Selective Logging, Fire, and Biomass in Amazonia

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Summary of Research

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from

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Biomass and rates of disturbance are major factors in determining the net flux of carbon between terrestrial ecosystems and the atmosphere, and neither of them is well known for most of the earth's surface. Satellite data over large areas are beginning to be used systematically to measure rates of two of the most important types of disturbance, deforestation and reforestation, but these are not the only types of disturbance that affect carbon storage. Other examples include selective logging and fire. In northern mid-latitude forests, logging and subsequent regrowth of forests have, in recent decades, contributed more to the net flux of carbon between terrestrial ecosystems and the atmosphere than any other type of land use. In the tropics logging is also becoming increasingly important. According to the FAO/UNEP assessment of tropical forests, about 25% of total area of productive forests have been logged one or more times in the 60-80 years before 1980. The fraction must be considerably greater at present. Thus, deforestation by itself accounts for only a portion of the emissions carbon from land. Furthermore, as rates of deforestation become more accurately measured with satellites, uncertainty in biomass will become the major factor accounting for the remaining uncertainty in estimates of carbon flux. An approach is needed for determining the biomass of terrestrial ecosystems.

Selective logging is increasingly important in Amazonia, yet it has not been included in region-wide, satellite-based assessments of land-cover change, in part because it is not as striking as deforestation. Nevertheless, logging affects terrestrial carbon storage both directly and indirectly. Besides the losses of carbon directly associated with selective logging, logging also increases the likelihood of fire.

This work was funded by the Terrestrial Ecology Program in NASA's Office of Earth Science as part of the Joint Program on Terrestrial Ecology and Global Change (TECO). The work also contributed to the Brazilian/NASA LBA Ecology experiment. LBA Ecology offers an excellent opportunity to obtain spatially detailed estimates of both disturbance and biomass for the same region and time. The work described here will be of value to LBA Ecology in integrating ground measurements of biomass and satellite-derived estimates of disturbance. The spatial data on biomass will help quantify the emissions and sinks of carbon from land management in Amazonia. They should also help interpret direct measurements of CO_2 flux at tower sites. That is, what portion of a measured carbon sink can be explained by recovery from past disturbances, as opposed to other environmental influences?

The larger rationale for the proposal is development of a technique, applicable globally, for determining the dynamics and spatial distribution of biomass. Biomass is continually changing as a result of disturbance and recovery, and the balance determines a major portion of the net flux of carbon between land and atmosphere. An on-going assessment of the distribution of disturbances and stages of recovery would seem to be a necessary part of a scheme for determining changes in terrestrial carbon storage.

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The work consisted of (1) **ground studies** in areas selectively logged and burned, where aboveground biomass and rates of forest growth were measured; (2) **satellite data** (Landsat and radar) to determine the rates, areal extent, and spatial distribution of logging and fire along the arc of deforestation in Amazonia; and (3) **modeling** to determine the spatial distribution of biomass resulting from current and past rates of logging and fire.

Ground studies

Fieldwork measuring biomass and rates of growth following logging/burning was conducted around Paragominas in eastern Amazonia. Measurement of the biomass of logged and burned forests were carried out at nine sites, including primary forests (n=2), logged forests (n=2), logged forests that burned approximately 5 years ago (n=2) and logged forests that burned in 1998 (n=2). A manuscript is in preparation and is expected to be submitted by September 2000.

Remote sensing

Two spatial scales were addressed. First, Landsat TM data were used to identify selectively logged areas in northeastern Para through identification of logging scars (areas indicating logging by roads in primary forest and "patios" or clearing for log storage). These scars "disappear" from TM data in about 1 year as a result of the growth of vegetation. Second, the spatial distribution of 2000 sawmills in Para and elsewhere throughout Amazonia was used to evaluate whether selective logging might be monitored remotely.

