SATELLITE DETECTION OF DEFORESTATION [1]

Steven E. Dicks and James A. Henry

The destruction of forests, along with desertification, is considered one of the most important land cover alterations presently occurring. Among the many potentially detrimental impacts on the environment are possible climatic changes. Potter et al. (1975) and Shukla and Mintz (1982) employed atmospheric circulation computer modeling techniques to show that substantial local and large regional disturbances in precipitation and circulation are possible by large scale deforestation. Henderson-Sellers and Gornitz (1984) modeled the effects that forest clearing might produce to increase surface albedo. They studied a worst-case scenario by simulating the equivalence of thirty-five to fifty years of deforestation at the current global rate (0.6 percent), but entirely concentrated in the Brazilian Amazon. They modeled a replacement of 4.94 million square kilometers of tropical moist forest with grass/savanna and concluded that rainfall in the cleared area would decrease approximately 200 mm per year, annual evapotranspiration would be 180 mm less, and cloud cover could be reduced as much as 15 percent.

A great deal of emphasis has also been given to the rise in atmospheric carbon dioxide produced by large-scale tropical deforestation. Recent lines of evidence suggest that forests loom large in the carbon dioxide balance of the atmosphere. Perhaps 55 percent of the stored carbon on land occurs in the tropical forests, so these areas represent a substantial pool of carbon, and tropical deforestation has the potential of changing the carbon dioxide content of the atmosphere.

A comprehensive review of the rates and causes of deforestation in developing countries is given in Allen and Barnes (1985). Clearly evident is a wide disparity in published estimates of forest clearing rates. Because of this disparity, remotely sensed data are increasingly being applied to deforestation mapping to obtain a more consistent and replicable data source. Common sources include air photos, radar, and satellite products. Landsat satellite multispectral scanner (MSS) imagery and digital data have been among the most widely used and have proven useful for forest and clearcut mapping for a variety of forest types and locations.

The long range objective of our study is to determine forest removal rates in tropical/subtropical areas, specifically in portions of Brazil and Florida, using Landsat satellite data and digital processing techniques. The first area chosen to study, and the one reported on here, is in the Amazon Basin of Brazil, where an area roughly the size of Connecticut is cleared each year. As noted below, the area has some factors in common with Florida, which should facilitate the future adaptation of the technique in the state. Another recent Florida/Brazil study (Myers 1986), which discusses nuclear winter effects in the tropics, addresses vegetational differences and similarities between the two areas. Because the vegetation cover is more heterogeneous in Florida, the Brazilian area, with its more uniform cover, should be a logical area in which to develop and test the technique. The potential application of the method in Florida is briefly discussed in the last section of the paper.

Study Area

The site analyzed here is located in the state of Para in the Amazon region of Brazil and encompasses 11,573 square kilometers (Fig. 1). The climate varies from tropical monsoon in the west to tropical wet-and-dry in the east. The area is in the transition zone between the drier northeast and the wetter

Amazon rainforest. The primary vegetation types are isolated tree savanna, parkland savanna, mixed open forest, and submontane forest. Forests cover 85 percent of the study area.

Para is one of the states in Brazil in which forest clearing has been the most intense (Fearnside 1982). Of particular interest in the area is the regional development associated with the construction of the PA-150 and PA-279 highways. The town of Xinguara, the major settlement in the area, is at the junction of these two roads. It is here that development is taking place. Prior to construction of the highways there was very little settlement or forest clearing in the region. With the completion of PA-150 and the beginning of PA-279, the population increased to 8,000 in 1978 and 30,000 in 1980 (Schmink 1981). As the population grew and access to the region became easier, cattle ranching, which is the main impetus for forest clearing in the area, increased dramatically (Godfrey 1979).

