Synopsis

This synopsis was not peer reviewed.

Illicit Crops in Tropical America: Deforestation, Landslides, and the Terrestrial Carbon Stocks

The 250 landslides that simultaneously occurred in the Río Tarazá basin, Antioquia Department, in Colombia after the torrential rains of 19 and 20 May 2007 (Fig. 1) rank among the major rainfall-triggered disasters in this country (1). According to an official report, about 3000 ha, mostly covered by illegal cash crops, were wasted, thus reviving the discussion on the ecological impacts of illicit crops in Tropical America. These landslides and debris flow killed 13 peasants associated with coca bush (*Erythroxylum coca*) crops, forced evacuation of 67 people from indigenous reservations, and caused the temporary relocation of 600 families from the partially flooded town. Road infrastructure, lowland crops, and private buildings were also damaged. Such a number of landslides far exceeded previous landsliding recorded in Colombia during very wet years. For instance, during La Niña 1999–2000, the wettest year in record nationwide, the departmental maximum was 80 landslides and the municipal maximum was 8 (1). Larger numbers of landslides have only occurred after earthquakes, volcanic activity, and localized infrequent torrential rainfall (>200 mm h^{-1}) in Colombia (2) and other regions of Tropical America (3).

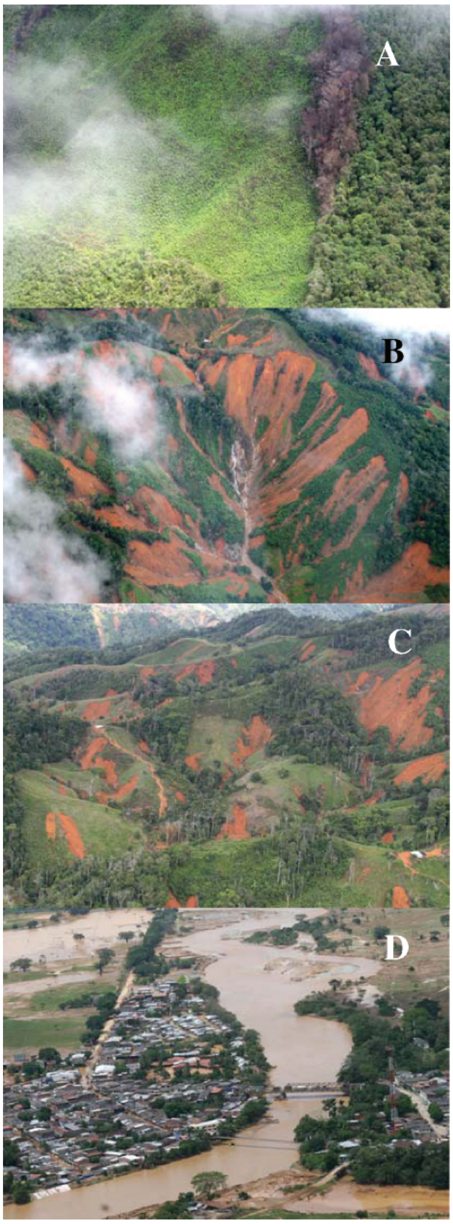
Landsliding Risk, Deforestation, and Illegal Crops

Land-use change in the Tarazá basin was probably the greatest influence on landsliding risk. During this rainfall event, a greater number of landslides occurred on crop lands and along roads than in forested lands. Such a pattern has been previously described in Central America and the Caribbean, where landsliding has been extensively studied (4). In rural areas of the Tarazá municipality, most mature forests have been converted to coca bush crops according to the United Nations Office for Drug and Crime (UNODC) (5). Contrary to the national trend, coca crops have steadily expanded since 2000 at both municipal and department level (Fig. 1). In 2004, this municipality contributed 23% of cultivated area to the department's total (5165 ha). Although cultivated area declined between 2000 and 2005 as a result of eradication efforts, a 7% increase at the national level was still observed between 2004 and 2005 because of expansion in several departments and within National Natural Parks (2003–2005: +62%).

