Selective Logging in the Brazilian Amazon

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Amazon deforestation has been measured by remote sensing for three decades. In comparison, selective logging has been mostly invisible to satellites. We developed a large-scale, high-resolution, automated remote-sensing analysis of selective logging in the top five timber-producing states of the Brazilian Amazon. Logged areas ranged from 12,075 to 19,823 square kilometers per year (±14%) between 1999 and 2002, equivalent to 60 to 123% of previously reported deforestation area. Up to 1200 square kilometers per year of logging were observed on conservation lands. Each year, 27 million to 50 million cubic meters of wood were extracted, and a gross flux of ~0.1 billion metric tons of carbon was destined for release to the atmosphere by logging.

Tropical forests have been threatened by increasing rates of deforestation or clear cutting during the past three or more decades (1). Although deforestation, largely for the conversion of land to food crops or pastures, is the major destructive force in tropical forests worldwide (2), other forest disturbances such as the selective harvest of timber have also increased in frequency and extent (3, 4). In selective logging, a limited number of marketable tree species are cut, and logs are transported off site to sawmills. Unlike deforestation, which is readily observed from satellites, selective logging in the Brazilian Amazon causes a spatially diffuse thinning of large trees, which is hard to monitor by using satellite observations. Selective logging causes widespread collateral damage to remaining trees, subcanopy vegetation, and soils; with impacts on hydrological processes, erosion, fire, carbon storage, and plant and animal species (3–10).

There is little known about the extent or impacts of selective logging throughout the tropical forests of the world, including the Amazon Basin. A survey of sawmills in the Brazilian Amazon suggested that 9,000 to 15,000 km^2 of forest had been logged in 1996–1997 (3). The large uncertainty in this reported area resulted from necessary assumptions of the wood volume harvested per area of forest. Sawmill surveys can, at best, provide only a general idea of where and how much logging occurs, because most operators buy timber at the mill gate rather than harvesting the wood themselves.

Objective spatially explicit reporting on selective logging requires either labor-intensive field surveys in frontier and often violently contested areas or remote detection and monitoring approaches. Previous studies of small areas show the need for high-resolution observations via satellite (11–13). Moreover, most of the traditional analysis techniques used for localized selective-logging studies have been insufficient for large-scale selective-logging assessments (11, 14, 15). A detailed comparison of Landsat satellite observations against field measurements of canopy damage after selective logging proved that traditional analytical methods missed about 50% of the canopy damage caused by timber harvest operations (16).

We advanced the computational analysis of Landsat Enhanced Thematic Mapper Plus (ETM+) satellite data using the new Carnegie Landsat Analysis System (CLAS) to detect and quantify the amount of selective logging in the major timber-production states of the Brazilian Amazon. This approach provides automated image analysis using atmospheric modeling; detection of forest canopy openings, surface debris, and bare soil exposed by forest disturbances; and pattern-recognition techniques. CLAS provides detailed measurements of forest-canopy damage at a spatial resolution of 30 m × 30 m, and it does so over millions of square kilometers of forest (17).