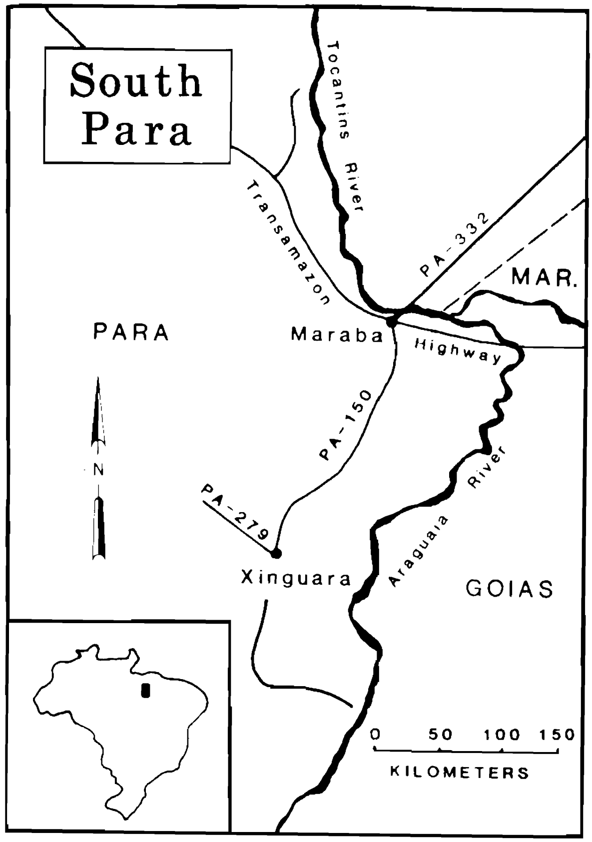

Fig. 1. The South Para Region.

Data

The primary data were collected by Landsat 1 MSS on 1 June 1975 (Scene Id. 175152-123640) and by Landsat 2 MSS on 28 June 1979 (Scene Id. 27916-123924). This was a period of very rapid deforestation in the study area. The data were obtained in the following forms: digital data on computer compatible tapes; and 1:500,000 black and white single-band images for bands 4, 5, 6 and 7 (reflective portions of the electromagnetic spectrum). Anniversary dates were used to minimize reflectance differences caused by seasonal vegetation changes, sun angle variation, and soil moisture differences (Jensen 1981). Ancillary data on vegetation, soils and geology were obtained from selected RADAM project reports (RADAM 1974).

Methodology

As noted previously, Landsat data have been used successfully in many forestry applications, including deforestation. However, these studies have also highlighted several caveats associated with the use of Landsat MSS data applied to tropical forest clearing. Singh (1984) noted that experience gained from using Landsat data to study temperate forests is not directly applicable to humid tropical forests because: (1) tropical forests are structurally more complex communities compared with higher latitude forests; (2) tropical forests display much weaker ecological site preferences than temperate forests; and (3) cultural practices in tropical areas exhibit a much greater variety than temperate areas. He concluded that Landsat data were optimally used for distinguishing forest/nonforest (80 percent accuracy), rather than attempting multiclass forest type classifications in tropical areas. Nelson (1983) also stated that Landsat data are best employed where forest/nonforest delineation is all that is required. Additionally, Woodwell et al. stated: "Experience led us to avoid to the greatest extent possible elaborate classification and inventory and to emphasize the detection of changes such as that from forest to nonforest" (1983, 1).

Based on these previous studies the methodology adopted here is a forest-to-cleared change detection. Many techniques have been developed to detect change in land cover between two dates. Jensen (1981) discussed five commonly used change detection algorithms: image differencing, image ratioing, classification comparison, comparison of preprocessed imagery, and change vector analysis. The method initially attempted in this study was a modified approach of Woodwell et al. (1983) and incorporating some of the techniques of Friedman and Angelici (1979) (e.g., eigenvector analysis and binary classification). The computer processing steps are outlined below.

Identical subsets of the two satellite scenes were extracted that were roughly centered on the settlement of Xinguara and included all of highway PA-279 (Figs. 2 and 3). Because some distortion is present in all Landsat scenes, it was necessary to "stretch" (a process called rubber sheeting) one of the images to geometrically match the other. In this study the 1975 data were chosen as the base to which the 1979 data were digitally overlayed. A third-degree polynomial mapping function was calculated from eighty-one control points located by an image correlation routine in the ELAS digital image processing software. This model was used along with cubic convolution resampling to obtain sub-pixel registration of the two images. Jensen (1981) noted that registration of one-fourth to one-half pixel is desirable for image differencing; registration of one-half pixel was obtained here.