Expansion of coca bush crops, and therefore deforestation, in Tropical America (specifically Colombia, Peru, and Bolivia) (Fig. 1) is driven by high profit, high prices in illicit international markets, and an expert-perceived increase in global consumption (5). Deforestation in Colombia also has been recently linked to the internal armed conflict, and particularly to financing through illicit crops (6, 7). In contrast, globalization of legal trade has promoted past (e.g., Puerto Rico) and current (e.g., Dominican Republic, Argentina) shift from agricultural to industrialized economy that has been accompanied by rural–urban migration and the abandonment of agricultural lands, which ultimately resulted in forest recovery in many countries of Tropical America (8).

Illegal Crop Impacts on Forest Carbon Stocks

Because deforestation will increase in several countries of Tropical America as long as illicit economies and armed conflicts continue, a scientific approach to study their ecological impacts is urgently needed. These impacts have been superficially discussed by the local scientific community and mass media; in part this superficiality is attributable to the limited data and the impossibility of surveying the affected areas (6). Biodiversity loss and water and soil contamination are the main impacts invoked (6), but little is said of ecosystem processes such as secondary succession and water and nutrient cycling. We focus on the terrestrial carbon (C) cycle because its anthropogenic alterations are directly linked to global climate warming (9). A three-stage conceptual model is proposed to address the impacts on terrestrial forest C stocks and flows based on available literature on forest succession after deforestation and landsliding in other regions of Tropical America. We propose that C is lost from terrestrial reservoirs throughout forest succession induced by illicit crops during *i)* initial slashing and burning of mature



Landslides at Río Tarazá basin on 19 May 2007. (A) Coca bush crops on the left and forest on the right, (B) landslide affecting a small watershed, (C) landscape mosaic formed by illicit crops and landslides, (D) flooded Tarazá municipality. (Photos: D. Zuluaga-El Colombiano.

and secondary forests, *ii)* mass wasting under extreme heavy rainfall, and *iii)* seasonal exports of overland flow and water infiltration.

Land for coca crops initially cleared with slash-and-burn methods releases enormous amounts of stored C on aboveground forest biomass (AGB). Recent studies in the Porce region (10), near the Tarazá basin, indicate that mature forests (>60 y old) stored a total average of 340 Mg ha^{-1}, while secondary forests (4–20 y old) stored 80 Mg ha^{-1}. Carbon losses with slashing and burning of AGB should correspond to 111 and 21 Mg ha^{-1}, respectively, that could be exported to the atmosphere as CO_2 during forest burning or to rivers as woody debris and litter during heavy rainfall. Unless stumps and coarse roots are upgrafted, belowground biomass does not seem to be significantly reduced by slash-and-burn agriculture as reviewed for Latin American secondary forests (11), and therefore most of soil biomass would be lost during mass wasting (3). Since coca bush crops are established right after slashing and burning, it is possible that soil C still contains most of secondary or mature forest reservoirs. Accordingly, belowground C export (including soil organic matter and fine and coarse roots) during mass wasting could reach up to 360 Mg ha^{-1} in lands previously covered by primary forests and 275 Mg ha^{-1} in secondary forests.

Even if mass wasting does not occur, soil C will be gradually exhausted as a result of erosion as long as coca crops are active. Recent estimates in Puerto Rico (8) showed that on a river-basin scale, sediment yield was greater from plantations, agriculture, and pastures (26, 22, and 17 Mg ha^{-1} y^{-1}, respectively) than from closed-canopy forests (8 Mg ha^{-1} y^{-1}). Modeled erosion rate increased 33% to 103% when all basin closed-canopy cover was converted to pastures or agriculture covers, respectively (8). High deforestation rates in the Urabá region in the Caribbean and most of the Colombian Andes are seemly responsible for the highest sediment yields in the Atlantic Ocean of South America (12). Sediment yield from the entire Urabá drainage is 86.4 Mg ha^{-1} y^{-1} (84.9% of the total for the Colombian Caribbean), while individual yields for the Amazon River and the Orinoco River do not exceed 2 Mg ha^{-1} y^{-1}. Sediment yields from river basins dominated by coca crops might resemble the above figures.