We applied CLAS to five states—Pará, Mato Grosso, Rondônia, Roraima, and Acre (fig. S6)—which account for ~90% of all deforestation in the Brazilian Amazon (18). The analysis was conducted on a time series of Landsat ETM+ imagery from 1999 to 2002. Across the five timber-producing Brazilian states, the annual extent of selective logging ranged from 12,075 to 19,823 km^2 (Fig. 1). These logging results represent new forest damage not accounted for in deforestation studies. Each year, the overlap between our results and the Brazilian National Institute for
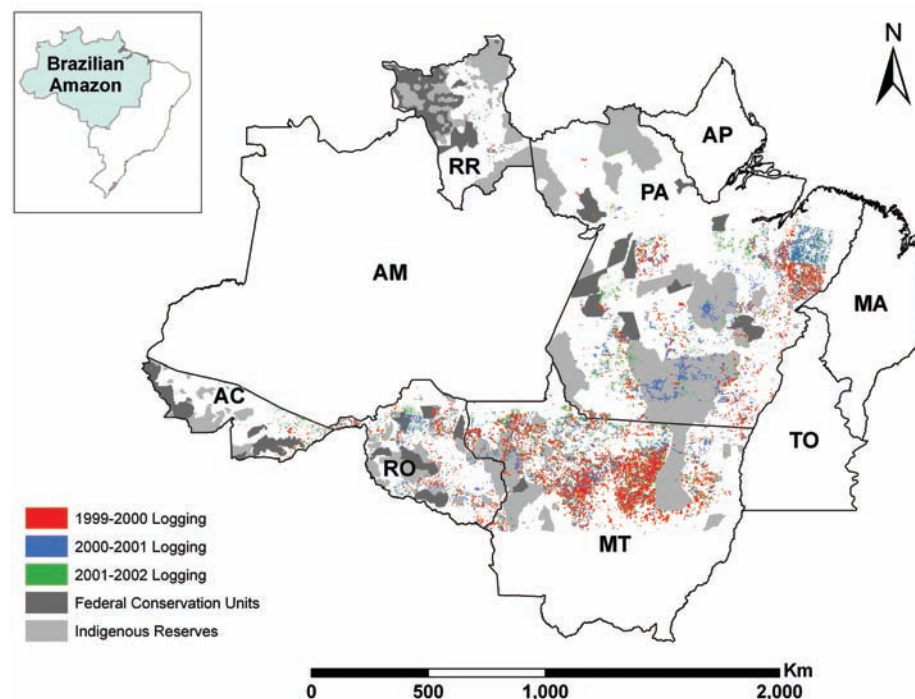
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Fig. 1. Spatial distribution of selective logging in five timber-production states of the Brazilian Amazon for the year intervals 1999–2000 (red), 2000–2001 (blue), and 2001–2002 (green). The states of Amazonas (AM), Amapa (AP), Tocantins (TO), Maranhao (MA), and the southern non-forested part of Mato Grosso were not included in the analysis. Light gray areas show the extent of indigenous reserves; dark gray areas delineate federal conservation lands as of 1999 (29). RR, Roraima; PA, Pará; MT, Mato Grosso; RO, Rondônia; AC, Acre.

Space Research (INPE) annual deforestation maps was only 6% (±5%) (17) (Fig. 2). Moreover, only 19% (±11%) of the total area logged in any given year was subsequently deforested 3 years later. Selective logging thus adds 60 to 123% more forest-area damage than has been reported for deforestation alone in the same study period (Table 1). Selective logging was concentrated in the states of Mato Grosso and Pará, where logging areas exceeded or nearly matched deforestation areas. In other smaller states, selective logging increased forest damage area by 10 to 35% over reported deforestation rates (Table 1).

Conservation units such as indigenous reserves, parks, and national forests generally afforded protection against logging. However, exceptions included areas in northern Mato Grosso, where up to 53, 291, and 50 km² of logging were measured each year in the Xingu, Aripuanã, and Serra Morena indigenous reserves, respectively (Fig. 1). In the southern portion of Pará state, major logging disturbances were observed in the Menkragnoti and Kayapó indigenous reserves, with up to 261 and 198 km², respectively, detected each year between 1999 and 2002. Federal forest reserves of Acre, Gorotire (Pará), and Juruena (Mato Grosso) were harvested for timber at rates of up to 23, 90, and 380 km² each year, respectively.

Extensive field validation studies showed that the detection of canopy damage within CLAS is precise and accurate (17). Field validation studies showed false-positive and false-negative detection rates of only 5%. Uncertainty caused by errors in atmospheric correction of satellite data, cloud cover, annualization, automated logging-area delineation, and manual auditing were 0.7 to 12.8%, individually. After combining all known sources of error, our analysis suggests an overall absolute uncertainty of up to 14% in total logging area.

