CIR AERIAL PHOTOGRAPHY APPLIED TO THE EVALUATION OF THE AIR POLLUTION IMPACT IN A TROPICAL FOREST: THE CASE OF CUBATÃO - BRAZIL

Dalton de Morisson Valeriano
Flávio Jorge Ponzoni
Instituto de Pesquisas Espaciais - INPE
Ministério da Ciência e Tecnologia - MCT
Av. dos Astronautas, 1758 - Caixa Postal 515
CEP 12201 - São José dos Campos, SP, Brazil

ABSTRACT

A 1:25,000 CIR air survey was utilized to map and evaluate the extent of the damage caused by the air pollution originated from Cubatão city's industrial plant on the Tropical Forest that covers the Serra do Mar mountain range in South-eastern Brazilian coast. The survey covered an area of $240km^2$ and encompasses a heavily damaged drainage basin and a preserved one. One primary forest and four secondary types were identified in the preserved area by means of their tonal and textural characteristics. Four types of damaged forest covers were discriminated in the polluted valley on the basis of the density and size of the remnant trees. DBH and tree height field measurements of these cover types reveal that the degradation process of the Tropical Forest takes place as a progressive elimination of the larger trees. Although the proliferation of smaller plants follows this process, the impact of the air pollution in the forest favors the occurrence of landslide in the rainy season.

1. INTRODUCTION

Along the southeastern coast of Brazil stretches a mountain range named "Serra do Mar" , which is a tectonic scarp that comprises the eastern border of the Brazilian Cristaline shield. It presents steep slopes in its eastern face and can reach altitudes that vary from 800 m to 2000 m (3).

As a natural barrier to the sea breeze it promotes high precipitation (over 1500 mm/year) well distributed over the year (4). Due to this water availability a Rain Forest originally covered the Serra do Mar and most of the adjacent coastal plains. It is generically named Atlantic Forest, a subdivision of the forests that once occupied the southeastern portion of South America (2).

In Brazil these forests were mostly converted for agricultural uses. The remainder are few and concentrated in the mountain ranges. The steepnees of their slopes hampers the timber logging which is the initial phase of the forest conversion.
These slopes are also subject of intense land forming processes which are consequences of their steepness, associated with the high level of precipitation. Landslides is one of the processes that take place in the relief forming in the Serra do Mar (1).

The dense forest cover promotes a delay in this erosive process since it can develop strong roots that envolves the bolders which results in a resistance to their movement. It also avoids infiltration and soil saturation by rain interception, favored subsurface flow, and by high rate of transpiration (6).

Due to the proximity of the cities of São Paulo and Santos, respectively the largest city and the largest port of Brazil, an industrial complex was instaled in the city of Cubatão, on the foothill of the Serra do Mar (Figure 1).

Beginning in the late fifties with a steel plant, it now comprises circa 30 industries in the areas of metallurgy, oil refinery and petrochemistry. Until recently few pollution control measures were observed which resulted in intense impact on public health, on the adjacent estuarine and mangrove wetland ecosystems and on the upland forested ecosystem.

The local atmospheric circulation pattern channels the gaseous output of the industrial complex into an adjacent valley: The Mogi river valley. Atmospheric thermal inversion contributes to the concentration of the pollutants within the valley.

Today the forest cover presents a degradation in its biomass structure comparable to the second and third stages of the pollution impact model on forest ecosystems proposed by Woodwell (1970) (7). According to this model, derived from the observation of forest covers exposed to pollutants of different nature (chemical and radio-active), the impact of the pollution on the ecosystem structure of a forest follows successive steps. At first there is a reduction of species composition due to the death of the ones which are more vulnerable to the effects of the pollutant. This stage is followed by the defoliation and death of the largest trees which can be followed by intense growth of the understory elements. This can lead to the disruption of the mechanisms for the maintenance of the ecosystem homeostasis (5) which gives place to the third stage, characterized by the reduction of the biomass and the loss of nutrients by the ecosystem, that looses its capacity to recover from the impact. Intense insect herbivory and accelerated erosion are likely to occur during the third and the second stages.