The next step involved the detection and measurement of forest cover change between the two dates. Initially, the technique suggested by Woodwell et al. (1983) was tested, which involves interactive parallelepiped classification followed by image differencing -- subtracting the imagery of one date from that of another. They achieved forest/nonforest classification accuracies exceeding 90 percent using this technique. However, the results of this procedure when conducted on the Para, Brazil data were difficult to interpret because of differing amounts of regrowth in clearings and the spectral similarity between savanna and cleared land cover. These problems were particularly difficult to overcome because of insufficient detailed field data. It is also possible that the results were not as readily interpretable as those obtained by Woodwell et al. because of the slightly different parallelepiped algorithm used here.

Three other means of differentiating between forest and nonforest were tested, including band 7/band 5 ratios, principal component transformation, and binary density slicing using band 5. Evaluation of each method was performed by visual comparison of the results with RADAM vegetation maps and with previously identified areas of known deforestation on the Landsat imagery. The simple

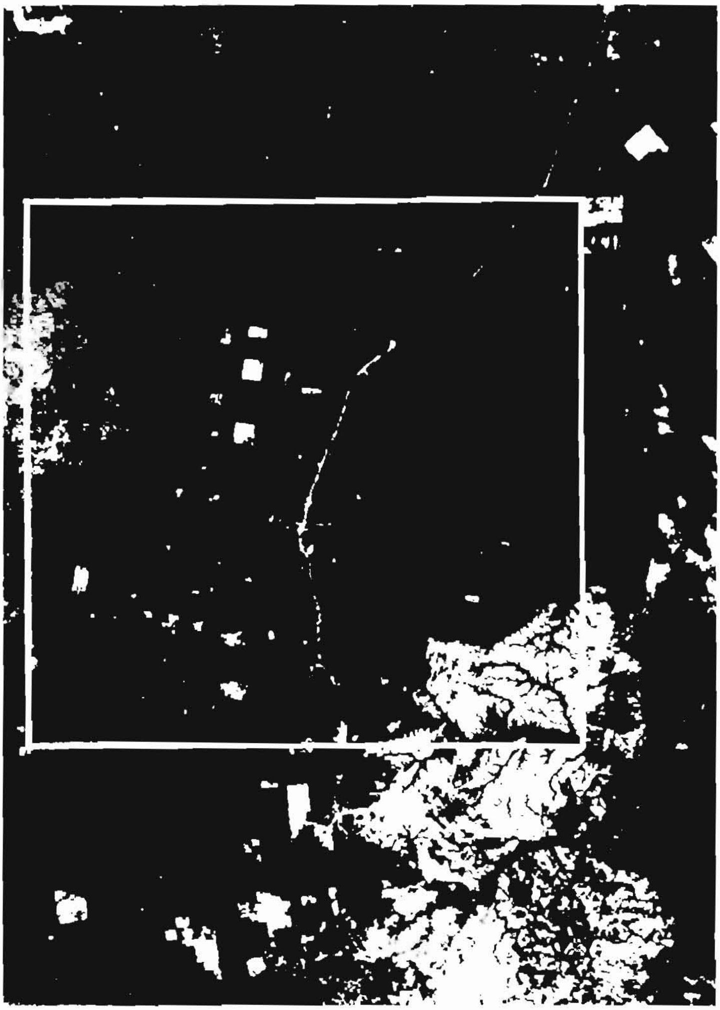

Fig. 2. The Xinguara study region, 1975. The white square is approximately 107 kilometers on a side.

