Tropical Deforestation in the Bolivian Amazon

Compton J. Tucker, Marc K. Steininger, John R. G. Townshend, Timothy R. Killeen and Arthur Desch

NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771 USA; Department of Geography, University of Maryland, College Park, Maryland 20742 USA; Missouri Botanical Garden, St. Louis, Missouri USA.

Abstract

Landsat satellite images from the mid-1980s and early 1990s were used to map tropical forest extent and deforestation in ~800,000 km² of Amazonian Bolivia. Forest cover extent, including tropical deciduous forest, totaled 472,000 km² while the area of natural non-forest formations totaled 298,000 km². The area deforested totaled 15,000 km² in the middle 1980s and 28,800 km² by the early 1990s. The rate of tropical deforestation in the >1,000 mm y⁻¹ precipitation forest zone of Bolivia was 2,200 km² y⁻¹ from 1985-1986 to 1992-1994. We document a spatially-concentrated “deforestation zone” in Santa Cruz Department where >60% of the Bolivian deforestation is occurring at an accelerating rate in areas of tropical deciduous forest.

Keywords: tropical forests, deforestation, habitat fragmentation, biological diversity, Landsat, GIS, Bolivia

Introduction


Remote-sensing analyses of the Brazilian Amazon have demonstrated dynamic deforestation frontiers, particularly in areas near highways or industrial-scale agriculture (Fearnside, 1986; Skole and Tucker, 1993). The spatial composition from these areas demonstrates high levels of fragmentation of the remaining, uncut forests. Fragmented forest patches and forest near clearance edges are susceptible to an array of human and bio-climatological impacts (Malcolm, 1994; Laurence, et al., 1997 and 1998; Cochrane and Schulze, 1999; Nepstad et al., 1999), and the isolation of forest fragments also affects local composition and diversity of both plants and mammals (Miller and Harris, 1977; Wilcox, 1980; Karieva, 1987; Laurence et al., 1999).

Bolivia, a land-locked country with a total national territory of ~1,098,000 km² in central South America, contains ~500,000 km² of forest and woodland, including more than 400,000 km² of lowland tropical forest within the Amazon Basin. The Bolivian lowlands, the Oriente, maintain a high degree of biological diversity and have been identified among the top 10 conservation priorities in the world (Dinerstein et al. 1995; Gentry, 1995; Killeen and Schulenberg, 1999). Part of the reason for the high biodiversity there is the large number of forest and savanna habitat types (see Prance and Schaller, 1982; Haase and Beck, 1989; Killeen et al., 1992, 1998; Prado and Gibbs, 1993; Hanagarth, 1993; Killeen and Schulenberg, 1999).
created. The average deforestation rate between time periods for the entire country was calculated as the intersection of the scene years and deforestation map.

Our analysis of Bolivia determined a total potential closed-canopy forest area of $471.800 \, \text{km}^2$, $322.000 \, \text{km}^2$ of non-forest, and $13.700 \, \text{km}^2$ of water (Table 1). Approximately $52.000 \, \text{km}^2$ of the potential forest was above $1000 \, \text{m}$ elevation. The land area deforested was $15.000 \, \text{km}^2$ by the middle 1980s and $28.800 \, \text{km}^2$ by the early 1990s. Of the $13.800 \, \text{km}^2$ of deforestation between time periods, $1.650 \, \text{km}^2$ was above $1000 \, \text{m}$. Cloud cover in both time periods obscured a combined total of $16.000 \, \text{km}^2$ of the surface. The average rate of anthropogenic deforestation between the middle 1980s and early 1990s for the entire area was $-2200 \, \text{km}^2 \, \text{yr}^{-1}$.

**Comparison with Previous Estimates of Forest Cover and Loss**

Our estimates of deforestation are significantly lower than those of the FAO (FAO, 1981, 1990, 1993, 1996, 1997; Lanly, 1982) which have been based upon compilation of survey data from non-satellite sources. Questions have been raised regarding the sampling strategy and accuracy of the FAO forest extent and deforestation numbers in Table 2 (Tucker and Townshend, 2000). The FAO deforestation numbers for Brazil have been challenged using analyses of satellite data by INPE (Tardin et al. 1979, 1980, and 1990) and Skole and Tucker (1993).

The FAO Production Yearbook (FAO, 1976) reports a total Bolivian forest and woodland cover of 599,500 km² for 1941-1945 falling to 592,000 km² for 1966. This figure decreases to 582,000 km² in 1970 and to 570,000 in 1975. This is considerably higher than our estimate of potential forest cover of 460,000 km². However, the FAO reported an average rate of 5,100 km² yr⁻¹ of deforestation for 1985 to 1995, a rate over twice ours (Table 2). Thus, their estimate of the area deforested in 1995 surpasses ours.