The objective of this report is to present an application of color infrared (CIR) aerial photography to the assessment of the impact of the air pollution on the biomass structure of the Atlantic Forest on the Serra do Mar near Cubatão.

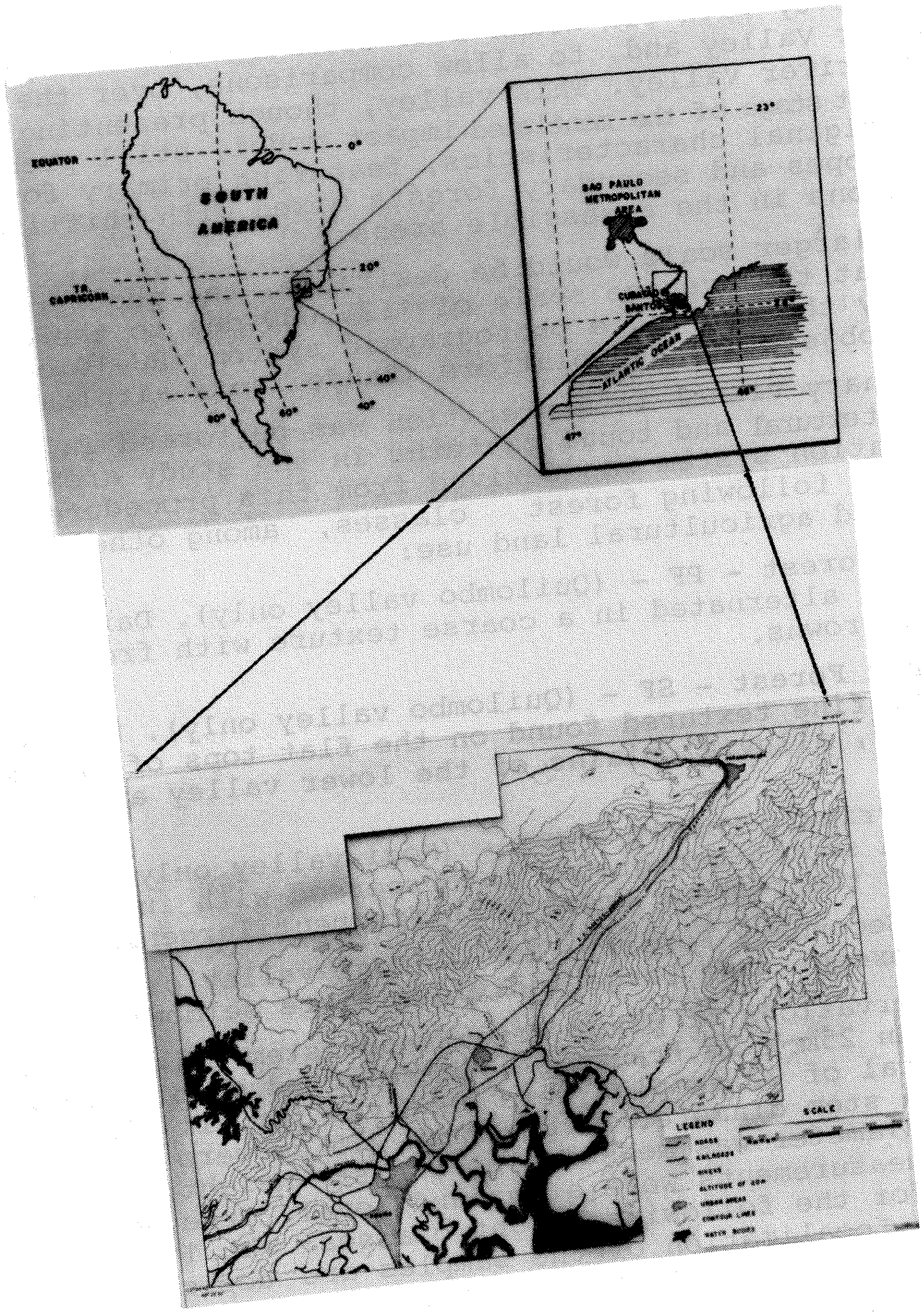

Figure 1 - Localization of the study area and of the ground verification sites.

