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Deforestation in a Complex Landscape

Alison Forrestel a & Kabir G. Peay b

a National Park Service Pacific Land Resources Program, 1111 Jackson Street, Suite 700, Oakland, CA, 94607, USA
b Department of Environmental Science, Policy and Management, UC Berkeley, 301 Mulford Hall, Berkeley, CA, 94720, USA

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Deforestation in a Complex Landscape: La Amistad Biosphere Reserve

Alison Forrestel
Kabir G. Peay

ABSTRACT. Deforestation is often the primary threat to conservation goals in tropical countries. However, accessing the remote locations in which most remaining forests of conservation value occur makes it difficult to quantify deforestation trends and to galvanize preventive action. Using remotely sensed images we were able to quantify rates of forest loss in La Amistad Biosphere Reserve, Panama. Annual deforestation rates were low between 1987 and 1998 at 0.05% but increased nearly 12-fold between 1998 and 2001 to 0.6%. Net forest loss was 0.56% between 1987 and 1998 and 2.34% between 1998 and 2001. Deforestation rates differed significantly between protected areas. Protected areas on the Caribbean side of the Biosphere Reserve experienced greater levels of deforestation than those on the Pacific, even though both absolute and percent forest cover are higher on the Caribbean. Most forest conversion was for cattle pasture and an area of industrial cattle ranching was identified within the Palo Seco and PILA protected areas as a priority for enforcement activities. Forest conversion to pasture was highly correlated with proximity to roads, rivers, and villages (p < 0.001). The spatial scale of correlation varied between feature types, suggesting a greater area of impact from roads and towns versus rivers. The acceleration of forest conversion from 1998 to 2001 confirms the negative ecological impact of the recent increase in population and development pressure in this previously isolated region. [Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com> © 2006 by The Haworth Press, Inc. All rights reserved.]
INTRODUCTION

The loss and degradation of native forest cover poses a major obstacle to biodiversity conservation and sustainable development. While rates of deforestation have decreased in North America and Europe (FAO, 2001), they remain high in the tropics where development and population pressure are still high. Unfortunately, species in tropical forests are particularly vulnerable to extinction from habitat loss due to their high levels of diversity (Tilman et al., 1994; Nee & May, 1992). One approach to preventing this ‘extinction debt’ has been to identify areas of both high diversity and high threat (Myers et al., 2000; Mittermeier et al., 1998). La Amistad Biosphere Reserve (LABR), spanning western Panama and southeastern Costa Rica, is an example of this dichotomous landscape. However, quantifying deforestation trends is challenging in remote areas and over large landscapes. Recently, remote sensing has become a viable alternative to intensive ground surveys in assessing both the nature and degree of forest threat (Chomentowski et al., 1994; Skole & Tucker, 1993; Booth, 1989).

In order to assess the level of threat to LABR, this study uses Landsat satellite images from 1987 to 2001 to quantify deforestation levels in the Reserve. We take advantage of advances in the availability and processing of remotely sensed image as an effective conservation tool (Hayes & Sader, 2001; Chomentowski et al., 1994; Green et al., 1994). Our goal is to determine realistic estimates of deforestation at a regional level in order to provide incentive and guidance for immediate conservation action. Furthermore, while primary causes of tropical deforestation, such as logging, grazing and agriculture (Kinnaird et al., 2003; Shapiro, 2001) are often distinguishable with satellite imagery, these activities themselves are often driven by social, economic and institutional dynamics not as readily visible. Our study is unique because it is part of an integrated rapid-assessment of forest conservation including analyses of social, economic, and political drivers that will address the problem of forest loss at multiple scales (see other papers in this volume). By determining rates and specific areas of forest loss, we hope to provide knowledge that managers and planners can implement alongside these social, economic, and political conditions in order to secure relevant and effective policy recommendations for LABR.
Study Region

Mesoamerica has been listed as one of the 10 major biodiversity hotspots by Conservation International (Myers et al., 2000). The area is home to 521 mammal species, 1,193 bird species and 1,145 reptile and amphibian species. Of these, 40% of mammals, 21% of birds, and 61% of reptiles and amphibians are endemic to the region (CEPF, 2001). However, this once vast biome has been reduced from an original 1,555,000 km² of primary vegetation to only 231,000 km² today (Myers et al., 2000). To stem the tide of deforestation and species loss, a number of national parks and regional corridor projects have been initiated, such as the Mesoamerican Biological Corridor and the Atlantic Biological Corridor.

