary level, of high density is constituted by individuals of 5 to 10 meters and with a closed canopy. The lower level is constituted by herbs and shrubs and has some palm trees and arborescents ferns until 3 meters high.

"Capoeira": is a secondary vegetation that grows after deflorestation or a very degraded primary vegetation. It is constituted mainly by wood individuals of secondary grow and by spontaneous species of a fast grow that colonize the deflorested areas. It was not a definitive structure, has thin trees with a compact distribution and a small number of species.

"Campo": is a unity of vegetation characterized by the predominance of grasses and herbs. It can be classified in two subtypes: the altitude fields or mountain fields present on "Serra da Mantiqueira", and the clean fields.

"Cerradão": is a vegetal formation constituted by three distintive levels. The upper has a few trees, usually with 6 to 12 meters high, mainly hardwood. The intermediary level presents trees and shrubs of crooked stems and branches, with thick suber, big leaves and only a few thorns. The lower level has grasses and herbs from 0.3 to 0.5 high.

"Cerrado": is a formation of peculiar phisionomy characterized by individuals until 6 meters high, with crooked stems, covered by thick and ridged cortex, with low branches, asimetric canopy, great, thick and leather leaves, without thorns, epiphytas and lianas.

"Campo Cerrado": is a country vegetation, mainly grasses with some distant small trees and shrubs. Can be a transition form between the other types or a degraded form of a cerrado.

"Meadow Natural Vegetation" is a small vegetation with a variable structure, characterized by its resistance to periodic inundations and located in the lowlands along river beds

"Mangrove": typical litoral vegetation under the tide action. It has only one tree level with a low diversity. The trees have compatible adaptations to the environmental specificity as aerial roots, sustentable roots, pneumatophoros (sructures to facilitate the gas changes) and xeromorfisme increased by the high quantity of salt, humates and low tax of oxigenium in the soil. All these factors make difficult the water absorption.

"Restinga": typical formation of the sand litoral, mainly arbustive, xeromorphique increased by poorness and permeability of the sand soil and by the dryer action of the winds.

Arbor Formations with Areas Smaller than The Minimum Classificatory Thematic Unity: arbor formations smaller than 4.0ha to the regions of smooth relief and 9.0ha to regions with irregular surface not classified into the anterior subjects described because they do not present a characteristic pattern of spectral answer in the TM/Landsat images and would be highly expensive to characterize each one in the field.

After the positive evaluation of the obtained results in the pilot project the mapping was done to all São Paulo State. With the disponibility of

images in form of photographic collor products in scale 1:50,000 the methodology utilized in the begining was modified.

According to the results of ELBSERSEN (1973) and GREHS (1974) in the eletromagnetic spectrum band selection to the vegetation identification, we selected the TM/Landsat bands and tests were done with four types of collor compositions in red, blue and green in four different regions of São Paulo State. The composition of the bands 5-3-4, compared with the compositions 4-3-5, 3-2-4, and 4-2-3, permitted a better diferentiation between the defined themes in the legend and between the other components of the landscape. The selected bands acts in the follow spectral bands: 630 to 690nm (band 3), 760 to 900nm (band 4) and 1,550 to 1,750nm (band 5).

To select the interesting scenes we used the criterian of the maximum coverage of the clouds equal to 10%, good average visibility of the scene related mainly to the absence of the atmosferique fog and to the image ilumination conditions, and the date of the more recente satellite passage. A total of 159 images of 159 sub-quadrants were selected with the Landsat passages at March 27th of 1988 to April 20th of 1989.

The identification of geographic parameters of images was done based on the cartographic plane in scale 1:50,000 of the Geography and Statistical Brazilian Institute Foundation - IBGE or from the Geographic Service Diretory. Using poliester tercron papers over the IBGE opr DSG maps we delimited the geographic coordinates, urban areas, Municipalities limits, roads and water disposed nets.

After this the papers were put over the images looking for a better adjust and them a visual analyses of themes was done, and the occurence areas were delimited over the poliester paper. The visual analyses was based on the image elements as: tonality, collor, size form, texture, pattern, hight, shadow, localization and context.

Complementary to the image informations, data about anterior vegetation surveys of this area (BORGONNOVI, 1965 and 1967; CHIARINI, 1969 and SERRA FILHO, 1975), bibliographic revision and mainly aerial photography in the scales 1:35,000 and 1:45,000. The aerial photographs helped in the mapping of regions of irregular surface or difficult entrance.

Concluding this stage a field work to stablish the association in homogeneous pattern, identified in the images, with the correspondent unities of the vegetation presented in the field. To each map was selected the vegetation types to represent these patterns of image, and after this we went to a field verification. The field analysis was based on the phisionomic aspects of the vegetation. In some cases the field work clarified some interpretation doubts. Some helicopter flyghts were done in some regions of difficult acess with the same purpose.

After the corrections or confirmations on the preliminary image analysis, the thematic maps were done in poliester paper with nanquing ink in scale 1:50,000 resulting in the Natural Vegetation Mapping of São Paulo State.

2nd Stage: Counting Areas in Thematic Maps

The counting of the map areas into each class was done starting from the thematic maps

To do it we utilized: digitalization table, microcomputer PC and a digital planimeter. The method was the digitalization of the thematic maps and in the grouping of data in each theme and Municipality. The final data was totalized by Municipality, an amount of 584 Municipalities and joined in eletronic cards.

3rd: Monitoring the Natural Vegetation

Consists in the following of changes in the State natural vegetation starting from the initial mapping.

