Human Migration and Agricultural Expansion

A Threat to the Maya Tropical Forests

By Steven A. Sader, Conrad Reining, Thomas Sever, and Carlos Soza

As in other parts of Central America, the once-remote tropical forests of Guatemala are being cut and burned to create new farmland. Evidence of the threat to the ancient lands of the Mayas comes from time-series Landsat Thematic Mapper observations and analysis. In this paper we estimate deforestation rates and look for trends. Satellite images were used to quantify and monitor rates, patterns, and trends of forest clearing during a period corresponding to new road construction and significant human migration into the newly accessible forest region.

The Peten District (36,000 square kilometers) is the largest and most remote region of Guatemala. The northern part of the district, along with adjacent Mexican states (Chiapas and Campeche) and Belize (Rio Bravo Conservation District), constitutes the largest contiguous tropical moist forest left in Central America. The center of the ancient Maya empire, it contains many of the largest and most famous classic Maya sites, including the popular tourist attraction Tikal National Park. In the thousand years since Maya culture waned, this area had not experienced significant population increases until the mid-1960s, when government policies began to encourage colonization of the region. In 1997 the Peten population is estimated at 500,000 people (N.B. Schwartz, pers. commun.)

The Maya Biosphere Reserve in the Peten District was established in 1990 by the congress of Guatemala. The reserve contains three types of management units. A core area of national parks and biological reserves has the highest level of protection. A large multiple-use zone allows some forms of extractive harvesting, ranching, farming, hunting, and commercial logging. A buffer zone, south of the reserve, has no land-use restrictions (Whitacre 1995). Although conservation organizations have been working diligently to develop sustainable programs in the reserve, real advances in conservation are difficult to achieve because of increasing human migration. Landless farmers (milperos) practice slash-and-burn agriculture and have had few incentives to employ more intensive and sustainable methods (such as terracing), perhaps out of fear that they could be evicted from the land (Schwartz 1990).

Whitacre (1996) cites other detrimental impacts on the Maya Biosphere Reserve, including road building, oil exploration, cattle ranching, hunting, taking of exotic fauna for pets and tropical plants for the floral trade, and high-grade logging of mahogany (Swietenia macrophylla) and cedar (Cedrela odorata). The socio-economic and cultural forces driving the recent migration and forest conversion have been reported by Stuart (1991); Southgate and Basterrechea...
(1992); Sader et al. (1994); Sader (1995); Whitacre et al. (1995); and Whitacre (1996).

Methods
Use of satellite images for monitoring tropical forest changes has been demonstrated by several authors (Fearnside 1986; Singh 1986; Sader et al. 1990; Skole and Tucker 1993). Satellite imagery is appropriate technology in a vast and remote tropical region where aerial photography and field surveys are not cost effective yet current data are essential for establishing conservation priorities. One challenge in conducting remote-sensing investigations in tropical regions is acquiring cloud-free images for the desired dates and seasons.

Portions of three Landsat scenes—identified by the Landsat Worldwide Reference System as path 19, row 48; path 20, row 48; and path 21, row 48—cover the width of the Maya Biosphere Reserve and its buffer zone. The middle scene (path 20) encompasses approximately 90 percent of the entire area. We were fortunate in our study to acquire nearly cloud-free Landsat Thematic Mapper (TM) images during the dry season (February to May) at two-to four-year intervals from 1986 to 1995 for all three Landsat locations.

Ground control points were selected to georeference and resample the 1990, 1993, and 1995 images to previously rectified 1986 TM base images at a 30-meter pixel resolution with a universal transverse Mercator zone 16 projection. The 1986 rectified TM images were acquired from NASA Stennis Space Center.

The time-series change detection technique applied in this study relies on the computation of the normalized difference vegetation index (NDVI) at each date (Sader et al. 1996) using the following formula:

\[
\text{NDVI} = \frac{(\text{near ir} - \text{red})}{(\text{near ir} + \text{red})}
\]

The NDVI has been shown to be highly correlated with green biomass, crown closure, and leaf area index, among other vegetation parameters (Tucker 1979; Sellers 1985).