The work with remote sensing (funded in part with other grants) had mixed success. Landsat data show the importance of land use, logging, and fire near Paragominas, Para. Undisturbed forests occupied only 6% of the areas surveyed, although the degradation of forests though logging and burning is missed with studies concerned only with deforestation (Alencar et al. 1997). On the other hand, radar data (L-band data from JERS-1), although they may distinguish among forest types more effectively than optical data (NDVI), do not distinguish differences in biomass. It is unclear what it is that the radar data recognize as different classes. The different classes were not distributed in discreet polygons as might be expected of forest types. Rather, they appeared as speckles, intermixed with each other and distributed throughout the landscape.

We also supported field work and remote sensing by Brazilian scientists at IMAZON (Instituto do Homem e Meio Ambiente da Amazônia), who have compiled data from sawmills over Amazonia. They developed a method for identifying selective logging and compared the results with field surveys (Souza and Barreto 2000). The approach is based on identifying log storage patios (high fractions of soil). The identification of these patios and their associated logging showed good agreement with field data, and the method looks promising for evaluating logging throughout Amazonia.

Modeling

The work in the first year included a compilation of biomass data from the literature. We distributed biomass over all of Amazonia based on spatial interpolation of these data. We also constructed a map of biomass for Amazonia based on wood volume data collected by the RADAMBRASIL Project over the period 1973-1982. We determined average biomass from allometric equations relating aboveground biomass to wood volume (Brown and Lugo 1992). Several other estimates of biomass (include Olson's classification, CASA, and percent tree cover) were used to construct alternative maps of biomass. A comparative analysis is in preparation and should be submitted for publication by the end of June, 2000.

Publications resulting, in part or entirely, from this research:

Alencar, A.A., D.L. Nepstad, E. Mendoza, I.F. Brown, and P. Lefebvre. 1997. Fires in Amazonia in 1994 and 1995: Four cases studies along the arc of deforestation. World Bank, unpublished report. [See also, Nepstad, D.C., A. Moreira, and Ane A. Alencar. 1999. *Flames in the Rain Forest. Origins, Impacts and Alternatives to Amazonian Fire*. The Pilot Program to Preserve the Brazilian Rain Forest, Brazilia, Brazil. University of Brazilia Press, Brazilia.]

Houghton, R.A., D.L. Skole, C.A. Nobre, J.L. Hackler, K.T. Lawrence, and W.H. Chomentowski. 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature 403*:301-304.

Souza, C., and P. Barreto. 2000. An alternative approach for detecting and monitoring selectively logged forests in the Amazon. *International Journal of Remote Sensing 21*:173-179.

Alencar, A., L. Solorzano, D. Nepstad. Forest fire probability as a function of landscape features in eastern Amazonia. In preparation.

Alencar, A. and D. Nepstad. Forest fire occurrence in eastern and southern Amazonia, 1994-95. In preparation.

Carvalho, O. Aboveground biomass in primary, logged, and burned forests of eastern Amazonia. In preparation.

Gerwing, J.J. Ecological and silvicultural impacts of forest degradation by logging and fire in the eastern Brazilian Amazon. Submitted.

Houghton, R.A., K.T. Lawrence, and J.L. Hackler. In preparation. The spatial distribution of forest biomass in Brazilian Amazonia: A comparison of estimates. In preparation.

Nepstad, D., K. Lawrence, G. Cardinot, J. Chambers, R. Houghton, C. Klink (others?) The ratio of below-ground to above-ground biomass in Amazonian forests. In preparation.

Included, below, are three abstracts that will be presented at the LBA Science Meeting in Belem, June 26-30, 2000.

R.A. Houghton.

The spatial distribution of forest biomass in Brazilian Amazonia: A comparison of estimates.

The amount of carbon released to the atmosphere as a result of deforestation is determined, in part, by the amount of carbon held in the biomass of the forests converted to other uses. Uncertainty in forest biomass is responsible for much of the uncertainty in current estimates of the flux of carbon from land-use change. Here we compare several estimates of biomass for Brazilian Amazonia, based on spatial extrapolations of direct measurements, climatic variables, and remote sensing data, and ask three questions. First, do the methods yield similar estimates? Second, do they yield similar spatial distributions of biomass? and, third, what factors need most attention if we are to predict more accurately the distribution of biomass over large areas?