Globally, 42% and 59% of soil C in mature forest and pastures are respectively lost when converted to crops (12, 13). Carbon exported on overland water flow from Puerto Rican hill slopes was 15 and 17 Mg ha^{-1} y^{-1} in pastures and 30-y old secondary forests, respectively, and 11 Mg ha^{-1} y^{-1} in mature forest (14). However, C loss with infiltrated water was significantly greater in pastures (37 Mg ha^{-1} y^{-1}) than in secondary and mature forests (23 and 30 Mg ha^{-1} y^{-1}). These figures indicate that pastures retain less C and that a major fraction of soil C is lost through infiltration during rainy periods. Coca bush crops are expected to retain less C than forests as a result of lower vegetation, unprotected soils, and higher soil respiration rates. Coca leaves are harvested three to six times per year, thus providing little opportunity to replenish the soil C reservoir. Besides, mass wasting may occur while coca crops are still active or soon after they are abandoned, not allowing development of pastures and young secondary forest. Therefore, soil C recovery due to crop transformation into pastures (18%), plantations (19%), or secondary forests (>53%) (13) seems unlikely for coca crops.

The trajectory of forest recovery from illicit crops would differ if secondary succession could start from landslide scars or abandoned coca bush lands. Forest recovery from landslides depends on the spatial heterogeneity induced by scars, ultimately influencing seed banks, seed rain, and soil nutrients (15). Small landslides exhibit faster recovery rates, reaching a similar tree composition to the previous cover and to the neighboring areas. Conversely, large, unstable slides with newly exposed mineral soil surrounded by small mature forest patches take longer recovery periods and their trajectories are less predictable (15). Tree composition remains different after many years, particularly if grass and ferns impede pioneer tree colonization; in these cases recovery of soil nutrient pools may take up to 50 y because recurrent landsliding in previous scars may further set succession back.

Forest recovery from abandoned coca bush lands may not necessarily be faster than from landslide scars. Evidence from Puerto Rico (8) and Colombia (10) showed that cleared areas recovered mature forest structure within 15 y and belowground biomass within 50 y after pasture abandonment, but tree species composition takes longer or may never recover. In Colombia, potential to return

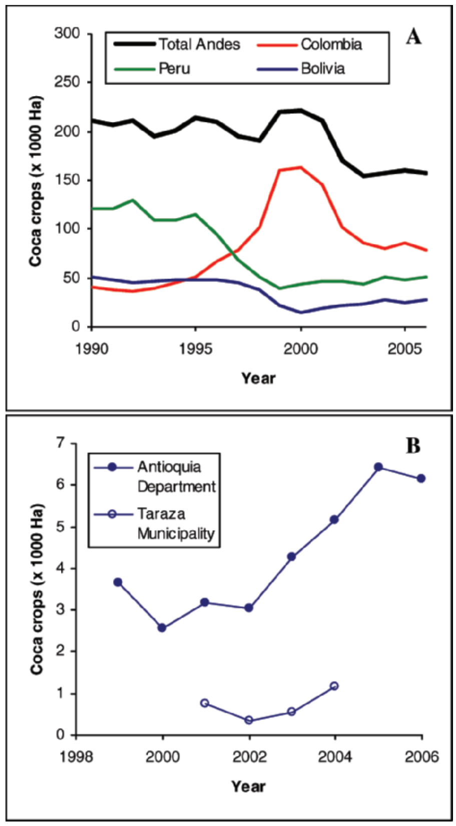


Figure 1. Illicit coca bush crops in Tropical America (5). (A) Cultivated area in the three major producers (Colombia, Peru, and Bolivia). Note an increase in Colombia by the mid-1990s after eradication efforts at Peru and Bolivia. (B) Exponential increase of cultivated area in Antioquia Department and at Tarazá Municipality in Colombia.

to original structure and composition seems to be low where forests were cleared and replaced by illicit crops because mature forest patches are currently surrounded by a large matrix of exotic-grass pastures (7). In heavily deforested regions, remnant forests cover ca. 11%, 72% of which is secondary and predominantly young (10–20 y) forest, prone to repeated clearing.

Conclusion

Illicit crops are a major threat not only to flora and fauna biodiversity (6) but to ecosystem processes such as the terrestrial C cycle. By releasing large C reservoirs and reducing C sequestration capability, illicit crops have the potential to propagate influences far beyond river-basin limits. We roughly estimate that slash-and-burn areas and successive landsliding in the 3000 ha affected by illicit crops in the Río Tarazá released altogether between 103.5 and 517.5 Gg of C. These estimates surpass previous accounts of C loss (108 Gg in a 2456 ha area) due to deforestation in the region (10) because soil C stock is lost during mass wasting. We assumed that forest cover at Tarazá basin was similar to other heavily deforested areas in Colombia (7), (28% primary and 72% secondary) and that 10–50% of land was denuded, which greatly exceeds rates in mature forests (15). Contrary to the arguments of local forest managers in national mass media, some forest properties may recover within 15–50 y, while others will never do so within our lifetimes. This "ecological disaster" is a unique opportunity for scientific communities, managers, and politicians to deeply understand the large-scale impacts of illicit crops and to address successful restoration programs at affected areas.