La Amistad Biosphere Reserve is a critical component in Mesoamerican conservation planning. It is one of the largest contiguous areas of intact forest in the region, spanning over one million ha in Costa Rica and Panama, and contains parts of two of the richest biomes in Mesoamerica, the Atlantic rainforest and the Talamancan highlands (De la Rosa & Nocke, 2000; Campbell, 1999; CEPF, 2001; Palminteri et al., 1999). La Amistad Biosphere Reserve (LABR) straddles a complex biological and social landscape. The reserve crosses two countries, multiple provinces within each country, and a variety of protected areas. Furthermore, the reserve contains a number of different ecosystems and life zones, ranging from low elevation rainforest to montane oak-forests and both the wet and dry forest-types of the Caribbean and Pacific. Topographic relief is extreme, ranging between 15 and 950 meters within the study area.

Our study is focused on the Panamanian side of La Amistad Biosphere reserve. The total area of the reserve in Panama exceeds 400,000 hectares, comprised of Parque International La Amistad (PILA) (209,277 ha), Palo Seco Protected Forest (162,522 ha), Volcan Barú National Park (15,450 ha) and Fortuna Water Reserve (25,378 ha) (Figure 1). These protected areas were established from the mid-1970s through the late 1980s. Volcan Barú and the Fortuna Reserve were both established in 1976. PILA, which makes up the core of the reserve in both Panama and Costa Rica, was established in Panama in 1988 (Chaverri et al., 2003). Differing levels of protection and use restrictions are enforced for the various types of protected areas. The Reserve is also home to a number of indigenous groups, including the Ngöbe-Búgle, the Bribri, and the Naso-Teribe.
Until very recently, access to La Amistad region was limited by lack of roads and transportation infrastructure. Combined with low levels of population growth and development, the area has been able to retain large tracts of undisturbed forest. However, the recent completion of a new road, a rapidly growing population, and increased development pressure have raised fears that major forest loss may be imminent or already underway (CEPF, 2001; Palminteri et al., 1999).

**METHODS**

Satellite imagery in general and Landsat images in particular have been used effectively to determine rates of deforestation, particularly in the tropics where there are large expanses of relatively inaccessible land (Chomentowski et al., 1994; Skole & Tucker, 1993).
Data

This analysis used Landsat satellite images (Path 14 Row 54) from three dates. Two images, from 17 January 1987 and 15 January 1998, were obtained from the Landsat Thematic Mapper sensor. The third image, from 01 December 2001, was obtained from the Enhanced Thematic Mapper Plus (ETM+) sensor. All images were acquired during the dry season and taken roughly one month apart. Landsat TM and ETM+ images both have a spatial resolution of 30 m × 30 m. Landsat TM has seven spectral bands while ETM+ has an eighth panchromatic band with 15 m × 15 m resolution (Jensen, 2000).

Image Preprocessing

All image processing was done using ER Mapper 6.3. The 1987 image was orthorectified to 50 m accuracy as part of NASA’s GeoCover-Ortho program and therefore did not require further orthorectification. The 1998 and 2001 images were orthorectified to the 1987 image using permanent landmarks such as intersections and large features such as airport runways or dams. We did not allow root mean squared error (RMSE) > 1.0 (Jensen, 1996).

Cloud-free images are rare in tropical regions. While all three images were < 20% cloudy within the study region, significant portions of the study area were covered in two images (1998 and 2001) and required some preprocessing because classification schemes often confuse clouds with other land features. Cloudy pixels are often removed from images in a first step using the thermal infrared band (Helmer et al., 2000; Jensen, 2000). We used the ratio of the blue band (Band 1: 0.45-0.52 µm) to the thermal infrared band (Band 6: 10.4-12.5 µm) to define cloudy pixels. Pixels with a value > 0.75 for the cloud index were assigned a null value, while all pixels with a value for the cloud index < 0.75 retained their original reflectance values. Images were then classified with the majority of cloudy pixels removed from the image. This process significantly reduced misclassification in later steps.

