An Assessment of Rainforest Change Using Satellite Images for the Bragantina Region of the Amazon River Basin

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ABSTRACT

Satellite technology has allowed for the evaluation of changes in the Amazon rainforest that might otherwise be difficult to assess. This study focuses on the region of Bragantina in the state of Para, Brazil. Two Landsat Thematic Mapper satellite images, from 1984 and 1994, were analyzed to evaluate the change in forest area. A classification was made for both images, producing maps that show major land cover/land use types. Statistical comparisons were made to evaluate changes from 1984 to 1994. The study area included approximately 74,331 hectares of advanced secondary succession/mature rainforest in 1984; by 1994 this had been reduced by 12,254 hectares to approximately 62,077 hectares. The results indicate, however, that during this period approximately 35,116 hectares of mature rainforest were logged or burned, but that 22,862 hectares of previously cleared land and early secondary succession forest regenerated into advanced secondary succession/mature rainforest. Although this suggests that a large portion of deforestation is being mitigated by reforestation, most of the reforested areas are fragmented into small noncontiguous parcels of land.

INTRODUCTION

Satellite remote sensing and spatial interpretation technology has allowed the scientific community to study large expanses of land and observe how it changes over time. One region that is ideal as a subject of satellite-based study is the Amazon River basin and its associated rainforest. The Amazon basin covers approximately 3.9 million km^2 of the South American continent and represents one of the most ecologically diverse ecosystems on Earth (Moran, 1990, Tucker *et .al.*, 1998). The rainforest in this area is threatened by logging, clearing for agriculture and urbanization. In 1975 only 30,000 km^2, or 0.6 %, of the Amazon rainforest had been cleared (McCracken *et. al.*, 1999). Since then, the rate of deforestation has steadily increased. By 1992 over 11% of the Amazon had been deforested (Mausel *et. al.*, 1993). The area cleared exceeded 15% (approximately 600,000 km^2) in 1998 and continues to expand (McCracken *et. al.*, 1999).

This paper presents research that examines forest and other land use/land cover change between 1984 and 1994 in the Amazon region of Bragantina in the state of Para, Brasil. The study area is located between 0º 45´ S and 1º 39´ S latitude and 46º 16´ W and 48º 15´ W longitude and surrounds the market town of Igarape-Açu. The study assesses change within the context of the following research questions: (1) was deforestation greater than reforestation between 1984 and 1994 and (2) how have different land cover/land use types affected the landscape?

An understanding of settlement history, farming practices and succession are necessary to interpret the changing landscape of this region. Such background information provides insight into why a region is divided a particular way and is essential to the interpretation of spatial data.

Bragantina is now dramatically different from what it was a century ago (Tucker *et. al.*, 1998). The initial attraction to the area was the rubber boom that occurred in the late 1800's, when old growth mature trees were first harvested so that natural rubber could be extracted and sold (Brondizio and Siqueira, 1997). This attraction to the virgin timber led to a large increase in regional population (Tucker *et. al.*, 1998). With this growth, the demand for agricultural products increased and the government responded with a colonization program to develop agriculture in the region (Tucker *et. al.*, 1998). This shift from logging to farming has had a dominant effect on the landscape (Brondizio and Siqueira, 1997).

Agriculture is currently a major contributor to rainforest deforestation in Bragantina (McCracken *et. al.*, 1999). The assumption that all farming involves clearing and burning large expanses of land is erroneous. Instead, the settlement history characterizes the farming practice and vegetation stage of a particular land parcel (McCracken *et. al.*, 1999). During the beginning stages of a smaller swidden farming operation only about 2 to 5 hectares of forest are cleared. Cash crops (e.g. maize and manioc) are grown until the soil fertility is depleted, and then the farm is either left to return to forest, converted into pasture for cattle grazing or converted into a perennial crop (e.g. black pepper and fruit trees). In contrast to smaller farming, larger farming operations plant perennial crops from the outset (McCracken *et. al.*, 1999).

Since agriculture is a leading factor in forest change, it has a large impact on successional patterns. There are three main stages of succession in this region: early secondary succession (SS1), middle secondary succession (SS2) and advanced secondary succession (SS3). SS1 occurs when an area is taken over by woody growth and is no longer able to support grazing (Moran and Brondizio, 1998). It is characterized by young species of vegetation that have, in the past, been deforested or cultivated (Moran and Brondizio, 1998). SS2 is characterized by a short life cycle, an increase in biomass and a high growth rate (Tucker *et. al.*, 1998). Although there are a large number of small trees, saplings dominate the area. Shade becomes more apparent in SS3 as the canopy closes (Moran and Brondizio, 1998) and the pioneer species die off and slower growing mature species begin to develop (Tucker *et. al.*, 1998).

Although succession occurs rapidly in the Amazon, the re-growth rate varies with the amount of soil nutrients, which in turn, varies the successional stage (Tucker *et. al.*, 1998). Different amounts of nutrients support distinct species of vegetation (Tucker *et.al.*, 1998). Overall, successional re-growth in Bragantina is relatively slower compared to other regions of the Amazon because the soils are mostly nutrient poor (Moran and Brondizio, 1998).