The answer to the first two questions is that estimates of biomass (including dead and belowground biomass) vary widely, from a low of 39 PgC to a high of 93 PgC for Brazilian Amazonia. Furthermore, the estimates disagree as to the regions of high and low biomass. The lack of agreement among estimates, despite extensive calibrations and validations for each, confirms the need for reliable methods for determining aboveground biomass over large areas. Candidates include direct measurement of aboveground biomass from satellite (for example, using lidar) or dynamic modeling of observed stand-replacing disturbances.

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Impacts of degradation by logging and fire on forest structure and biomass in eastern Amazonia

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In the eastern Brazilian Amazon, widespread unplanned logging and fire are degrading forest composition and structure in ways that are not captured by the traditional forest – nonforest classification schemes used to determine deforestation rates. This forest degradation often consists of a stepwise process commencing with one or more unplanned logging episodes making way for one or repeated fires of varying intensities. The purpose of this study was to determine the relative impacts of logging and fire on forest biomass, structure, and species composition.

Field inventories in forests ranging from intact to logged and heavily burned were conducted in 14, 10 x 500-m plots located on 10 properties in the region of Paragominas, Pará. Live aboveground biomass of intact forest was estimated at 309 t/ha. This value declined 20%

following moderate intensity logging and 48% following repeated or high intensity logging. Logged and moderately burned forest also showed a 48% reduction in live biomass whereas this parameter was reduced by 83% in logged and heavily burned forest. Increased amounts of coarse woody debris and reduced canopy cover, particularly in forests subjected to repeat logging, have greatly increased the risk of fire in these degraded forests. Furthermore, recovery of pre-degradation biomass and forest structure is likely to be impeded by abundant lianas and the high incidence of crown and stem damage among the remaining trees. As timber industries in senescing logging frontiers, such as Paragominas, begin to close, it is likely that repeat logging of previously logged stands will become more common thus exacerbating the problem of forest degradation.

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Detecção da Degradação Florestal pela Exploração Madeireira e Queimadas na Amazônia Oriental Utilizando Imagens de Satélite

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As florestas da Amazônia Oriental têm sofrido mudanças rápidas impostas pela exploração madeireira e por queimadas. Imagens de satélite Landsat TM e SPOT podem detectar "cicatrizes" e assinatura espectral de exploração madeireira e queimadas, respectivamente. Após 2-3 anos, as "cicatrizes" e assinaturas espectrais desaparecerem com a regeneração, dificultando a detecção nas imagens. Neste trabalho, propomos uma metodologia para corrigir este problema, e mapear a evolução da degradação florestal.

Utilizamos imagens georetificadas (Landsat TM de 1984, 1988, 1991 e 1996 e SPOT de 1999) cobrindo uma área de 3.600 km^2 do Município de Paragominas. Inicialmente, as imagens foram classificadas individualmente em: i) floresta; ii) floresta explorada; iii) floresta queimada; iv) não floresta (áreas desmatadas e floresta secundária); e v) água. Para esse propósito, aplicamos classificação não supervisionada, agrupamento de "clusters" para compor as classes de interesse, finalizando com interpretação visual para remoção de ambigüidades espectrais. As florestas exploradas foram mapeadas utilizando imagens de abundância de solos, obtidas com modelos de mistura de pixel. Por último, aplicou-se um algoritmo de detecção de mudança para corrigir a classificação inicial, o que permitiu incluir novas classes no mapa final: vi) floresta explorada antiga; vii) floresta queimada antiga; viii) floresta degradada; e ix) floresta super-degradada.

O método mostrou uma boa correlação com os dados de campo. Os erros de classificação estão associados com a resolução temporal utilizada, que não deve ser maior que 3 anos. Por último, o método mostrou-se eficaz para mapear a distribuição de biomassa nos