2. METHODOLOGY

An air survey with CIR Kodak 2443 film was executed over the Mogi river Valley and, to allow comparisons, over the adjacent Quilombo river valley. This valley, though presenting evidences of the first stage of the mentioned impact model, still preserves much of its original characteristics, featuring primary forests in the midslopes and secondary forests mixed with shifting cultivations in the accessible areas.

Though a larger scale would be desirable, the photographs were obtained at the average scale of 1:25,000 due to the constraints imposed by the available photographic system (RC-10 camera with a 150 mm objective) and platform (Bandeirante airplane).

A preliminary visual interpretation was performed in order to identify textural and tonal patterns in the study area. An attempt classification system was derived from this procedure, discriminating the following forest classes, among others related to urban and agricultural land use:

- Primary Forest - PF - (Quilombo valley only). Dark magenta and cyan alternated in a coarse texture with frequent large rounded crowns.
- Secondary Forest - SF - (Quilombo valley only). Dark or bright magenta, fine textured found on the flat tops of the mountains, foothills, alluvial plains of the lower valley and on landslide scars.
- Damaged Primary Forest - DPF - (Mogi valley only). Light magenta with a smooth background interspersed with individualized crowns of the remnant trees with frequent large individuals.
- Damaged Secondary Forest - DSF - (Mogi valley only). The same as DPF, except that large individuals are seldomly found.

Field observations of plant height and stem diameter were conducted in 25m x 2m transect in selected samples of each class. A total of 32 samples were observed for all classes. Only plants with stem diameter larger than 2.5 cm were considered. Tree stem diameter was measured at breast height; for the shrubs the measurements were at ground level. Tree height was estimated for the following height classes: <1m, 1-2m, 2-5m, 5-10m, 10-20m, >20m. Localization of the samples are depicted in figure 1. Decision for sample allocation were based on accessbility, size and internal homogeneity of the area covered by the class under consideration and representativeness of this area of the photographic pattern of the class. Due to time constraint no attempt were made toward a floristic characterization of the analised vegetation covers.

The analysis of the field data indicated that it was possible to discriminate two damage intensity levels for the Damaged Primary Forest. It was also found that a non-forested class, previously considered as an anthropogenic grassland was in fact an intensely damaged Secondary Forest, reduced to a scrub with few small trees and palms protruding over the smooth scrubbish canopy. Large anthill and charcoals are commonly found in these areas.

Therefore, besides PF and SF classes, the final classification system presents the following forest and forest related classes:

- Moderately Damaged Primary Forest - MDPF - A subdivision of the DPF with Cover Index for remnant trees layer above 50%.
- Heavily Damaged Primary Forest - HDPF - The complement of the above class with the mentioned Cover Index below 50%.
- Moderately Damaged Secondary Forest - MDSF - The some as the formerly defined DSF.
- Heavily Damaged Secondary Forest - HDSF - Light magenta with a very smooth aspect with sparse dark spots corresponding to the small trees and palms. Restricted to the surroundings of the industrial plant.

A final photointerpretation was realized after the definition of the classification system, and its results were transfered to a 1:25,000 topographic map with the aid of a Zoom Transfer Scope.

3. RESULTS AND DISCUSSIONS

The final map comprises a set three 1:25,000 quadricule (7'30^{o} x 7'30^{o}) which does not permit its reduction for the presentation in this report with the maintenance of its pictorial information. It clearly demonstrate that all of vegetation cover of the Mogi valley falls into one of the damaged classes with the highest intensity classes concentrated around the industries and along the valley floor.