The area's settlement pattern also affects the succession of a forest (McCracken *et. al.*, 1999). Typically areas closest to a city are deforested first. Once trees are cleared they begin to re-grow if the land is not maintained. During economic boom more trees are cut, while during a recession agricultural land that is not maintained will begin to grow and the succession process starts (Brondizio, 1999).

METHOD

Landsat Thematic Mapper (TM) images from 1984 and 1994 were used to asses land cover/land use change. The images were georeferenced to the Universal Transverse Mercator

(UTM) coordinate system and were processed and classified using the ERDAS Imagine® 8.4 digital image processing software (ERDAS, 1999). Both images have a spatial resolution of $30m^2$. The green (0.52-0.60μm), red (0.63-0.69μm), near-infrared (0.76-0.90μm) and two mid-infrared (0.76-0.90μm and 2.08-2.35μm) bands were used in the classification. Before classification, it was necessary to de-haze the 1994 image using a haze reduction algorithm. Haze was present in the image due to smoke from the slash-and-burn forest clearing method of swidden agriculture.

The images were classified using the Iterative Self-Organizing Data Analysis (ISODATA) algorithm unsupervised classification and land cover/land use (LCU) maps were created. This classification technique involves allowing the computer to group image pixels into spectrally-defined classes, or clusters (ERDAS, 1999). The analyst identifies the resulting clusters in terms of the desired LCU classes. ISODATA clustering was performed three separate times on each image using 15, 30 and 40 clusters. Analysis of the results determined that 30 and 40 clusters produced more information than necessary and increased the difficulty in distinguishing spectrally similar clusters. Thus the results of the 15 cluster classification were used. The original 15 clusters were merged to obtain classes: water, SS3/mature forest, SS2/SS3 forest, SS1/SS2 forest, sparse vegetation (mostly stressed crop, shrub or grasses), crop/pasture (healthy) and urban/bare ground.

The process of determining classes based on clusters was done through the interpretation of spectral signatures. Each LCU class was identified by examining the relationship of reflectivity (digital numbers) in the different wavelength bands. Cluster statistics were analyzed and then verified visually by examining the images. Next, each cluster was attributed by assigning a color to see if the interpretation was logical. Viewing the image was important because many spectral signatures were similar, especially in the forest classes. Factors that dealt with the life cycles of forests, deforestation and reforestation were used in the image interpretation. These included elements such as forest proximity to an urban area or a water body, as well as the natural growth stages of the forest.

After classes were determined and the maps created, statistics were collected and land cover change was assessed. For the two maps, the area (in hectares) and percent of land area for each LCU class were obtained. The change analysis was done by performing a matrix function. A matrix function is used to determine the areas of coincidence for each LCU class between the two maps (ERDAS, 1999).

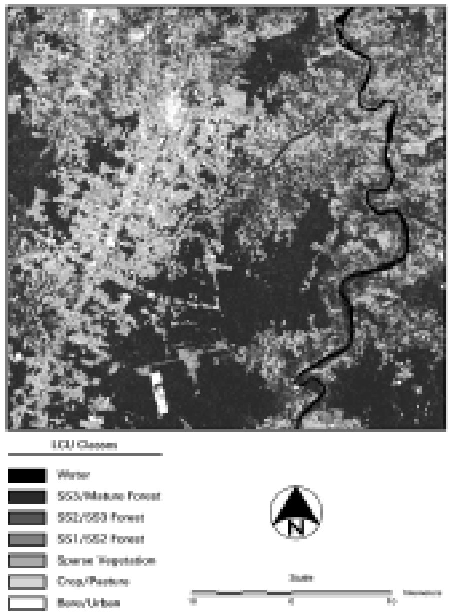
RESULTS

Both deforestation and reforestation were analyzed by LCU class. The statistics for LCU class change are displayed in Table 1. The classification maps are shown in Figures 1 (1984) and 2 (1994). An examination of the statistics and maps indicates that there is evidence of significant change between 1984 and 1994.

One class of particular interest is the SS3/mature forest class. Of the original 74,331 hectares in 1984, only 39,215 (52%) remained in 1994. However, with re-growth in many previously cleared areas, SS3/mature covered 62,077 hectares in 1994, for a total loss of only 12,254 hectares. The spatial pattern of forest clearing can be seen when comparing the1984 map (Figure 1) with the 1994 map (Figure 2). On the 1984 map there is a large grouping of SS3/mature in the southern section. Fragmentation of this area, along with smaller areas of continuous mature forest, is evident on the 1994 map. Many areas of re-growth are difficult to distinguish on the 1994 map (Figure 2) because most are fragmented into small areas and visually overwhelmed by the surrounding non-forest classes. Also, usually a forest is first cut close to an urban center and is gradually cut back deeper and deeper into the forest area. As the urban center expands, as displayed in the 1994 map, the SS3/mature forest class is converted to urban, crop/pasture or sparse vegetation. Approximately 15,634 hectares of the 1984 original SS3/mature area was lost due to conversion into sparse vegetation, crop/pasture or urban/bare ground. Approximately 7,996 hectares were cleared but were allowed to regenerate into secondary succession class SS1/SS2.

