Tropical Deforestation in the Bolivian Amazon

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Abstract

Landsat satellite images from the mid-1980s and early 1990s were used to map tropical forest extent and deforestation in ~800,000 km^2 of Amazonian Bolivia. Forest cover extent, including tropical deciduous forest, totaled 472,000 km^2 while the area of natural non-forest formations totaled 298,000 km^2. The area deforested totaled 15,000 km^2 in the middle 1980s and 28,800 km^2 by the early 1990s. The rate of tropical deforestation in the >1,000 mm y^{-1} precipitation forest zone of Bolivia was 2,200 km^2 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 dry forest.

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

Introduction

Deforestation has occurred in the tropics throughout history (Tucker and Richards, 1983; Richards, 1984; Hecht and Cockburn, 1989; Williams, 1989 and 1990) and has accelerated recently, particularly in areas of seasonally-deciduous tropical forests (Schmink and Wood, 1984; Janzen, 1986; Fearnside, 1986, 1993; Houghton et al. 1991; Myers, 1991; Skole and Tucker, 1993; Maas, 1995). Accurate information on the extent of tropical forests and deforestation is essential for estimation of changes in surface energy balance and atmospheric greenhouse gas emissions (Cook et al. 1990; Gash and Shuttleworth, 1991; Houghton, 1991; Keller et al. 1991; Dixon et al. 1994; Fearnside, 1996). Precise information about the spatial distribution of deforestation is also necessary to estimate the impacts of habitat destruction and fragmentation on biological diversity (Harris, 1984; Skole and Tucker, 1993; Pimm, 1995; Laurence and Bierregaard, 1997; Laurence et al. 1997, 1998; Chiarello, 1999).

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 km^2 in central South America, contains ~500,000 km^2 of forest and woodland, including more than 400,000 km^2 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., 1993, 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 km^2, 322,000 km^2 of non-forest, and 13,700 km^2 of water (Table 1). Approximately 52,000 km^2 of the potential forest was above 1000 m elevation. The land area deforested was 15,000 km^2 by the middle 1980s and 28,800 km^2 by the early 1990s. Of the 13,800 km^2 of deforestation between time periods, 1,650 km^2 was above 1000 m. Cloud cover in both time periods obscured a combined total of 16,000 km^2 of the surface. The average rate of anthropogenic deforestation between the middle 1980s and early 1990s for the entire area was ~2,200 km^2 y^{-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 compellation 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 km^2 for 1941-1945 falling to 592,000 km^2 for 1966. This figure decreases to 582,000 km^2 in 1970 and to 570,000 in 1975. This is considerably higher than our estimate of potential forest cover of 460,000 km^2. However, the FAO reported an average rate of 5,100 km^2 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 km^2 deforested by 1990 reported by CUMAT (1992) is close to ours; however, they estimated that only 375 km^2 of this area was cleared between 1985 and 1990. The Bolivian National Secretary of Natural Resources reported that 3,000 km^2 of lowland forest were cleared from 1975 to 1993 (MDSMA, 1995). This is lower than our estimate since we report 13,800 km^2 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) (Metraux, 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 – Cochabambe 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).

Aramburú, C.E., 1984. Expansion of the agrarian and demographic frontier in the Peruvian Selva. In *Frontier Expansion in Amazonia.* Edited by M. Schmink and C.H. Wood, Gainesville: Univ. of Florida Press, pp. 153-179..

Block, D., 1994. *Mission Culture on the Upper Amazon.* Lincoln: Univ. of Nebraska Press. 240 pp.

Chiarello, A.G., 1999. Effects of fragmentation of the Atlantic forest on mammal communities in south-eastern Brazil. *Biological Conservation* 89:71-82.

Cochrane, M.A. and M.D. Schulze, 1999. Fire as a recurrent event in tropical forests of the eastern Amazon: effects on forest structure, biomass and species composition. *Biotropica* 31:2-16.

Cook, A.G., A.C. Janetos, and W.T. Hinds, 1990. Global effects of tropical deforestation: towards an integrated perspective. *Environmental Conservation* 17:201-212.

Cordecruz, 1994. *Plan del Uso del Suelo.* Santa Cruz de la Sierra, Bolivia, Proyecto de Protecion de los Recursos Naturales del Departmento de Santa Cruz, Bolivia.

Cross, A. M., J. J. Settle, N. A. Drake, and R. T. M. Paivinen. 1991. Subpixel measurement of tropical forest cover using AVHRR data. *Int. J. Remote Sensing* 12:1119-1129.

CUMAT, 1992. *Desbasque de la Amazonia Boliviana.* Vegetation Map. La Paz: Capacidad de Uso Mayor de la Tierra.

Denevan, W.M., 1966. *The Aboriginal Cultural Geography of the Llanos de Mojos of Bolivia.* Berkeley: Univ. of California Press.

Dinerstein, E. D. Olson, M. Graham, D. J. Webster, A. L. Rim, A. A. Bookbinder M. P. & Ledec, G. 1995. *A conservation assessment of the terrestrial ecoregions of Latin America and the Caribbean.* World Wildlife Fund - The World Bank, Washington DC. 135 pp.

Dixon, R. K., S. Brown, R. A. Houghton, S. M. Solomon, M. C. Trexler, and J. Wisniewski, 1994. Carbon pools and flux of global carbon forest ecosystems. *Science.* 263:185-190.

Downton, M.W., 1995. Measuring tropical deforestation: development of the methods. *Environmental Conservation* 22:229-240.

Fearnside, P. M., 1986. Spatial concentration of deforestation in the Brazilian Amazon. *Ambio* 15:74-81.

Fearnside, P. M., 1993. Deforestation in Brazilian Amazonia: The effect of population and land tenure. *Ambio 22,* 537-545.

