ND01: Land-cover conversion and forest degradation in Amazônia: evaluating environmental and land-use controls on pasture sustainability, forest integrity and forest succession

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ABSTRACT

We propose an integrated remote sensing and field-based examination of the causes and biogeochemical consequences of regional land-cover change within the Arc of Deforestation in the southern Amazon Basin. Research components include field observations, regional synthesis, and multi-resolution studies, with a major focus on remote sensing. We will refine the standardized methods we developed during LBA-ECO Phase I for consistent mapping of regional land-cover conversion through time. The techniques will be expanded to include diverse environmental variation, and new methods will be developed to map forest degraded by logging, fire, and fragmentation. These remote sensing products will be combined with ancillary data sets and field measurements to evaluate the relative importance of environmental and human controls on patterns of land-cover change, and the consequences of land-cover change for vegetation growth and succession and for soil and stream biogeochemistry. Our previous research in Rondônia shows that variations in topography and rock type generate significant gradients in natural soil fertility and stream nutrient concentrations across the state. Roads and urban networks, superimposed on this natural variation, constrain or accelerate land-cover conversion and have important consequences for human impacts on stream biogeochemistry.

Our questions represent diverse academic disciplines, but all aim to combine remote sensing with field measurements to develop an integrated understanding of regional patterns in land-cover change and its biogeochemical consequences. In addition to producing a variety of remote sensing products to monitor land-cover change, we will address the following questions: How can remote sensing methods be combined with field measurements to better quantify changes in vegetation community structure due to selective logging, and how extensive are those changes? What are the topographic and geologic determinants of soil mineralogy and fertility across the state of Rondônia, and how does this natural variation in soil type constrain or promote land-cover conversion? Finally, how do vegetation conversion and the evolving human settlement system affect terrestrial and aquatic biogeochemistry and over what scales do these drivers operate?

Our research approach can be divided into three intersecting phases: 1) mapping and monitoring a suite of land-cover changes; 2) evaluation of the natural and human drivers of forest conversion; and 3) measurement of the impacts of those changes on forest structure in selectively logged areas and on soil and stream biogeochemistry in areas converted to pasture. The research will be conducted in the Brazilian states of Rondônia and Mato Grosso, which show significant intra- and interstate variations in deforestation rates, selective logging intensity, urban development, and environmental gradients. An important aspect of the project is a dedication to exchange research methods and techniques in the LBA/Amazon research community, most intensively among Imazon, INPE, and UCSB. Institutional exchanges will provide an opportunity for intensive training, data sharing and research collaboration among U.S. and Brazilian participants.

SCIENTIFIC OBJECTIVES

1) Land-Cover Change and Land-Use Science:

i) What are the rates and mechanisms of forest conversion in areas with a range of soil fertility levels? We propose: 1) Continual monitoring of land-cover conversion in Rondônia; 2) Extended analysis to include data from 2001 to 2004; 3) Expanded spatial coverage from from five to eight scenes, including two in southeastern Rondônia and one covering Sinop, Mato Grosso.

Expansion in Rondônia is crucial because deforestation rates remain high while land use varies locally within the state, in part due to differences in soils, climate and settlement history. Expansion towards Vilhena adds some of the oldest settlements to the study and a greater range of soils, including very nutrient-poor white quartz sands. Expansion to Sinop enables us to develop a transect across a range of forest degradation processes, ranging from fragmentation in the west, to selective logging and fire effects in Mato Grosso.

ii) What are the dynamic properties of pasture and second growth that characterize temporal variability, duration, and frequency of repeat disturbance? How do edaphic variables affect these land-cover dynamics? In Rondônia, we have found that pastures tend to be relatively stable and second growth ephemeral. However, the proportion of cleared lands in these two categories and the degree to which they undergo transitions from one class to another vary spatially.

iii) What is the area affected by forest degradation, how much degraded forest is ultimately deforested, and how long does this process take? Here, we propose to take methods for mapping degradation developed in other portions of the Amazon and port them to Rondônia. This will provide a means of comparing different degradation processes in Amazônia, ranging from fire-impacted, selectively logged regions of Mato Grosso to highly fragmented forests in Rondônia, where selective logging is rare, using common methodologies. A key component of this research is the observation that multitemporal data sets are required to fully characterize the extent of degraded forest. This research will also help establish age limits at which forest degradation is no longer evident from remote sensing.

