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# An Integrated Use of Experimental, Modeling and Remote Sensing Techniques to Investigate Carbon and Phosphorus Dynamics in the Humid Tropics

## Final Technical Report for NASA NAGW-5253


Alan R. Townsend
INSTAAR and EPO-Biology
Campus Box 450
University of Colorado
Boulder, CO 80309
alan.townsend@colorado.edu

Gregory P. Asner
Geological Sciences and Environmental Studies
Campus Box 399
University of Colorado
Boulder, CO 80309
gregory.asner@colorado.edu

Mercedes M.C. Bustamante
Dept. de Ecologia
Universidade de Brasilia
Brasilia-DF, Brazil
mercedes@unb.br

## Executive Summary

Moist tropical forests comprise one of the world's largest and most diverse biomes, and exchange more carbon, water and energy with the atmosphere than any other ecosystem. In recent decades, tropical forests have also become one of the globe's most threatened biomes, subjected to exceptionally high rates of deforestation and land degradation. For example, roughly 2% of the remaining forest area is converted to pasture or agricultural land every year, with a litany of potential environmental consequences, ranging from global scale effects on atmospheric chemistry and climate, to regional scale disruption of hydrologic cycles and ecological communities, to permanent losses of species. Recent evidence has also suggested that tropical forests may be storing excess atmospheric $CO_2$ at rates comparable to those estimated for mid-latitudes of the northern hemisphere. Thus, the importance of and threats to tropical forests are undeniable, yet our understanding of basic ecosystem processes in both intact and disturbed portions of the moist tropics remains poorer than for almost any other major biome.

Our approach in this project was to take a multi-scale, multi-tool approach to address two different problems. First, we wanted to test if land-use driven changes in the cycles of probable limiting nutrients in forest systems were a key driver in the frequently observed pattern of declining pasture productivity and carbon stocks. Given the enormous complexity of land use change in the tropics, in which one finds a myriad of different land use types and intensities overlain on varying climates and soil types, we also wanted to see if new remote sensing techniques would allow some novel links between parameters which could be sensed remotely, and key biogeochemical variables which cannot. Such links could potentially allow large scale assessments of the biogeochemical consequences of land use change that still retained a high degree of spatial precision.

Second, we addressed two general questions about the role of tropical forests in the global carbon cycle. First, we used a new approach for quantifying and minimizing non-biological artifacts in the NOAA/NASA AVHRR Pathfinder time series of surface reflectance data so that we could assess potential links between Amazonian forest dynamics and ENSO cycles (Asner et al. 2000, appended). Second, we showed that the disequilibria in $^{13}C$ exchanges between land and atmosphere following tropical deforestation probably has a significant impact on the use of atmospheric $^{13}CO_2$ data to predict regional fluxes in the global carbon cycle. Our work suggests that once this land use effect on atmospheric $^{13}CO_2$ data is accounted for, moist tropical forests appear to

have been a major sink for anthropogenic $CO_2$ throughout the1990's except during the strong 1997/1998 ENSO event (Townsend et al. 2001, appended).

Much of our work focused on a region south of Santarém, Para state, Brazil, where we established several sites that comprise pasture age gradients on two soil types (highly sandy entisols and high clay oxisols). Data obtained from these sites show a suite of biogeochemical changes as pastures age, including losses of soil organic matter, N, P, Ca, Mg and K. In addition, while both soils demonstrate these declines, there are significant differences at every pasture age between the soil types. Foliar data from pasture grasses suggest dramatic increases in N, P and Ca limitation with pasture age on both soil types. The changes in phosphorus cycling with pasture age are particularly striking, and showed some unexpected patterns (Townsend et al. 2001, appended). For example, significant losses of total P are seen on both soil types, but the majority of these losses come from pools that are traditionally assumed to be highly recalcitrant and immobile. Second, although plant-available pools of inorganic P decline with pasture age, apparently causing severe P limitation in older pastures, organic forms of P actually increase or remain stable with pasture age. Given the assumed importance of organic P to fertility in tropical agriculture, this set of changes is puzzling. Our current working hypothesis (for which we now have evidence from sites in Costa Rica) is that deforestation to cattle pasture causes large changes in soil microbial communities that are responsible for mineralizing organic P into available forms, thus creating a combination of increasing organic P pools concomitant with declining pools of labile inorganic P.

Our results also showed that strong indicators of pasture degradation that are potentially quantifiable with remote sensing techniques, such as aboveground biomass and net primary production (NPP), were highly correlated with reasonably easy to measure pools of plant available nutrients. We note that the identity of the key limiting nutrient is likely to vary across axes of management, soil type and climate, but that regardless of the key limiting element, regional analyses which could separate degrading pastures from those which remained productive would allow much more meaningful and accurate estimates of regional biogeochemistry. Thus, we developed a method to estimate key biophysical properties of Amazon pastures using hyperspectral reflectance data and photon transport inverse modeling. This method allowed remote estimates of live and senescent biomass across the pasture sites that were strongly correlated with plant-available forms of P and Ca, and provides a basis for monitoring pasture condition and biogeochemistry using spaceborne hyperspectral sensors (Asner et al. 1999, appended).

In summary, this project supported several different activities, ranging from field-based biogeochemical studies in the central Amazon, to large scale modeling analyses of tropical carbon dynamics. Four publications from the project are appended to this report;

these 4 papers describe both the field sites and the range of activities supported. In addition, we wish to note that this project supported two graduate students at the Univ. of Colorado (co-PI Asner and C. Cleveland), and two Brazilian graduate students (G. Nardoto and G. Cardinot),as well as several undergraduate students at CU-Boulder. As is the intent of the NIP program, the project was also enormously helpful in starting the careers of not just one, but two assistant professors.

**Summary of Publications receiving support from this project:**
**(those with asterisks are appended to this report)**


*Asner, G.P. A.R. Townsend and M.C. Bustamante. 1999. Spectrometry of pasture condition and biogeochemistry in the Central Amazon. *Geophysical Research Letters* 26(17):2769-2772.

Cleveland, C.C., A.R. Townsend, D.S. Schimel, H.Fisher, R.W. Howarth, L.O. Hedin, S.S. Perakis, E.F. Latty, J.C. Von Fischer, A. Elseroad and M.F. Wasson. 1999. Global patterns of terrestrial biological nitrogen ($N_2$) fixation in natural ecosystems. *Global Biogeochemical Cycles*, 13(2):623-645.

*Asner, G.P, A.R. Townsend and B.H. Braswell. 2000. Satellite observation of El Niño effects on Amazon forest productivity. *Geophysical Research Letters*, 27(7):981-984.

*Townsend, A.R., G.P. Asner, C.C. Cleveland, M.E. Lefer and M. M. C. Bustamante. 2001. Unexpected changes in soil phosphorus dynamics following tropical deforestation to cattle pasture. Journal of Geophysical Research (LBA special issue), in review.

*Townsend, A.R., G.P. Asner, P.P. Tans and J.W. C. White. 2001. Tropical land use effects on atmospheric $^{13}C$ imply a sizable terrestrial carbon sink in equatorial latitudes. Geophysical Research Letters, in review.

Nardoto, G., G. Asner, A. Townsend and M.C. Bustamante. Phosphorus sorption dynamics across gradients of pasture age and soil type in the central Amazon. In prep for Soil Science Society of America Journal.

Asner, G.P, A.R. Townsend, C.C. Cleveland, M.E. Lefer, G. Nardoto and M. M. C. Bustamante. Biogeochemical changes following the conversion of forest to pasture on two soil types in the central Amazon. In prep for Ecological Applications.