Atmospheric corrections using minimum value subtraction from deep, clear-water pixels were applied to the visible red (TM 3) and near-ir band (TM 4) prior to computation of NDVI. A linear contrast stretch was computed to stretch the NDVI values across the 8-bit digital range (0–255). The four NDVIs, one for each of the image dates, were combined into a four-layered file for each of the three Landsat scenes. An unsupervised (clustering) classification technique (ERDAS 1996; Jensen 1996) was performed separately on each of the three scenes containing the NDVI images. The classified images were one-channel files, each representing 45 multitemporal NDVI cluster classes.

The Landsat scenes were analyzed separately and merged after classification, editing, and recoding into change, no-change categories. The change, no-change class labels were assigned to each cluster class through observation of the NDVI cluster means at each date in reference to known ground locations in the study area and guided by interpretation of TM false color composites of each date and selected 70mm and 35mm oblique aerial photography. Major shifts in NDVI due to forest clearing and vegetation regrowth can be detected for Landsat pixels that changed between two or more dates. Many of the clusters show no significant change, as indicated by nearly equal NDVI values at each date. Screen digitizing of clouds, cloud shadows, and water edges was required to eliminate false readings. A 5-by-5 majority filter was applied to reduce isolated pixels and consolidate the boundaries of the change, no-change classes. The final step was merging the three scenes into the time-series forest change detection map (fig. 2). A more detailed description of image processing and NDVI change detection methods can be found in Sader et al. (1996).

Aerial and Field Checking
A few oblique aerial photos of the study area had been taken in 1994. Field visits were conducted along some of the surface roads in 1994 and 1996. The 1993 to 1995 forest changes observed on the change detection map (fig. 2) corresponded well with the recent slash-and-burn boundaries, but the older change events (before 1993) could not be evaluated because there were no historical data for comparison.

One problem in conducting satel-
Figure 2. Time-series satellite imagery (1986 to 1995) shows forest clearing in the entire Maya Biosphere Reserve and buffer zone and along four corridors in the multiple-use zone: (1) northwest Guatemala border; (2) El Naranjo–Rio San Pedro; (3) northeast Guatemala border, and (4) El Cauce–Carmelita.
Table 1. Annual forest-clearing rates from 1986 to 1995 on the Maya Biosphere Reserve management units.

<table>
<thead>
<tr>
<th>Area</th>
<th>Percent of total area</th>
<th>Forest-clearing rates 1986–90</th>
<th>1990–93</th>
<th>1993–95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tikal National Park</td>
<td>55,005 ha</td>
<td>2.62%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Laguna del Tigre National Park</td>
<td>289,912</td>
<td>13.94</td>
<td>0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>El Mirador National Park</td>
<td>55,148</td>
<td>2.63</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Sierra del Lacandon National Park</td>
<td>191,867</td>
<td>9.57</td>
<td>0.13</td>
<td>1.18</td>
</tr>
<tr>
<td>Rio Azul National Park</td>
<td>61,763</td>
<td>2.95</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cerro Cahui Reserve</td>
<td>555</td>
<td>0.03</td>
<td>0.20</td>
<td>0.06</td>
</tr>
<tr>
<td>El Zotz Reserve</td>
<td>34,934</td>
<td>1.69</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>Dos Lagunas Reserve</td>
<td>30,719</td>
<td>1.47</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Laguna del Tigre Reserve</td>
<td>45,168</td>
<td>2.17</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Multiple-use zone</td>
<td>826,352</td>
<td>40.08</td>
<td>0.05</td>
<td>0.16</td>
</tr>
<tr>
<td>Buffer zone</td>
<td>408,973</td>
<td>22.85</td>
<td>0.74</td>
<td>2.71</td>
</tr>
<tr>
<td>Total area</td>
<td>2,000,396 ha</td>
<td></td>
<td>3.76</td>
<td></td>
</tr>
</tbody>
</table>

Results and Discussion

The estimates of the time-series forest clearing were computed for the entire Maya Biosphere Reserve, each management unit, and the buffer zone south of the reserve. The results (table 1) are reported as the percent of clearing per year, using the following formula:

\[
\frac{(\text{forest } b - \text{ forest } e / \text{ forest } b) \times 100}{n}
\]

where \( n \) = years in the period, \( b = \text{beginning, and } e = \text{end.} \)

Results were as follows:

<table>
<thead>
<tr>
<th></th>
<th>Forest-clearing rate per year</th>
<th>Estimated forest-clearing rate per year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in reserve</td>
<td>in buffer zone</td>
</tr>
<tr>
<td>1986–90</td>
<td>0.04%</td>
<td>0.74%</td>
</tr>
<tr>
<td>1990–93</td>
<td>0.23</td>
<td>2.71</td>
</tr>
<tr>
<td>1993–95</td>
<td>0.33</td>
<td>3.76</td>
</tr>
</tbody>
</table>

For 1990–93 and 1993–95, annual clearing was nearly 12 times higher in the buffer zone than in the reserve.