Fearnside, P. M., 1996. Amazonian deforestation and global warming: carbon stocks in vegetation replacing Brazil's Amazon forest. *Forest Ecology and Management* 80:21-34.

FAO, 1976. FAO Production Yearbook. Food and Agricultural Organization of the United Nations, Rome.

FAO, 1981. *Tropical Forest Resources Assessment Project. Forest Resources of Tropical America.* Food and Agricultural Organization of the United Nations, Rome.

FAO, 1990. *Interim Report on Forest Resources Assessment 1990 Project.* Committee on Forestry, Tenth Session, Rome, Italy. Food and Agricultural Organization of the United Nations, Rome.

FAO, 1993. *Forest resources assessment 1990.* FAO Forestry Paper 112, Food and Agricultural Organization of the United Nations, Rome.

FAO, 1996. *Forest resources assessment 1990: Survey of tropical forest cover and study of change processes.* FAO Forestry Paper 130, Food and Agricultural Organization of the United Nations, Rome.

Laurence, W., L., L.V. Ferreira, , J.M. Rankin-de Merona and S. G. Laurance, 1998. Rainforest fragmentation and the dynamics of Amazonian tree communities. *Ecology* 79: 2032-2040.

Ledec, G. (1989). *Bolivia Eastern Lowlands Development Project: Appraisal of Natural Resource Planning and Management Component*. Washington, D.C.: World Bank.

MDSMA, 1995. *Memoria Explicativa. Mapa Forestal.* Vegetation Map. La Paz: Sectretaría Nacional de Recursos Naturales.

Maass, J.M., 1995. Conversion of tropical dry forest to pasture and agriculture. In *Seasonally Dry Tropical Forests.* Edited by S.H. Bullock, H.A. Mooney and E. Medina, pp. 399-422. . Cambridge: Cambridge University Press.

Malcolm, J. R., 1994. Edge effects of Amazonian forest fragments. *Ecology* 75: 2438-2445.

Malingreau, J.P., F. Achard, G. D'Souza, H.J. Stibig, J. D'Souza, C. Estreguil and H. Eva, 1995. AVHRR for global tropical forest monitoring: the lessons of the TREES project. *Remote Sensing Reviews* 12:29-40.

Malingreau, J. P., and Tucker, C. J., 1988. Large-scale deforestation in the southeastern Amazon basin of Brazil. *Ambio* 17:49-55.

Metreaux, A. Tribes of eastern Bolivia and the Madeira headwaters. In *Handbook of South American Indians.* Edited by J. Steward. Vol. 3:351-454. Washington: U.S. Government Printing Office.

Miller, R. I. and L. D. Harris, 1977. Isolation and extirpations in wildlife reserves. *Biological Conservation* 12:311-315.

Myers, N. 1991. Tropical forests: present status and future outlook. *Climatic Change* 19 : 3-32.

Nepstad, D. C., Verissimo, A., Alencar, A., Nobre, C., Lima, E., Lefebvre, P., Schlesinger, P., Potter, C., Moutinho, P., Mendoza, E., Cochrane, M. and Brooks, V., 1999. Large-scale impoverishment of Amazonian forests by logging and fire. *Nature* 398:505-508.

Pacheco, P., 1998. *Estilos de Desarollo, Deforstación y Degradacióde los Bosques en las Tierras Bajas de Bolivia.* 389 pp. La Paz: CEDLA.

Painter, M., 1995. Upland-lowland production linkages and land degradation in Bolivia. In *The Social Causes of Environmental Destruction in Latin America.* Edited by Painter, M. and W.H. Durham, pp. 133-168. Ann Arbor: Univ. of Michigan Press.

Pimm, S. L., Russell, G. J., Gittleman, J. L., and Brooks, T. M., 1995. The future of biodiversity. *Science* 269:347-350.

Prado, D. E. & Gibbs, P. E. 1993. Patterns of species distributions in the dry seasonal forests of South America. *Ann. Missouri Bot. Garden* 80: 902-927.

Richards, J. F. 1984. Global patterns of land conversion. *Environment* 26 (9): 6-38.

Roche, M. A. & N. Rocha, 1985. Precipitacioes anuales. Programa Climatólogico e Hidrológico de la Cuenca Amazónica Boliviana (PHICAB): Servicio Nacional de Meteología e Hidrología (SENAHMHI) - ORSTROM, La Paz.

Sanabria, H., 1993. *The Coca Boom and Rural Social Change in Bolivia.* Ann Arbor: Univ. of Michigan Press.

Schmink, M. and C. H. Wood, eds. 1984. *Frontier Expansion in Amazonia.* Gainesville: Univ. of Florida Press. 502 pp.

Skole, D. L., and Tucker, C. J., 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. *Science* 260:1905-190.

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 $km^2\ y^{-1}$. 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.

Department	Potential Forest	Forest	Non-Forest	Deforested by the 1980s*	Deforested By the 1990s	Deforestation 1980s – 1990s	Water	Cloud	No data	Total Area
Beni	92,277	87,712	105,699	816	2,909	2,093	9,564	3,030	2,646	211,560
Cochabamba	26,390	20,322	27,834	1,520	2,774	1,255	492	3,346	2,964	57,732
La Paz	64,351	56,318	37,422	1,238**	2,869**	1,627**	849	6,781	24,391	128,626
Pando	58,789	55,999	1,726	665	1,541	876	773	1,264	2,103	63,405
Santa Cruz	218,914	199,373	125,179	10,835	18,616	7,782	2,051	1,390	20,552	367,160
Chuquisaca	11,039	10,842	24,756	-	91	91	62	151	14,982	50,884
Sum	**471,760**	**430,566**	**322,615**	**15,073**	**28,801**	**13,724**	**13,791**	**15,961**	**67,638**	**879,367**