On the other land, the Quilombo river valley still preserve its forest structure without any evidence of pollution impact on this feature of the ecosystem.

The pattern of the degradation of the biomass structure of the forest cover is demonstrated in Figure 2, where histogram of tree count per 100m² is presented by height class for the PF,MDPF, and HDPF classes.

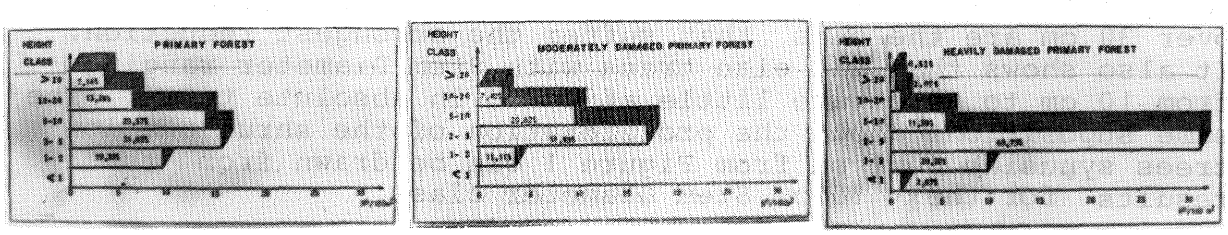

Figure 2 - Vertical profile of the forest structure for the Primary Forest and related classes.

The progressive thinning out of the top layer of the forest structure is evidenced by the reduction of the proportion of trees with height superior 10m from circa 20% in the PF class to ca. 7% in the MDPF and to less than 3% found in the HDPF.

The proliferation of the understory elements is described in the HDPF histogram. Assuming these classes in a chronological sequence, one can supose that either there is a delay in the response of this synusiae to the opening of the above canopy or there is a threshhold for the triggering of its intensive growth.
The corresponding impact on the Basal Area Distribution can be observed in Table 1.

Stem Diameter Class	PF		MDPF		HDPF	
	nº trees/ 100m²	%	nº trees/ 100m²	%	nº trees/ 100m²	%
> 30 cm	3.5	7.14	0.8	2.47	0.5	1.03
20–30 cm	3.0	6.12	1.2	3.70	3.5	5.62
10–20 cm	6.0	12.24	6.4	19.75	6.0	10.36
< 10 cm	30.5	74.48	24.0	74.87	40.5	88.08

Table 1 - Stem Diameter distribution for the Primary Forest and related classes.

Table 1 demonstrates that the large trees, with Stem Diameter over 30 cm are the ones that suffer the strongest reduction. It also shows that mid-size trees with Stem Diameter ranging from 10 cm to 30 cm are little affected in absolute terms. The same supositions about the proliferation of the shrub and low trees synusiae derived from Figure 1 can be drawn from the results for the < 10 cm Stem Diameter class.

The Secondary Forest was found to be more vulnerable to the atmospheric pollution than the Primary Forest. This can be due to the coincidence of its occurrence near the areas where the industries were installed or to the fact that as disturbed ecosystems, it possess weaker mechanisms for the maintenance of ecosystem homeostasis.

Figure 3 shows the Plant Height histograms for the SF, MDSF and HDSF, where the drastic degradation of the biomass structure of the Secondary Forest is evident.

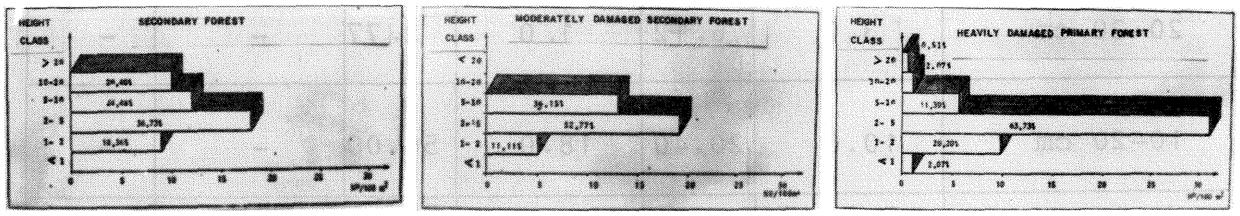

Figure 3 - Vertical profile of the forest structure for the Secondary Forest and related classes.