Selective logging contributes substantially to gross carbon fluxes from the Brazilian Amazon. We combined forest-damage results from CLAS with field-based forest-canopy gap-fraction (19, 20) and roundwood-extraction data (21) to calculate the total wood-extraction rates (17). In 2000, 2001, and 2002, roundwood production averaged 49.8, 29.8, and 26.6 million m³, respectively. The mean annual harvest intensities were 26.6, 21.7, and 21.4 m³ ha⁻¹, which were generally lower than those reported by sawmill owners in 1996 (3, 22). The total volume harvested equates to 10 million to 15 million metric tons of carbon (MtC) removed (23). In addition to roundwood, residual stumps, branches, foliage, and roots are left to decompose in the forest, subsequently returning to the atmosphere as carbon dioxide over about a decade. Our calculated average harvest intensity of 23.2 m³ ha⁻¹ is equivalent to ∼8 MgC ha⁻¹ contained in roundwood, with an associated 34 to 50 MgC ha⁻¹ of fine and coarse debris (23–25). Integrated to the regional scale, the processing of roundwood and the decomposition of residues lead ultimately to a gross flux of carbon from the forest of up to 0.08 GtC for each year of logging (26). This value increases the estimated gross annual anthropogenic flux of carbon from Amazon forests by up to 25% over carbon losses from deforestation alone (27). Post-harvest forest regeneration reduces the net flux of carbon to the atmosphere below these values, but the pace of regeneration after logging varies considerably (9, 28).

Selective logging doubles previous estimates of the total amount of forest degraded by human activities (Table 1), a result with potentially far-reaching implications for the ecology of the Amazon forest and the sustainability of the human enterprise in the region. In the future, improved monitoring of tropical forests will require high-performance satellite observations and new computational techniques. Our results, presented with explicit uncertainty analysis and transparency of method (17), have located and quantified ubiquitous but previously cryptic disturbances caused by selective logging.

Fig. 2. High-resolution example of selective-logging results in 2001–2002 from the CLAS processing (**right**), compared with deforestation mapping provided by the INPE (**left**) (18).

Table 1. Selective-logging rates from 1999–2002 in five major timber-producing states of the Brazilian Amazon, with comparison to the deforestation rates reported by the INPE (18).

State	1999–2000 rates (km² year⁻¹)		2000–2001 rates (km² year⁻¹)		2001–2002 rates (km² year⁻¹)	
	Logged	Deforested	Logged	Deforested	Logged	Deforested
Acre	64	547	53	419	111	727
Mato Grosso*	13,015	6,176	7,878	7,504	7,207	6,880
Pará	5,939	6,671	5,343	5,237	3,791	8,697
Rondônia	773	2,465	923	2,673	946	3,605
Roraima	32	253	55	345	20	54
Total	19,823	16,112	14,252	16,178	12,075	19,963

*Only the northern 58% of Mato Grosso containing forested lands was included in the analysis.

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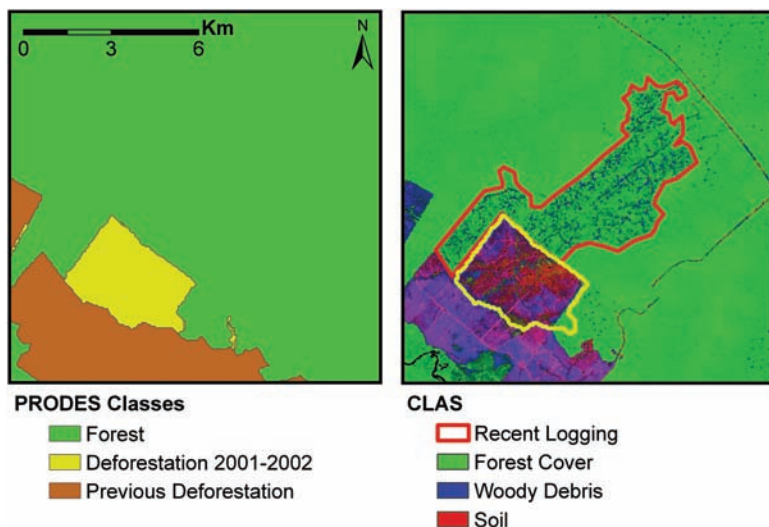14. T. A. Stone, P. Lefebvre, *Intl. J. Rem. Sens.* **19**, 2517 (1998).