References and Notes

1. Instituto Colombiano del Hidrología, Meteorología y de Estudios Ambientales (IDEAM). 2000. *Mass-wasting Hazard in Colombia during the La Niña 1999–2000*. Reporte Técnico. IDEAM, Bogotá, Colombia, 22 pp. (In Spanish).
2. Hermelin, M. (ed). 2005. *Natural Disasters in Colombia: 1979–2004*. Univ. EAFIT, Univ. del Valle, OSSO, Medellín, Colombia. (In Spanish)
3. Restrepo, C. and Álvarez, N. 2006. Landslides and their contribution to land-cover change in the mountains of Mexico and Central America. *Biotropica 38*, 446–457.
4. Larsen, M.C. and Parks, J.E. 1997. How wide is a road? The association of roads and mass-wasting in a forested montane environment. *Earth Surf. Process. Landf. 22*, 835–848.
5. United Nations Office for Drug and Crime (UNODC). 2007. 2007 World Drug Report. (http://www.unodc.org/pdf/research/wdr07/WDR_2007.pdf)
6. Fjeldså, J., Álvarez, M.D., Lazcano, J.M. and León, B. 2005. Illicit crops and armed conflict as constraints on biodiversity conservation in the Andes region. *Ambio 34*, 205–211.
7. Etter, A., McAlpine, C., Phinn, S., Pullar, D. and Possingham, H. 2006. Unplanned land clearing of Colombian rainforests: spreading like disease? *Landsc. Urban Plann. 77*, 240–254.
8. Grau, H., Aide, T.M., Zimmerman, J., Thomlinson, J., Helmen, E. and Zou, X. 2003. The ecological consequences of socioeconomic and landuse change in postagriculture Puerto Rico. *Bioscience 12*, 1159–1169.
9. Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Summary for policy makers*. IPCC WGII 4th Assessment Report. IPCC, Czech Republic, 23 pp.
10. Sierra, C.A., del Valle, J.I., Orrego, S.A., Moreno, F.H., Harmon, M.E., Zapata, M., Colorado, G.J., Herrera, M.A., et al. 2007. Total carbon stock in a tropical forest landscape of the Porce region, Colombia. *For. Ecol. Manag. 243*, 299–309.
11. Guariguata, M. and Ostertag, R. 2001. Neotropical secondary forest succession: changes in structural and functional characteristics. *For. Ecol. Manag. 148*, 185–206.
12. Restrepo, J.D. and Kjerfve, B. 2000. Water discharge and sediment load from the western slopes of the Colombian Andes with focus on Rio San Juan. *J. Geol. 108*, 17–33.
13. Guo, L.B. and Gifford, R.M. 2002. Soil carbon stocks and landuse change: a meta analysis. *Glob. Chang. Biol. 8*, 345–360.
14. López-Rodríguez, S.R. 2006. *Water and Element Fluxes as Influenced by Tropical Land-Use Change*. MSc Thesis, University of Puerto Rico, Río Piedras, Puerto Rico.
15. Walker, L., Zarin, D.J., Fetcher, N., Myster, R.W. and Johnson, A.H. 1996. Ecosystem development and plant succession on landslides in the Caribbean. *Biotropica 28*, 566–576.

16. Support for research in Puerto Rico was provided by an Institutional Research Award from NASA, the Luquillo LTER Program, the Department of Biology, and the Institute for Tropical Ecosystem Studies at the University of Puerto Rico, Río Piedras, and the USDA Forest Service International Institute for Tropical Forestry. We thank Frederick Scatena, Carla Restrepo, and Brian Bock for their comments on the manuscript and language.

Sara R. López-Rodríguez
namanereis@yahoo.com

Juan F. Blanco-Libreros
blanco@matematicas.udea.edu.co

Their address:
Instituto de Biología
Universidad de Antioquia
Ciudad Universitaria, Medellín
Antioquia, Colombia