The larger number of trees in the highest height class for the SF class is the aspect which is responsible for its fine texture in the aerial photographs. The high percentage of understory plants is also a typical characteristics of secondary growth communities.

The histogram for MDSF shows evidences of an increase in the intensity of the air pollution impact on the forest structure when compared with the degraded primary forests. The height of the stand is very reduced with a high percentage of intermediate plants.

A peculiarity of this class is the high percentage of palm trees which reaches ca. 64% of the total of the considered plants. Though spreaded over all of the subformations of the Atlantic Forest, palm trees feature high concentrations in the Coastal Plain fascie of this forest formation, but not with such high frequency. Therefore a mechanism is acting in the way to favor the palm trees populations.

The HDSF completely lost its forest structure becoming a scrub. Evidences of fire and insect outburst suggest a great difficulty of natural recovery of this vegetation toward a forest assemblage.

Table 2, which depicts the Stem Diameter distribution of those three classes shows not only the elimination of the larger trees but also a reduction in the number of plants that were considered in this work. This is a reflection of the loss of biomass that occurs in the last stage of forest degradation model previously described.

Stem Diameter Class	SF		MDSF		HDSF	
	nº trees/ 100m²	%	nº trees/ 100m²	%	nº trees/ 100m²	%
> 30 cm	1.0	2.04	-	-	-	-
20-30 cm	3.0	6.12	1.0	2.77	-	-
10-20 cm	10.0	20.40	18.0	50.00	-	-
< 10 cm	35.0	71.42	17.0	47.23	18.0	100.00

Table 2 - Stem Diameter distribution for the Secondary Forest and related classes.

4. CONCLUSIONS

Besides the assessment of the spatial distribution of the different impact levels in the study area, the main result from this work is the demonstration of the utility of aerial photography to the evaluation of the structural organization of forest stands with different characteristics and under different external pressures.

5. BIBLIOGRAPHY

1. CRUZ, O.; A Serra do Mar e o litoral na área de Caraguatatuba: contribuição à geomorfologia litorânea tropical (The Serra do Mar and the coast in the Caraguatatuba region: contribution to the tropical coastal geomorphology). São Paulo, SP, Brazil, IG-USP, Serie Teses e Monografias, 11, 1974,181 pp.

2. HUECK, K.; As florestas da América do Sul - ecologia, composição e importância econômica (The Forest of South America - ecology, composition and economic value). São Paulo, SP, Brazil, Editora Polígono, 1972, 466 pp.

3. MOREIRA, A.A.N.; CAMELIER, C.; Relevo (Relief) In: IBGE, Geografia do Brasil - Região Sudeste (Geography of Brazil - Southeastern Region). Rio de Janeiro, RJ., Brazil, FIBGE, 1977, p.1-50.

4. NIMER E.; Clima (Climate). In IBGE, Geografia do Brasil - Região Sudeste (Geography of Brazil - Southeastern Region) Rio de Janeiro, RJ, Brazil, FIBGE, 1977, p.51-89.

5. ODUM, E.P.; The strategy of ecosystem development. Science, Vol. 164 (3876): 262-270.

6. PRANDINI, F.L.; IWASA, O.Y.; OLIVEIRA, A.M.S.; A cobertura vegetal nos processos e evolução do relevo: o papel da flo-

resta (The vegetation cover in the relief processes and evolution: The role of the forest). Silvicutura em São Paulo, V 16 A, part 3: 1568-1582, 1982.

7. WOODWELL, G.M.; Effects of pollution on the structure and physiology of ecosystems. Science, Vol 168 (3930): 429-433, 1970.