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mean debris amounts found in logged forests (~30 m³ ha⁻¹ harvested) subtracting the woody debris found in undisturbed forests. Upper and lower estimates were based on mean debris amounts plus root mean squared (rms) error, accounting for the uncertainty of estimates for both background and logged sites. Total debris was estimated as 1.4 times fallen debris to account for standing dead and roots. Data are available at ftp://lba.cptec.inpe.br/lba_archives/TG/TG-07/Palace/, with additional synthesis provided by (*30*).
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Transmission of Equine Influenza Virus to Dogs

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Molecular and antigenic analyses of three influenza viruses isolated from outbreaks of severe respiratory disease in racing greyhounds revealed that they are closely related to H3N8 equine influenza virus. Phylogenetic analysis indicated that the canine influenza virus genomes form a monophyletic group, consistent with a single interspecies virus transfer. Molecular changes in the hemagglutinin suggested adaptive evolution in the new host. The etiologic role of this virus in respiratory disease was supported by the temporal association of rising antibody titers with disease and by experimental inoculation studies. The geographic expansion of the infection and its persistence for several years indicate efficient transmission of canine influenza virus among greyhounds. Evidence of infection in pet dogs suggests that this infection may also become enzootic in this population.

Transmission of virus from one host species to another is a crucial feature of the ecology and epidemiology of influenza virus (*1*). Two basic mechanisms of interspecies transmission of influenza virus are possible (*2, 3*). One is the direct transfer of an essentially unaltered virus from one species to another. Examples of this mechanism include the recent human infections with the H5N1 subtype of avian influenza virus (*4–6*). The second mechanism is a consequence of the segmented nature of the influenza genome. Simultaneous coinfection of a host with viruses from different species can result in reassortment of the segmented viral genes and the generation of a reassortant virus with the ability to infect other species. For example, novel viruses generated by gene reassortment between avian and human influenza viruses resulted in influenza pandemics in 1957 and 1968 (*2, 3, 7*).

Most direct transmissions of whole influenza viruses from the natural host species to a different one do not result in sustained transmission in the new host species. Multiple virus-host interactions are necessary for replication and horizontal transmission and provide a barrier to perpetuation of influenza viruses in the new host (*8*). Therefore, establishment of new, long-lived host-specific lineages of influenza virus is uncommon and has only occurred in domestic poultry, pigs, horses, and humans (*2, 3*). In this report, we describe an unprecedented interspecies transfer of a complete equine influenza virus to the dog, and the emergence of a new canine-specific influenza virus associated with acute respiratory disease.

In January 2004, an outbreak of respiratory disease occurred in 22 racing greyhounds at a Florida racetrack (supporting online text). Two clinical syndromes were evident: a milder illness characterized by initial fever and then cough for 10 to 14 days with subsequent recovery (14 dogs) or a peracute death associated with hemorrhage in the respiratory tract (8 dogs for a case-fatality rate of 36%). Postmortem examinations were performed on six of the eight fatal cases (*9*). All dogs had extensive hemorrhage in the lungs, mediastinum, and pleural cavity. Histological examination of the respiratory tract revealed tracheitis, bronchitis, bronchiolitis, and suppurative bronchopneumonia (fig. S1). The epithelial lining and airway lumens in these tissues were infiltrated by neutrophils and macrophages. Lung homogenates prepared from these dogs were inoculated into a variety of monkey, human, bovine, and canine cell lines for virus culture (*9*). The lung homogenate from one dog caused cytopathic effects in Madin-Darby canine kidney (MDCK) epithelial cells cultured in the presence of trypsin and the cell culture supernatant agglutinated chicken red blood cells (*9*). Preliminary evidence of an influenza type A virus was provided by a commercial enzyme-linked immunosorbent assay (ELISA) for detection of the nucleoprotein

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