2) Nutrient Dynamics:

i) What are the regional controls on soil nutrient levels? How do these feed back into rates of land-cover conversion and urbanization? The natural controls on soil nutrient variation will be investigated and used to construct a context for changes incurred by land-cover conversion. This research will address such questions as: 1) At what scale is land cover highly correlated with soil nutrients? 2) Is land cover the dominant control at any one scale? and 3) Does every environmental variable exert influence at all scales, or are soil formation drivers clearly defined at different ranges?

ii) How do the amounts, rates, and composition of human inputs to stream nutrient loading change with time since colonization and with watershed size? In particular, how do rates of vegetation conversion, the rates of urbanization, and cattle stocking density change with time in watersheds of different sizes?

iii) How do processes other than vegetation conversion affect stream nutrient loads? In particular, how do urban areas and dairy and cattle processing industries influence nutrient concentrations?

iv) What effects do impervious surfaces created by roads and cattle paths have on the rates and mechanisms of nutrient transport to streams via overland flow? Here we will take advantage of high resolution IKONOS satellite data to map the extent of impervious surfaces, and then we will combine those data with field studies of the magnitude and chemical composition of overland flow on those impervious surfaces.

INTEGRATION AND SYNTHESIS

Data sharing, LBA collaborations, primarily with scientists working in Rondônia (ie, G. Kirkman, L. Guild, L. Martinelli, J. Caviglia-Harris, D. Lu). Example research problems include: NO fluxes, water chemistry, drivers of land-cover change, monitoring second growth forest.

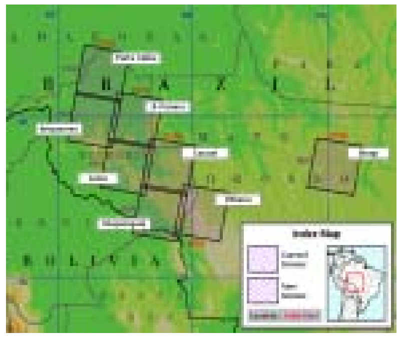
Educational outreach; technology transfer of remote sensing methodology from UCSB to IMAZON/INPE, transfer of IMAZON techniques to UCSB.

LBA participation in key topical areas, such as forest degradation (Souza), land-use/land-cover change (Roberts), impacts of land-cover change on soil and stream chemistry (Holmes, Biggs).

Guest Editor in Remote Sensing of Environment, LBA Ecology special issue, joint publications and submissions to LBA special issues.

APPROACHES

Expanded Coverage

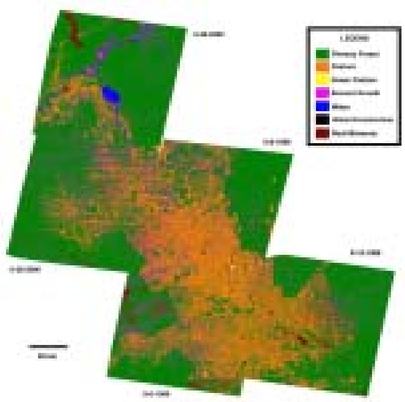


The current study site is shown to the left, located in the state of Rondônia, including an area sampled by 5 Landsat scenes. The region has experienced extensive forest clearing starting in the early 1980s after BR364 was paved. The Phase two proposal will expand the spatial coverage to include two regions to the southeast (Vilhena, Chapuingaia), and a scene in Sinop. Temporal coverage will be extended from 2001 to 2004.

Remote Sensing Analysis

Remote Sensing analysis includes standardized methodology for mapping land-cover and monitoring land-cover change described by Roberts et al, 2002. This approach utilizes spectral mixture models to map surface composition, temporally invariant targets to intercalibrate Landsat data and decision tree classifiers to map land-cover classes from spectral fractions. Accuracy is assessed using airborne digital videography acquired in 1997 and 1999 over Rondônia. For Phase 2, the general procedure has been modified to include terrain illumination corrections and a haze correction developed by Carlotto. Spectral fractions, particularly for NPV and soil, will be analyzed using techniques developed by Carlos Souza to quantify forest degradation.

Examples of haze corrected images, a land-cover map generated using the DTC approach, estimated deforestation rates and maps of forest degradation are shown below.