Some of the management units in the Maya Biosphere Reserve experienced increases in forest-clearing rates after 1990. Tikal, Mirador, and Rio Azul National Parks and Dos Lagunas Biological Reserve had no detectable forest clearing. These management units are remote, and all but Tikal are inaccessible by surface roads. Only trace amounts of forest clearing were detected for Cerro Cahui and Laguna del Tigre Reserves between 1986 and 1995.

Sierra del Lacandon National Park had the highest rates of forest clearing and the largest area cleared of all management units inside the reserve (table 1). More land was cleared in this park in 1990–95 than in the entire multiple-use zone. Sierra del Lacandon is bordered by roads on the northwest and southwest sides. Along the southeast boundary lies a ranch of approximately 44 square kilometers, nearly half of which is inside the national park. Most of the reserve proper is relatively inaccessible by surface roads. Essentially all the change within the reserve and buffer zone has occurred near a road or river corridor. A previous study (Sader 1995) based on analysis of TM data for 1986 and 1990 in two study sites within the reserve indicated that more than 90 percent of all new clearings were within 3 kilometers of roads.

Sites of Encroachment

Nearly all the forest clearing between 1986 and 1995 occurred in four major corridors (identified by number in figure 2) inside the multiple-use zone:

1. The northwest Guatemala border with the state of Tabasco, Mexico, adjacent to the Laguna del Tigre Biological Reserve.
2. The Laguna del Tigre road directly north from El Naranjo and along the Rio San Pedro River, north and east of El Naranjo.
3. The northeast Guatemala border with Belize, adjacent to the road near Melchor de Mencos.
4. The road from El Cuc Health Los Aguaadas to Carmelita, northwest of Lago Peten-Itza.

Arbitrary boundary polygons were drawn around the zone of influence to describe corridors 3 and 4. Corridors 1 and 2 were defined by the multiple-use zone boundaries of these discrete units.

Forest-clearing rates were less than 1 percent per year in 1986–90 for all four areas (table 2). Only the El Cuc Health–Carmelita corridor did not experience a significant increase in forest clearing from 1986 to 1995. The most recent clearing rates for El Cuc Health–Carmelita (1993–95) were substantially lower (< 0.5 percent per year) than for the other areas (more than 3 percent). The El Cuc Health–Carmelita corridor has been settled longer than the other three areas, and its population is stable.

Remote-sensing investigations in remote tropical regions is verifying the accuracy of the results when access is limited. Accuracy assessments of historical events on a spatial scale are more difficult than verifying a recent land cover classification because the potential sources of reference data (historical aerial photography) are not available for this region. We have therefore not had the opportunity to conduct an accuracy assessment of the forest change detection map.
in 1986–90 (0.58 percent) and 1990–93 (0.51 percent), but the figure jumped to 3.04 percent in 1993–95. In contrast to the abrupt increase at Melchor de Mencos, forest clearing along the Laguna del Tigre and Río San Pedro corridor was incremental: 0.49 percent per year in 1986–90, 1.69 percent in 1990–93, and 3.07 percent in 1993–95.

In the Maya Biosphere Reserve, forest-clearing activity in the Laguna del Tigre National Park is being closely monitored by the Guatemala government and nongovernment organizations (NGO). The satellite change detection data (table 2, fig. 2) indicate a sharp increase in forest-clearing activity in 1993–95 along the Laguna del Tigre Road and Río San Pedro corridor. The change detection map (fig. 2) verified earlier ground reports about recent encroachment by milperos into the reserve.

**Conservation Challenges**

The forest-clearing rates and trends as detected by Landsat from the mid-1980s to the mid-1990s indicate that agricultural expansion is now well established within the buffer zone and is encroaching into the Maya Biosphere Reserve along some accessible corridors. The buffer zone has been rapidly changing from a forested landscape with scattered agricultural patches to an agricultural landscape with increasingly fragmented forest. The threat to the biodiversity of the reserve is imminent: the function of the buffer zone may soon be lost, and farmers and ranchers will be crossing reserve boundaries in search of new forests to clear.