Figure 1: 1984 Land Cover/Land Use Classes

Bragantina, Para, Brazil



The statistics for SS2/SS3 class indicate that approximately13,641 hectares (39.6%) of this class in 1984 re-grew to the SS3/mature forest in 1994. Statistics also suggest that deforestation occurred in the SS2/SS3 class. Approximately 7,538 hectares (36.8%) of the SS2/SS3 forest class was cut down and converted to sparse vegetation, crop/pasture, or urban/bare ground. Both deforestation and regrowth are also evident for the SS1/SS2 class. Approximately 3423 hectares (36.1%) of the area matured from SS1/SS2 to SS2/SS3 or SS3/mature class; while approximately 6,036 hectares (63.7%) of the forest was cut down and converted into sparse vegetation, crop/pasture or bare/urban ground.

An overall assessment of LCU change indicates that although deforestation during the study time period took a toll on the rainforest in Bragantina, there was considerable reforestation.

Approximately 45,996 hectares of all stages of forest (SS3/mature, SS3/SS2, SS1/SS2) were lost to sparse vegetation, crop/pasture or urban/bare ground. Reforestation from sparse vegetation, crop/pasture, or urban/bare ground to the combined forest classes totaled 39,818 hectares. It is important to note that of this reforested area, the majority (31,862 hectares) returned to earlier secondary succession classes and not SS3/mature forest. With the continual plot rotation of local swidden agricultural practices, a large amount of this area most likely will be cut down repeatedly.

DISCUSSION

The results of this study provide insight into how the Amazon rainforest is changing. It shows that even with forest regeneration, the mature old growth rainforest is being depleted in the Bragantina region. However, because the Amazon regenerates quickly, it is highly unlikely that development will take over the entire area. Fast regeneration and succession will most likely aid in the recovery of the rainforest. Nonetheless, one issue that the inhabitants of this area need to resolve is improving conservation, since different land use practices affect the regeneration and fragmentation of the rainforest (Moran, 1990). Because the rainforest is so large, complete enforcement of conservation laws and local regulations is impossible (Brondizio, 1999).

More research using remote sensing needs to be done to assess land cover and land use change in the Amazon (Moran and Brondizio, 1998). The use of more recent satellite images would improve our understanding of the changes currently occurring in the region. Unfortunately, due to the high cost of current satellite images, this study was limited to using older images. Still, even with this limitation, the research shows that satellite remote sensing can be used to monitor deforestation. The results of studies such as this one could be used to increase awareness of the threat to the environment and perhaps encourage voluntary conservation efforts. If the people of Brazil are aware of how their decisions and actions affect the Amazon landscape, the rainforest will survive as one of the world's most valuable resources.

Figure 2: 1994 Land Cover/Land Use Classes

Bragantina, Para, Brazil

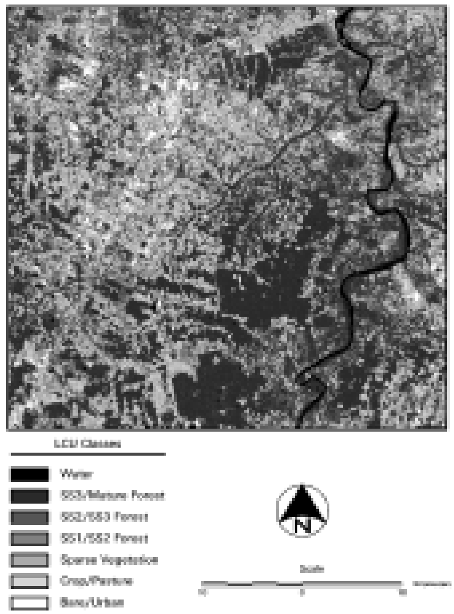


Table 1. Total Area (hectares) and Percent of Area LCU Change, 1984 to 1994.

	1994 LCU Classes					
1984 LCU Classes	**SS3/Mature**	**SS2/SS3**	**SS1/SS2**	**Sparse Vegetation**	**Crop/ Pasture**	**Bare/ Urban**
SS3/ Mature	39,215 (52%)	11,484 (15.4%)	7,996 (10.7%)	5,182 (6.9%)	8,532 (11.4%)	1,919 (2.6%)
SS2/SS3	13,641 (39.6%)	8,036 (23.3%)	5,153 (14.9%)	2,257 (6.6%)	4,274 (12.4%)	1,007 (2.9%)
SS1/SS2	1,267 (13.4%)	2,156 (22.6%)	2,695 (28.4%)	857 (9.1%)	2,019 (21.3%)	463 (4.9%)
Sparse Veg.	4,917 (15.9%)	6,172 (20.1%)	8,643 (28.1%)	2,710 (8.8%)	6,122 (19.9%)	2,111 (6.9%)
Crop/ Pasture	2,590 (9.5%)	5,443 (19.9%)	8,058 (29.5%)	2881 (10.5%)	6,558 (23.9%)	1,781 (6.5%)
Bare/ Urban	444 (5.3%)	1,118 (13.4%)	2,428 (28.9%)	1,049 (12.5%)	1,995 (23.8%)	1,327 15.8%)

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