Prior to classification, the images were subset to focus on the La Amistad Biosphere Reserve including the maximum extents of PILA, Palo Seco Protected Forest, Volcan Barú National Park, and the Fortuna Hydrological Reserve.
Image Classification

Mountainous terrain causes anisotropic reflection in areas of high slope, which can confuse classification efforts (Colby & Keating, 1998). A number of strategies have been proposed to address the problems inherent in classifying remotely sensed images in mountainous tropical areas. These include band rationing (Crippen et al., 1988; Jensen, 1996), topographic correction (Minnaert, 1941; Smith et al., 1980; Meyer et al., 1993; Colby, 1998; Gu & Gillespie, 1998), and parallel classification of sun and shade features (Helmer et al., 2000). In our case band rationing did not provide a significant improvement in classification accuracy. While topographic correction would probably have resulted in the highest levels of accuracy, as is often the case in tropical regions, the scale of the DEM available to us (1 km) was too coarse to significantly improve classification. However, use of parallel classification of sun and shade features proved to be a viable alternative to topographic correction.

We followed the procedures outlined in Helmer et al. (2000) and performed a supervised classification. Land classes were divided into sun and shade-forest, sun and shade-pasture, soil, cloud and water. Similar classification schemes have been effective in quantifying forest cover change in other montane tropical regions (Sanchez-Azofeifa et al., 2002; Tole, 2002; Kinnaird et al., 2003). Training regions were placed in the same location for each image (with minor exceptions, such as clouds) and were selected based on field observations and visual inspection of both 741-RGB false color composite, 321-true color composite and a Tassled-Cap RGB. Supervised classification was performed with the enhanced maximum likelihood algorithm (ER Mapper 6.3) using all seven Landsat bands.

Analysis

The classified images were used to determine forest loss over the time periods between 1987-1998 and 1998-2001. Before calculating area statistics for our image subset we substituted clouded pixels with the corresponding classified pixels from the previous image where possible. For example, a cloudy pixel in the 1998 image would take on the classification value of that pixel in the 1987 image when area statistics were calculated. Thus, for clouded areas we assumed no change in land cover over the intervening time period. This “no change” hypothesis process ensures that area statistics are comparable between time peri-
ods. It also means that our estimates of land cover change are probably conservative. After substituting clouded pixels, area statistics were calculated for each classified image. Area statistics were also calculated separately for each of the four designated protected areas in La Amistad Biosphere Reserve at each time period. Changes in the amount of land in each cover type were calculated between the three time periods to give estimates of both rates and absolute amounts of forest loss.

The classification maps for each period were then exported to ARCGIS 8.1 as raster layers. Based on our classification, a change detection map was created to identify pixels where forest was lost over the time period. In ARCGIS, the distance from forested and deforested pixels to rivers, roads, and villages was calculated. This data was then exported to SAS v8.1 and a binary logistic regression model was developed to test relationships between forest loss and pixel location within the landscape with respect to these variables. For each variable, the distances were broken into 7 classes, spanning a maximum distance of approximately 6 km for rivers and 30 km for roads and towns.

**Accuracy Assessment**

Satellite data were groundtruthed over a 10-day period from March 7 through March 17, 2003. Patches of at least 30 m × 30 m of various cover types were identified and photographed and their position on a UTM grid was determined using a GPS unit with an accuracy of 10 m. Ground-truthed data were used to assess the accuracy of the supervised classifications. Overall accuracy as well as user and producer accuracy for each class were determined. User accuracy is a measure of the probability that a pixel classified as being a certain cover type is actually that cover type. Producer accuracy is a measure of the probability that a given location on the ground is accurately classified in the analysis (Stehman & Czaplewski, 1998; Kuegler, 2003).

**RESULTS**

The 1987, 1998, and 2001 unclassified images with clouds removed are shown in Figure 2. Classification schemes provided good separation between land-cover types (Table 1) and are shown in Figure 3. The signatures of sun vs. shade features were generally distinct and parallel as in Helmer et al. (2000).
FIGURE 2. La Amistad Biosphere Reserve. The white lines represent the protected area boundaries. These are the unclassified images from 1987, 1998, and 2001 with cloud cover removed.
FIGURE 3 (continued)

1998 Supervised Classification

2001 Supervised Classification
Table 2 quantifies the percent, absolute area, and rates of change of each cover type for both the entire biosphere reserve and for each of the protected areas that make up the reserve. Total percent forest loss was small from 1987 to 1998, with less than 1% of forest cover lost. Between 1998 and 2001 forest cover loss was much greater, at 2.34%.

Table 1. Distance between means for supervised classification schemes.