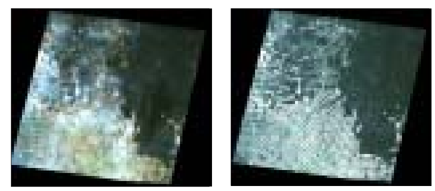


Figure above showing Landsat 321 RGB False Color composite before (left) and after (right) reducing smoke contamination. This scene was acquired over Ji-Paraná on September 22, 1996.

The figure to the left, shows a land-cover cover classification for five scenes in Rondônia. The classification was developed using a DTC and standardized fraction images developed using spectral mixture analysis. Time series was used to remove a majority of disallowed transitions. Through standardization, the same set of rules was applied to 41 Landsat TM scenes. Note that non-forested areas are dominated by pasture. Second growth, when it occurs, rarely persists more than nine years. This same methodology has been applied to Manaus, Marabá, Paragominas and portions of Mato Grosso.

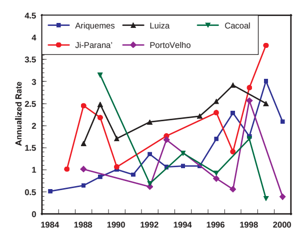
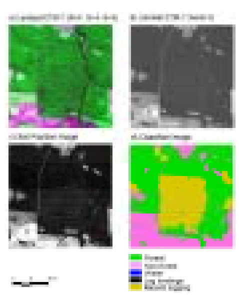
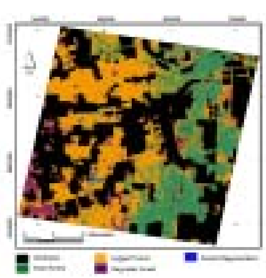


Figure above showing deforestation rates, calculated based on transitions from forest to non forest between image acquisitions. The figure reports annual rates, calculated as the percentage deforested between scenes divided by the number of years between acquisitions.

Mapping Forest Degradation



The figure above shows log landings located using the soil fraction image and texture.



The figure above shows forest degradation mapped using a decision tree classifier applied to GV, NPV, soil and Shade fractions.

Soil and Water Chemical Sampling and Analysis

Water Chemistry:

*Chemical analysis will be conducted of overland flow from pastures (6-10 events) and roads (3-5 events). This includes the analysis of nutrients and cations, anions, and suspended sediments.

* Chemical analyses will be performed of water from soil column experiment at Nossa Senhora site in Rondônia. Extracts from cattle manure will be passed through soil monoliths 30 cm diameter with a KBr tracer.

* Ground water samples at Nossa Senhora will be analyzed for nutrients, cations, anions, and some samples for DOC.

* Survey data of dairy and meat packing plant production statistics will be analyzed.

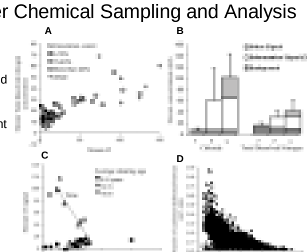


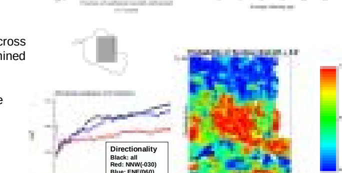
Figure A. Shows increasing stream Cl and total dissolved N concentrations with deforestation extent (dry season) B. Relative contributions of deforestation and urbanization to stream signal concentrations. F=forested catchments, P=more than 40% deforested, U = catchments with more than 5 urban residents/ km^2. C. Importance of pasture age on stream Cl concentrations (Similar for total dissolved N and K). D. Average clearing age and the fraction of the catchment recently deforested. Shows that older catchments, while they show strong stream solute signals, do not have high current deforestation rates.

Soil Chemistry

* We will Investigate geochemical weathering and element depletion across the landscape and with depth in the soil mantle. These will be determined using total element analyses and a mass balance approach

* We will evaluate mineral composition, which controls cation exchange capacity and P-sorption properties, determined using X-ray diffraction.

* Geostatistical analysis of environmental controls on soil nutrient levels at multiple spatial scales will be performed.



Map of the probability of pH > 5.0. Determined using simple kriging with a locally varying mean, using the residuals of the logit model:

pH ~ f (Z + profile curvature + roughness + precipitation + geology + soiltype)