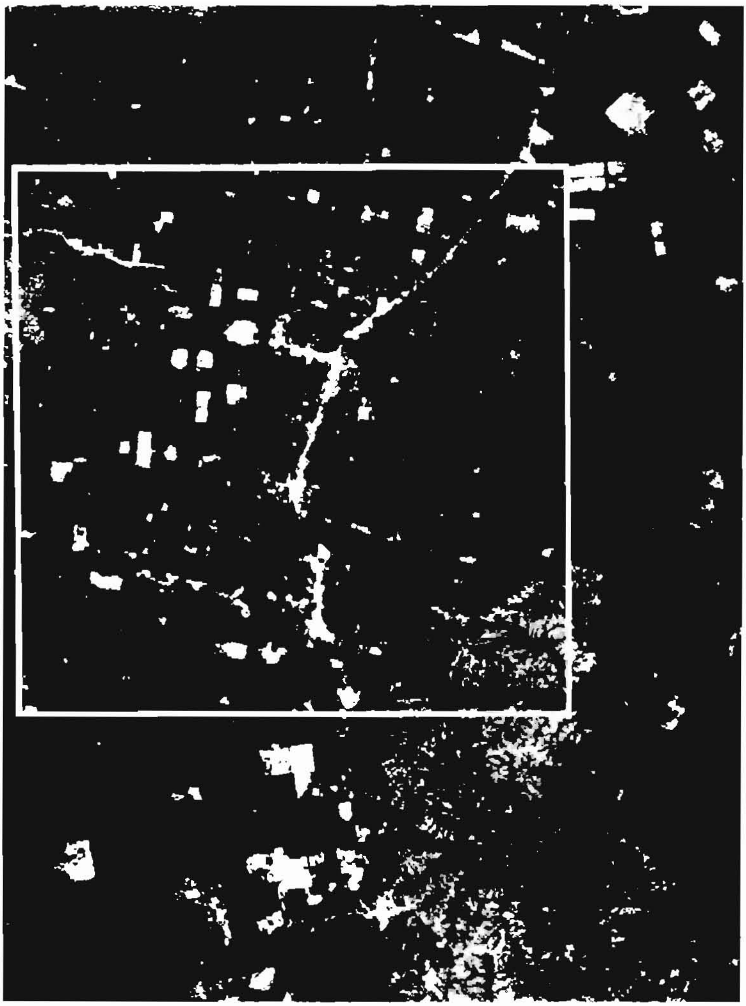

Fig. 3. The Xinguara study region, 1979.

binary density slice technique produced results comparable to the much more complex methods and was therefore chosen for the forest/nonforest analysis.

Next, the two resulting images produced by the binary density slice were digitally compared pixel by pixel. If a pixel was classified as nonforest in 1979 and forest in 1975, it was designated as a change area. If a pixel was forest in 1979 or nonforest in both dates, it was designated as not having undergone change. This method allows the detection of change from forest to nonforest and excludes areas of regrowth, thus producing a change-detection image that represents deforestation.

Woodwell et al. (1983) pointed out that even with sub-pixel registration of two images it is still possible that the edges of deforested areas and single-pixel-wide features such as roads and rivers may be incorrectly classified as areas of change when image comparisons are made. To minimize such misclassification, areas designated as change that consisted of five contiguous pixels (approximately 2.2 hectares) or less were removed from the final change image. This value was selected by visual comparison of the results produced from iterations using various values. Nearly all of these removed pixels were located along cleared boundaries and rivers. Visual comparison with Landsat band 5 imagery showed that the number of truly changed areas removed by this method was minimal.

Total amount of change (deforestation) between 1975 and 1979 was then calculated from the number of pixels in the resulting change image. This amount was then adjusted for mixed pixel effects at deforested boundaries as suggested by Woodwell et al. (1983) by subtracting one-half of the edge pixels from the total area of change.

Results and Conclusions

Using Landsat MSS digital data and the method described above, an area of 731 square kilometers of deforestation was measured in the study area between June 1975 and June 1979. This represents 6.3 percent of the study area and 7.4 percent of the forested area, and does not include land cleared prior to 1975. Because there was very little cleared land in the study area in 1975, these figures indicate nearly the entire deforestation that had occurred to 1979. The 7.4 percent value yields a 1.6 percent average annual deforestation rate, which is four times greater than the highest estimated annual rate for Brazil as a whole that was cited in Allen and Barnes (1985).

The primary difficulty encountered using digital techniques during this study was distinguishing between natural nonforested areas and anthropogenically produced nonforest land cover (i.e., deforested areas). Deforested areas were easily recognized by their shapes and/or locations adjacent to roads, but their spectral similarity to savannas made automatic detection based on spectral response alone impossible. The image comparison method, however, provides a means of separating natural from anthropogenic nonforest covers since savanna areas were largely unchanged between the two dates and were therefore excluded from the change class.