<table>
<thead>
<tr>
<th>Year</th>
<th>Clouds</th>
<th>Shade-Forest</th>
<th>Shade-Pasture</th>
<th>Soil</th>
<th>Sun-Forest</th>
<th>Sun-Pasture</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>0.000</td>
<td>6.734</td>
<td>6.412</td>
<td>6.334</td>
<td>3.963</td>
<td>4.593</td>
<td>21.408</td>
</tr>
<tr>
<td>1998</td>
<td>0.000</td>
<td>6.093</td>
<td>7.452</td>
<td>4.453</td>
<td>5.214</td>
<td>3.087</td>
<td>21.228</td>
</tr>
<tr>
<td>2001</td>
<td>0.000</td>
<td>8.317</td>
<td>7.253</td>
<td>2.869</td>
<td>5.999</td>
<td>4.185</td>
<td>21.793</td>
</tr>
</tbody>
</table>

Table 2 quantifies the percent, absolute area, and rates of change of each cover type for both the entire biosphere reserve and for each of the protected areas that make up the reserve. Total percent forest loss was small from 1987 to 1998, with less than 1% of forest cover lost. Between 1998 and 2001 forest cover loss was much greater, at 2.34%. 

<table>
<thead>
<tr>
<th></th>
<th>FOREST</th>
<th>PASTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILA</td>
<td>204466.31</td>
<td>203615.56</td>
</tr>
<tr>
<td>PALO</td>
<td>153071.84</td>
<td>151409.01</td>
</tr>
<tr>
<td>VBARU</td>
<td>13175.43</td>
<td>13422.84</td>
</tr>
<tr>
<td>FORTUNA</td>
<td>22471.87</td>
<td>22435.24</td>
</tr>
<tr>
<td>TOTAL</td>
<td>393185.45</td>
<td>390882.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CLOUD</th>
<th>WATER</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILA</td>
<td>3531.91</td>
<td>3531.91</td>
</tr>
<tr>
<td>PALO</td>
<td>5094.84</td>
<td>5094.84</td>
</tr>
<tr>
<td>VBARU</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td>FORTUNA</td>
<td>370.22</td>
<td>370.22</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8627.96</td>
<td>8627.96</td>
</tr>
<tr>
<td>---------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>PILA</td>
<td>76.68</td>
<td>241.08</td>
</tr>
<tr>
<td>PALO</td>
<td>101.53</td>
<td>264.88</td>
</tr>
<tr>
<td>VBARU</td>
<td>834.99</td>
<td>958.78</td>
</tr>
<tr>
<td>FORTUNA</td>
<td>953.83</td>
<td>632.42</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1967.03</td>
<td>2097.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>% Forest Cover (87)</th>
<th>% Forest Cover (98)</th>
<th>% Forest Cover (01)</th>
<th>Total % Deforestation</th>
<th>Annual % Forest Loss (87-98)</th>
<th>Annual % Forest Loss (98-01)</th>
<th>Rate Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILA</td>
<td>97.70</td>
<td>97.29</td>
<td>96.35</td>
<td>1.35</td>
<td>0.04</td>
<td>0.24</td>
<td>6.37</td>
</tr>
<tr>
<td>PALO</td>
<td>94.19</td>
<td>93.16</td>
<td>88.51</td>
<td>5.68</td>
<td>0.09</td>
<td>1.16</td>
<td>12.51</td>
</tr>
<tr>
<td>VBARU</td>
<td>85.27</td>
<td>86.88</td>
<td>85.17</td>
<td>0.10</td>
<td>−0.15</td>
<td>0.43</td>
<td>−2.92</td>
</tr>
<tr>
<td>FORTUNA</td>
<td>88.55</td>
<td>88.40</td>
<td>88.92</td>
<td>−0.37</td>
<td>0.01</td>
<td>−0.13</td>
<td>−9.87</td>
</tr>
<tr>
<td>Total</td>
<td>95.29</td>
<td>94.73</td>
<td>92.39</td>
<td>2.90</td>
<td>0.05</td>
<td>0.59</td>
<td>11.54</td>
</tr>
</tbody>
</table>
Similarly, annual rates of forest cover loss were negligible from 1987 to 1998, at 0.05% but much higher between 1998 and 2001, at 0.59%.

There were significant variations in forest cover and change between protected areas. Percent forest cover in 1987 was highest in the PILA and Palo-Seco protected areas, at 97% and 94%, respectively. Forest cover in 1987 at Volcan Barú and Fortuna were lower, at 85% and 88%, respectively. Total forest area in 1987 followed the same trend, at approximately 205,000 ha in PILA, 153,000 ha in Palo Seco, 13,000 ha at Volcan Barú and 22,000 ha at Fortuna.