The forces driving the changes in the four multiple-use corridors, in the buffer zone, and in various management units within the reserve appear to be operating differently. Although nearly all the forest-clearing activity between 1986 and 1995 was near a road, oil pipeline, or river, accessibility alone does not explain the variability of the clearing rates between time periods in different zones.

Some of the "protected" national parks and biological reserves inside the Maya Biosphere Reserve are experiencing forest conversion; others are not. Compare, for example, Sierra del Lacandon with Tikal and Mirador National Parks (table 1). Both Sierra del Lacandon and Tikal have roads into or adjacent to the parks, but Tikal (with no forest clearing) is a popular tourist attraction and has a 24-hour gate patrol. Prevention of slash-and-burn encroachment into Sierra del Lacandon National Park has not been successful and continues unabated. Several families were already living inside the park when its boundaries were drawn in 1990, and many more have arrived since. The juxtaposition of Sierra del Lacandon with the buffer zone and the road system does not bode well for the survival of this forest and its biodiversity.

In 1991 the US Agency for International Development in cooperation with NGOs initiated a conservation and economic development program for the reserve. Conservation International, one of the cooperating NGOs, established a program to promote sustainable development. In 1997, however, government and NGO employees were taken hostage by 60 armed men, and a biological station administered by Conservation International was burned to the ground. The director of the program negotiated the release of the hostages and an agreement to allow reconstruction in exchange for assistance in establishing local agricultural concessions; within the agreed-on boundaries of these poligonos agrícolas, farming, selective logging, and hunting are permitted. Communities granted such concessions agree to cooperate with the government to limit further migration into the area and practice sustainable agriculture and forestry.

**Conclusions**

Satellite time-series forest change detection helps draw attention to a region of Central America that has seen high rates of forest clearing during the past decade. According to the United Nations' tropical forest survey report (FAO 1993), southern Mexico and Central America had a deforestation rate of 1.5 percent per year in the 1980s—second only to southeast Asia, at 1.6 percent. Our study, using data from the early 1990s, indicates that the forest-clearing rates in the buffer zone and some corridors in the reserve's multiple-use zone exceeded 3 percent per year—more than twice the regional average reported by the UN for the 1980s.

The satellite imagery has caught the attention of the Guatemala government and helped NGOs visualize the extent of the deforestation. Although the study was hampered by the lack of historical data and ground information for accuracy assessments, a comprehensive forest-monitoring program is being designed for future studies. Conservation International proposes to continue satellite and aerial videography acquisitions every two years. Linked to a global positioning system, the aerial videography data and aerial photos will pinpoint the location of field plots and support both training set selection (for Landsat-supervised classifications) and accuracy assessment of the final maps. The vast size of the reserve and buffer zone (2 million hectares) and the need for low-cost and timely monitoring preclude the use of

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**Table 2. Annual forest-clearing rates in four corridors of the Maya Biosphere Reserve multiple-use zone.**

<table>
<thead>
<tr>
<th>Corridor</th>
<th>1986–90 (percent)</th>
<th>1990–93 (percent)</th>
<th>1993–95 (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW Guatemala border–Mexico</td>
<td>0.40</td>
<td>3.96</td>
<td>3.88</td>
</tr>
<tr>
<td>Laguna del Tigre–Río San Pedro</td>
<td>0.49</td>
<td>1.69</td>
<td>3.07</td>
</tr>
<tr>
<td>NE Guatemala–Melchor de Mencos</td>
<td>0.58</td>
<td>0.51</td>
<td>3.04</td>
</tr>
<tr>
<td>El Cruce–Carmelita</td>
<td>0.23</td>
<td>0.48</td>
<td>0.44</td>
</tr>
</tbody>
</table>
other methodologies, including complete aerial photo coverage. As the geographic information systems established by NGOs in the region become operational, satellite-based monitoring will become an indispensable tool for updating regional maps and for supporting conservation planning and policy decisions. 

**Literature Cited**


WHITACRE, D.F. 1996. Main factors and processes threatening biological diversity and integrity of the Maya Biosphere Reserve, and recommendations for reducing and/or mitigating these impacts. Boise, ID: The Peregrine Fund.


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