The estimate of 24,000 km² deforested by 1990 reported by CUMAT (1992) is close to ours; however, they estimated that only 375 km² of this area was cleared between 1985 and 1990. The Bolivian National Secretary of Natural Resources reported that 3,000 km² of lowland forest were cleared from 1975 to 1993 (MDSMA, 1995). This is lower than our estimate since we report 13,800 km² of change between the 1980s and 1990s alone. We believe that the inconsistencies in these products, particularly in estimates of change, are caused by limitations in the visual interpretation approach to deforestation mapping, especially interpretation differences, data co-registration and boundary generalization.

**Distribution of Bolivian deforestation**

Deforestation in Amazonia can be prehistoric but in Bolivia historically began with the founding of Jesuit missions in Chiquitos (Santa Cruz) and Moxos (Beni) (Metcalf, 1948; Denevan, 1966; Block, 1994). Some of these settlements remain as small villages, although Santa Cruz de la Sierra, at the base of the Andes, became an agricultural center in the 1950s. Most of the deforestation by the 1970s in Santa Cruz was in sugar, rice, corn, and citrus farms immediately surrounding the city (Stearman, 1985; Thiele, 1996; Pacheco, 1998; Hecht, 1999). Several planned colonies of highlanders were settled north and west of the city. Further north, pastures began to appear on the Brazilian shield, and several Mennonite communities have settled east of Santa Cruz de la Sierra.

By the 1980s, spontaneous colonization had increased around the city and along the new Santa Cruz – Cochabamba highway. Also in the 1990s, industrial soybean farmers had arrived and rapidly cleared large areas east of the city. The result was that the area deforested by the middle 1980s had nearly doubled by the early 1990s. Despite a national population of 6 million and lowland population of only 1.5 million, the rate of deforestation over this period was similar to rates reported for Maranhão, Mato Grosso and Rondônia, Brazil during the early 1980s (Skole and Tucker, 1993).


Cordecruz, 1994. Plan del Uso del Suelo. Santa Cruz de la Sierra, Bolivia, Proyecto de Proteccion de los Recursos Naturales del Departamento de Santa Cruz, Bolivia.


Table 1. Summary of deforestation estimated for Bolivian forests, based on digital analysis of Landsat Thematic Mapper (TM) and Multispectral Scanning System (MSS) images. All areas are in km$^2$ and rates are in km$^2$ yr$^{-1}$. Data from the 1980s are from 1984 to 1987, the 1990s are from 1992 - 1994. All forest in the < 1000 meter precipitation zone were mapped.

*Areas deforested by the middle 1980s were only mapped below 1000 m elevation. 1,645 km$^2$ of the total deforestation between the time periods were in areas over 1000 m above sea level. **For one scene of montane forest in La Paz (002-71), only data from the 1990s were available, and thus there is no change estimated for this area.

<table>
<thead>
<tr>
<th>Department</th>
<th>Potential Forest</th>
<th>Forest by the 1980s</th>
<th>Non-Forest</th>
<th>Deforested by the 1980s*</th>
<th>Deforested by the 1990s</th>
<th>Deforestation 1980s - 1990s</th>
<th>Water</th>
<th>Cloud</th>
<th>No data</th>
<th>Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beni</td>
<td>92,277</td>
<td>87,712</td>
<td>105,699</td>
<td>816</td>
<td>2,909</td>
<td>2,093</td>
<td>9,564</td>
<td>3,030</td>
<td>2,646</td>
<td>211,560</td>
</tr>
<tr>
<td>Cochabamba</td>
<td>26,390</td>
<td>20,322</td>
<td>27,834</td>
<td>1,520</td>
<td>2,774</td>
<td>1,255</td>
<td>492</td>
<td>3,346</td>
<td>2,964</td>
<td>57,732</td>
</tr>
<tr>
<td>La Paz</td>
<td>64,351</td>
<td>56,318</td>
<td>37,422</td>
<td>1,238**</td>
<td>2,869**</td>
<td>1,627**</td>
<td>849</td>
<td>6,781</td>
<td>24,391</td>
<td>128,026</td>
</tr>
<tr>
<td>Pando</td>
<td>58,789</td>
<td>55,999</td>
<td>1,726</td>
<td>665</td>
<td>1,541</td>
<td>876</td>
<td>773</td>
<td>1,264</td>
<td>2,103</td>
<td>63,405</td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>218,914</td>
<td>199,373</td>
<td>125,179</td>
<td>10,835</td>
<td>18,616</td>
<td>7,782</td>
<td>2,051</td>
<td>1,390</td>
<td>20,552</td>
<td>367,160</td>
</tr>
<tr>
<td>Chuquisaca</td>
<td>11,039</td>
<td>10,842</td>
<td>24,756</td>
<td>-</td>
<td>91</td>
<td>91</td>
<td>62</td>
<td>151</td>
<td>14,982</td>
<td>50,884</td>
</tr>
<tr>
<td>Sum</td>
<td>471,760</td>
<td>430,566</td>
<td>322,615</td>
<td>15,073</td>
<td>28,801</td>
<td>13,724</td>
<td>13,791</td>
<td>15,961</td>
<td>67,638</td>
<td>879,367</td>
</tr>
</tbody>
</table>