Overall and annual rates of deforestation were also significantly higher on the Caribbean side. Total percentage of deforestation was 5.68% in the Palo-Seco Protected Forest, 1.35% at PILA, and 0.1% at Volcan Barú National Park, and forest cover actually increased by 0.37% at the Fortuna Hydrological Reserve. Annual deforestation rates between the two time periods increased six-fold and nearly 13-fold in PILA and Palo Seco, respectively. This trend can be seen in Figures 5 and 6. However, on the Pacific side, deforestation rates doubled in Volcan Barú and forest loss in Fortuna reversed.

Results from logistic regression models showed significant associations between distance to roads (DF = 6, $\chi^2 = 66012$, $P > \chi^2 < 0.0001$), rivers (DF = 6, $\chi^2 = 11383$, $P > \chi^2 < 0.0001$) and towns (DF = 3, $\chi^2 = 71049$, $P > \chi^2 < 0.0001$) and deforestation risk. Relative risk of deforestation was greatest in the closest distance classes for roads, rivers, and towns. Deforestation risk for pixels in the nearest roads distance class was 8.46 times greater than the farthest distance class, 6.98 times greater for the rivers variable, and 7.5 times greater for the towns variable.

Based on our accuracy assessment, overall accuracy was 74.67% (Table 3). User accuracy was 75% for forests, 80% for pasture, 69% for soil and 100% for water. Producer accuracy was 93% for forests, 21% for pasture, 90% for soil and 100% for water.
DISCUSSION

Despite its previous isolation from the major social and economic centers of Mesoamerica, development has begun to leave its mark on Panama’s La Amistad Biosphere Reserve. Our results show that forest loss has accelerated greatly across the Reserve, with a nearly 12-fold increase in annual deforestation rates between 1987 to 1998 and 1998 to 2001. Additionally, we have detected an “ocean effect,” where previously remote areas on the undeveloped Caribbean side of Panama are experiencing rapidly accelerating rates of deforestation due to development pressure and population increases. Volcan Barú and Fortuna, which have significantly lower percent forest coverage as well as lower total forest area, are well connected through transportation infrastruc-
FIGURE 5 (continued)
ture to the major social and economic centers of Panama, such as David and Panama City. These areas most likely experienced an earlier rash of deforestation coinciding with the economic development of the rest of the country. The more recent completion of roads and airports in the Caribbean province of Bocas del Toro most likely explains its lag behind the rest of Panama.

Land-tenure in Panama is nowhere more complicated than where it involves nationally protected parks and forests. Most protected areas in Panama have been created by government fiat, and overlaid on top of existing land claims. When created, Palo Seco—and to a lesser extent PILA and Volcan Barú—included significant indigenous communities and inholdings. Privately owned inholdings are not purchased or seized by the government and the restrictions on land use by residents within protected areas are neither clearly defined nor well enforced. Accordingly, deforestation rates were highest in the Palo Seco reserve. Furthermore, a large portion of Palo Seco overlaps with the autonomous
TABLE 3. Accuracy assessment of landcover classification algorithms.

<table>
<thead>
<tr>
<th>Classified Data</th>
<th>Ground Truth Data</th>
<th>Forest</th>
<th>Pasture</th>
<th>Soil</th>
<th>Water</th>
<th>Classified Pixels</th>
<th>User Accuracy</th>
<th>Producer Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>42</td>
<td>13</td>
<td>1</td>
<td>0</td>
<td>56</td>
<td>75.00</td>
<td>93.33</td>
<td></td>
</tr>
<tr>
<td>Pasture</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>80.00</td>
<td>21.05</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>2</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>13</td>
<td>69.23</td>
<td>90.00</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>100.00</td>
<td>100.00</td>
<td></td>
</tr>
<tr>
<td>Ground Truth Pixels</td>
<td>45</td>
<td>19</td>
<td>10</td>
<td>1</td>
<td>75</td>
<td>Overall accuracy</td>
<td>74.67</td>
<td></td>
</tr>
</tbody>
</table>

The indigenous territory of the Ngöbe-Búgle Indians, and is home to significant indigenous populations. The Ngöbe are currently experiencing high rates of population growth, and anecdotal evidence from other indigenous groups in the region suggests the Ngöbe are expanding their economic activities throughout Palo-Seco and PILA.