For this we brought two systems of modular images treatment, the SITIM 150, developed by the Spatial Researches Institute - INPE, and basically compound of a microcomputer, a semigraphic color video terminal and a keyboard, two unities of a floppy disk, one unity of hard disk, one unity of tape and a set of programs. To the SITIM is associated a geographic information system, the SGI, developed by INPE and a digitalization table.

Preliminary was introduced in the SGI, through digitalization, the informations of the 408 maps of the Natural Vegetation Mapping of São Paulo State. Each map was considered as a project. To each project we created informations planes with geographic elements as: roads, hidrography and vegetation. This last information plane was introduced in the form of polygons correspondent to the natural vegetation divided in nine classes according the nine themes previously described.

The utilized images in this stage were obtained in form of digital products in tapes type "streamer" compatible with the SITIM system. They are in quadrants, with the bands 3, 4 and 5 of the TM/Landsat and with geometric corrections of the system done by resampling of the cubic convolution type. The interesting scenes are selected following the same criterious used in the mapping phase.

The received image are registrated and turned into the system of cartographic projection of IBGE and DSG, permitting to superpose the images to the thematic maps. To the visual analyses of images we utilize operations in the visual unity that objective the superposition of the three used bands and the manipulation of the contrast to a best combination of the colors red, blue and green, and the superposition of the informations plane.

The image analyses is done to detect the changes after the mapping. The changes can be positives, when increase the vegetation areas; or negatives, when deforestation occurs; or classificatory changes, when the area presents a kind of vegetation different of the map. These data are wrote on the mapping papers and in cards. In cards we write the collected informations from the analisis of images and after we write the field informations about the extention of the modified

area, the localization and its situation related to legally protected areas or, the conservation unities in the State with a Federal, State or Local administration. To this work another informations plans were introduced as state parks, ecological stations, biological reserves, special protected areas, ambiental protected areas, falling areas, forestal reserves, indian areas, and so on. Other collected informations in the cards are relative to the DEPRN action on this area, as the control that can be a administrative penalty and reports to the Public Ministry to support civil actions, or the activities of licensing, consession of licenses and certified documents.

In this stage were analysed 52 images correspondent to 49 quadrants. The scenes related to the Landsat passage of December 30th of 1990 to the September 14th of 1991. The area studied is 90% of the State territory.

RESULTS

The results of the mapping are presented as 408 maps in the scale 1:50,000 and all together is the Natural Vegetation Mapping of São Paulo State.

The Table 1 presents the results of the counting of the thematic maps areas. In this Table the State is divided in three regions, that are the actuation area of each DEPRN Regional Division (Figure 3).

During the monitoring, 90% of the São Paulo State territory was studied by the analyses of 52 TM/Landsat images. Now the work is in the field check about the changes detected in the images to posterior actualization of mapping. The collected informations from the images, mainly the negatives ones, show priority areas to the DEPRN actuation. Figure 3

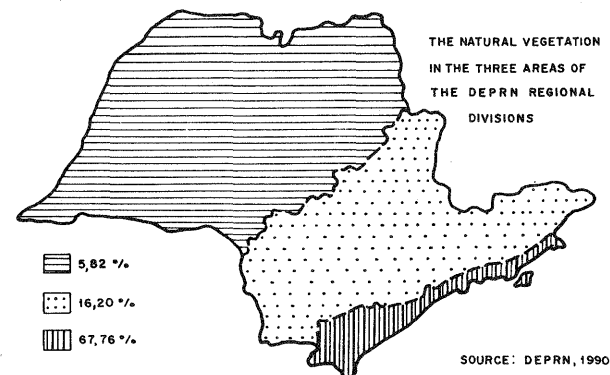


Table 1 NATURAL VEGETATION OF SÃO PAULO STATE

REG.	SURFACE (Ha)	FOREST	%	CAPOEIRA	%	CERRADÃO	%	CERRADO	%	CAMPO CERRADO	%	CAMPO	%	MEADOW NAT. VEG.	%	RESTINGA	%	MANGROVE	%	AREA WITHOUT CLASSIF.	%	TOTAL	%
1	8,646,300	637,739	7.38	663,947	7.91	4,234	0.05	24,065	0.28	338	—	615	0.01	26,070	0.30	—	—	—	—	23,858	0.28	1,400,891	16,20
2	14,087,500	314,787	2.23	160,070	1.14	68,940	0.49	184,561	1.31	1,494	0.01	—	—	68,491	0.49	—	—	—	—	22,141	0.16	820,488	5.82
3	1,646,100	894,438	54.34	139,896	8.50	—	—	—	—	—	—	1,317	0.08	39,515	2.40	31,609	1.92	8,054	0.49	545	0.03	1,115,377	67.76
TOT	24,379,900	1,846,966	7.58	983,914	4.04	73,175	0.30	208,647	0.86	1,833	0.01	1,933	0.01	134,077	0.55	31,609	0.13	8,054	0.03	46,545	0.19	3,336,757	13.69

SOURCE: DEPRN, 1990

CONCLUSIONS

The use of TM/Landsat satellite sensing image to mapping and monitoring the natural vegetation is a help in the planning of control and licensing the

natural resources, contributing to increase the quality, speed and efficiency of these activities. The continuity of this work will have the continuous monitoring of State natural vegetation and the introduction in the SGI of more

informations useful to the licensing, for example, the water captation point to the public distribution and the parts of each private land legally protected, denominated Legal Reserves (art. 16 of Federal Law 4771/65).

The possibility of periodic observation of all São Paulo State territory including areas of difficult access, and the optimization of limited resources as human, cars and equipments make this work a success.

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