Florida Application

Recent discussions of the possible impact of deforestation (as well as river channelization and the draining of wetlands) on Florida's climate have appeared in the popular and scientific literature. The "special report" by Boyle and Mechen (1982) suggests the same possibility propounded by Small (1929): large-scale human interference in the hydrologic cycle in Florida could produce desert-like conditions in the state. Some of the suggested impacts are perhaps journalistic hyperbole, but because vegetation transpires [illegible] atmosphere up to three times faster than water evaporates from an open water surface, and because modeling results indicate potential effects on the climate, forest clearing rates should be closely monitored.

A modified form of the method discussed above is presently being used in four north-central Florida counties (Baker, Bradford, Columbia, and Union) to test its applicability to determine forest clearing rates in the state. Deforestation in Florida is perhaps at a smaller scale than that in Brazil, and often the harvesting of trees in Florida is within areas maintained for that purpose. Therefore environmental consequences of deforestation in Florida may not be as great as in Brazil and other developing countries. Still, assessing total deforestation in planted and pristine areas over time within the state will aid in understanding one of the many human impacts within Florida.

* * *

1. The authors would like to thank Dr. Marianne Schmink, Charles Wagley, and Charles Wood for their assistance in obtaining funding from the Amazon Research and Training Program at the University of Florida. We are also grateful to Doug Jordan, Ray Seyfarth, and Dr. Virginia Hetrick for their assistance in processing the data, and Paul Stayert for aiding in the preparation of graphics.

References

Allen, J. C., and Barnes, D. F. 1985. The causes of deforestation in developing countries. Annals of the Association of American Geographers 75:163-84.

Boyle, R. H., and Mechen, R. M. 1982. Anatomy of a man-made drought. Sports Illustrated, 15 March, pp. 46-54.

Fearnside, P. M. 1982. Deforestation in the Brazilian Amazon: How fast is it occurring? Interciencia 7:82-88.

Friedman, S. Z., and Angelici, G. L. 1979. The detection of urban expansion from Landsat imagery. Remote Sensing Quarterly 1:58-79.

Godfrey, B. 1979. Rush to Xingu Junction. Master's thesis, University of California, Berkeley.

Henderson-Sellers, A., and Gornitz, V. 1984. Possible climatic impacts of land cover transformations, with particular emphasis on tropical deforestation. Climatic Change 6:231-57.

Jensen, J. R. 1981. Urban change detection mapping using Landsat digital data. The American Cartographer 8:127-47.

Myers, R. L. 1986. Florida's freezes: An analog of short-duration nuclear winter events in the tropics. Florida Scientist 49: 104-15.

Nelson, R. F. 1983. Detecting forest canopy change due to insect activity using Landsat MSS. Photogrammetric Engineering and Remote Sensing 49: 1303-14.

Potter, G. L.; Ellsaesser, H. W.; MacCracken, M.; and Luther, F. M. 1975. Possible climatic impact of tropical deforestation. Nature 258: 697.

RADAM. 1974. Projeto RADAM: Programa de integracao nacional. Ministerio das Minas e Energia, Levantamento de Recursos Naturais, Vol. 4, Folha SB.22, Araguaia e Parte da Folha SC.22 Tocantins. Rio de Janeiro: Departmento Nacional de Producao Mineral.

Schmink, M. 1981. A case study of the closing frontier in Brazil. Amazon Research Papers Series No. 1. Gainesville, Florida: Center for Latin American Studies, Univ. of Florida.

Shukla, J., and Mintz, Y. 1982. Influences of land surface evapotranspiration on the earth's climate. Science 215:1498-1501.

Singh, A. 1984. Discrimination of tropical forest cover types using Landsat MSS data. In Proceedings, Eleventh International Symposium of Machine Processing of Remotely Sensed Data, pp. 395-404. West Lafayette, Indiana: Purdue Research Foundation.

Small, J. K. 1929. From Eden to Sahara. Princeton, New Jersey: The Science Press Printing Co.

Woodwell, G. M.; Hobbie, J. E.; Houghton, R. A.; Melillo, J. M.; Peterson, P. J; Shaver, G. R.; Stone, T. A.; and Park, A. B. 1983. Deforestation measured by LANDSAT: Steps toward a method. DOE/EV/10468-1. Washington, D.C.: U.S. Department of Energy.