The existence of transportation or access routes in relation to problems of forest conversion and deforestation has been widely studied (Forman & Alexander, 1998; Trombulak & Frissell, 2000; Wilkie et al., 2000). The construction of the road between Almirante and Changuinola has increased access to and human population pressure on the remote areas of LABR. This hypothesis was strongly supported by results from our logistic regression. However, roads are not the single constraining variable. Our GIS analyses showed that proximity to rivers and villages was also highly related to the probability of pixel deforestation. While roads are not the only way of accessing forests, their presence expedites large-scale movement of goods to markets and encourages the use of rivers to make major incursions into protected areas. While our regression results showed a strong relationship between proximity to roads, rivers, and villages and deforestation, the spatial scale of this effect was different between variables. Deforestation was correlated with rivers at a very small scale (approximately 500 to 1000 m). However, the effect of roads and villages was evident at much larger spatial scales (5 to 10 km). This suggests that rivers provide immediate access to forests while roads and villages provide the markets or market access that drives consumption of forest products. This finding casts serious doubt upon government plans to construct an “ecological road” through the Volcan Barú National Park (see Jones, this issue).
and suggests that market driven impacts might be much larger than the mere footprint of the road.

Major incursions into PILA and Palo Seco are easily identifiable in both satellite and aerial photographs. Analysis and ground surveys reveal that the primary cause of forest clearing in this area is for cattle ranching. According to local sources the major incursion of industrial cattle ranching located in Palo Seco and PILA is related to expanding economic interests from the high population growth region of Chiriqui Province (see Connelly and Shapiro, this issue). While these pastures were evident in the 1987 image, their scope and extent has increased dramatically over the nearly 14 years covered by this analysis. With the source of deforestation clearly identified, enforcement efforts can be efficiently allocated.

Our accuracy assessment demonstrates that overall, the accuracy of our classification and analysis is quite high. Unfortunately, the sample size of our ground truth data was limited in quantity by field logistics. Also, it was not possible to collect ground truth data using a systematic sampling scheme. As a result of these two factors, our accuracy assessment provides only a rough estimate of the accuracy of our classification. However, useful conclusions can be drawn from this estimate. User and producer accuracy were quite high (ranging from 69% up to 100%) with the exception of producer accuracy in the pasture class which was only 21%. This means that there may be a high probability that areas that had been converted to pasture on the ground were not picked up by our analysis and were erroneously classified as forest. This is probably particularly likely in the case of pastures that are close to or smaller than the 30 m × 30 m pixel size. The misclassification of pasture as forest was systematic throughout all time periods of our analysis. Therefore, measures of forest loss remain accurate. However, measures of absolute forest cover may significantly overestimate the amount of forest cover in the region.

Overall, our results show strong trends in deforestation that should be of concern to the maintenance of ecosystem integrity. As discussed above, these results are conservative. In addition to the fact that our classification may have overestimated the amount of forest cover present, the classification also does not differentiate between secondary and primary forest types. While secondary forests play an important role in forested ecosystems, the higher conservation value of primary forests is generally well documented (Brown & Lugo, 1990; Aide et al., 1995; Guariguata et al., 1997). Additionally, forest cover does not correlate perfectly with species presence. Hunting and other pressures may lead
to the “empty forest syndrome” (Redford, 1992). Our field visits included numerous montane communities where forest cover was intact but the wildlife community was clearly depauperate.

CONCLUSIONS

We have determined the existence of a threat to the integrity of conservation interests in the La Amistad Biosphere Reserve. Net annual rates of deforestation within the LABR are on par with rates of deforestation in other Latin American countries, such as Brazil and Costa Rica (Tole, 2002). However, what may be acceptable rates of short-term forest loss outside of protected areas may not be acceptable within protected areas. The recent acceleration of deforestation rates was confirmed by on the ground observations by our field team and local conservation actors. We have also clearly identified the exact location of deforestation hotspots and the major transportation routes enabling this trend. These findings have substantial utility in guiding and prioritizing planning and enforcement activities. Finally, our survey is unique in that it occurs in conjunction with a suite of interdisciplinary assessments for conservation that deal with the indirect social and economic roots of deforestation. We hope that this study enables policymakers to focus their efforts when implementing biodiversity conservation and sustainable development projects addressing the problem of deforestation in the LABR.

REFERENCES


