Annual Progress Report: January 2005-December 2005

Effects of Logging, Plantation Conversion, Biomass Burning and Regrowth on Carbon Dynamics in Bornean Peat and Dipterocarp Forests: Implications for Global Carbon Cycle

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Principal Investigator
Dr. Lisa M. Curran,
Yale University, Tropical Resources Institute, School of Forestry & Environmental Studies,
370 Prospect Street, New Haven, CT 06511 USA
lisa.curran@yale.edu
http://www.yale.edu/forestry/bios/curran.html

Co-Investigators
Dr. Simon Trigg,
University of Maryland – College Park, Department of Geography,
2181 LeFrak Hall, College Park, MD 20742 USA
trigg@umd.edu
http://www.geog.umd.edu/people/Trigg.htm

Dr. Daniel C. Nepstad,
Woods Hole Research Center, P.O. Box 296, Woods Hole, MA 02543-0296 USA
dnepstad@whrc.org
http://www.whrc.org/about_us/whos_who/CV/dnepstad.htm

Dr. Richard Houghton,
Woods Hole Research Center, P.O. Box 296, Woods Hole, MA 02543-0296 USA
rhoughton@whrc.org
http://www.whrc.org/about_us/whos_who/CV/rhoughton.htm

Collaborators
Dr. Gary Paoli, Post-doctoral Consultant, Yale University, New Haven, CT USA
Alice McDonald, MSc., Geographical Research Consultant, Brookings, SD USA
Iskandar Zulkernan, MSc., Consultant, Indonesia
Dwi Astiani, MSc., Tanjungpura University, Dept. of Forestry, West Kalimantan, Indonesia
Y. Martin Hardiono, Drs., Consultant, Jakarta/West Kalimantan, Indonesia
Pahrian Siregar, Drs., SIMPUR, West Kalimantan, Indonesia
Dessy Rasel, Drs., SIMPUR (local NGO), West Kalimatan, Indonesia
Rusnawir Hamid, M.A., Regional Land Use Planning and Development, West Kalimantan, Indonesia
Nova Sirait, M.A., Regional Land Use Planning and Development, West Kalimantan, Indonesia

Abstract

Indonesia plays a major, yet highly uncertain role in the global carbon cycle. Indonesian Borneo (Kalimantan, 540,000 km^2) in particular is experiencing rapid and intensive land use change and large-scale fires, especially during El Niño Southern Oscillation (ENSO) events. Severe droughts during the 1997/8 ENSO event provoked forest fires that released ~1 Pg of carbon to the atmosphere, equivalent to half the average annual emission from land use change worldwide. The goal of the proposed research is to reduce the considerable uncertainty of the Bornean carbon budget through a combination of remote sensing, iterative field research and validation, and modeling.

Our research aims to develop carbon models based on: (1) a regional-scale database that can be used to quantify variations in terrestrial carbon storage as a function of forest cover and land use type, and (2) new regionally-specific approaches based on multiple satellite sensors (e.g. Landsat, MODIS, IKONOS) and field surveys to map the extent of peat forest by phasic zones, as well as oil palm plantations, and areas burned. Within our focal peatland along the west coast of West Kalimantan, we will assess the spatio-temporal patterns of degradation and land cover change and estimate biomass damage from a time-series of satellite imagery. Synergistically drawing on field-derived parameters (from surveys detailing peat depth, condition, vegetation, biomass; experimental fires yielding estimates of susceptibility, biomass burned) and satellite-derived classifications, we will generate local peat zonation and susceptibility maps for our focal peatland, and use the resultant methodologies to scale up to map Kalimantan's peatlands. These data sets and products will contribute to the parameterization of R. Houghton's process-level carbon model (CARLUC), and allow a refinement of Bornean carbon budgets, as well as comparisons to the Amazon. Carbon implications for future land cover scenarios will also be investigated with CARLUC.

In addition to providing a refined understanding of the role Indonesian peatlands play in the global carbon budget, we will assess the natural and anthropogenic factors influencing the carbon sources and sinks in forests of this region, and investigate the relative importance of regionally-observed factors on the global carbon cycle.

Keywords

(Note: The Keyword Table was not accessible on the LCLUC website; we are hoping to hear from Deirdre soon.)

1) Research Fields: carbon dynamics, land conversion, biomass estimation
2) Geographic Area/Biome: Indoneisan Borneo, tropical forests, tropical peatlands
3) Remote Sensing: peat zonation, time-series analysis, Landsat
4) Methods/scales: local, regional, global

Relevant NASA ESE Scientific Questions

What are the changes in land cover and/or land use in lowland dipterocarp forests and peat swamp/coastal mangrove ecosystems across Borneo?
In this first phase of the project (Year 1), we have focused on field surveys within peat forests, aerial surveys spanning peat and dipterocarp forests, the compilation of both GIS and remote sensing datasets, all of which will help to refine our mapping methodology. Remote sensing methodologies are iterating toward sound classification techniques.

What are the socio-economic and political drivers of LCLUC within Indonesian Borneo?
For this phase, we focused on illegal logging and conversion of peat swamps with oil palm expansion.

What are the consequences of LCLUC?
For this phase, we are specifically focusing on the vulnerability of peat and logged dipterocarp forests to drought and fire with the vulnerability of rural forest-dependent livelihoods. We are also examining human conflicts surrounding oil palm plantation expansion and opportunity costs for household livelihoods. The major consequences of the LCLUC in peatlands of interest to this project is their increased susceptibility to ground fires, that is fires that burn below-ground biomass within the peat layer. Since below-ground peat can be up to 20m thick, its combustion can produce emissions of CO2 and other trace gasses to the atmosphere that are disproportionately large per unit area. Thus, a major consequence of LCLUC in peatlands is to contribute disproportionately to the accumulation of greenhouse gasses and hence to global warming.

Project Proportion Estimations
Proportion of Social Science/ Human Dimensions: 35%,
Proportion of the Themes: 60% Carbon; 25% Policy and Governance; 15% Biodiversity

Project Accomplishments

This first year of the project has been the 'dataset compilation/preliminary development of remote sensing methodologies' stage. We have compiled crucial datasets derived from remotely sensed imagery, GIS, and field work:

1) Digitized Roads –non-paved 1990 vs 2000 (in progress). These data layers are essential for both the oil palm delineation (oil palm plantations can be readily diagnosed from their regular pattern of management roads) and the peatland susceptibility analysis (the construction of unpaved roads increases the susceptibility of peatlands to fire).
2) Human Population – Spatially explicit representation of population for all of Kalimantan at the district level
3) Oil palm – Mapping the extent of oil palm in 1990 vs 2000, – in progress 2005
4) Focal Peat Swamp Surveys – conducted field campaigns during summer 2005 that have detailed above and below –ground biomass, have also assessed disturbance level and vegetation and measured peat depth, as necessary to parameterize the process-level carbon model.

5) Experimental burn peat swamp site. – purchased peatland for experimental burn; completed a detailed survey of above- and below-ground biomass, begun to develop a methodology for conducting experimental burns
6) August 2005 Landsat 5 image of our focal peat site obtained from Thai Ground Station (scene received late November 2005). This image was acquired within 1 month of our biomass surveys as necessary to assess the feasibility of using Landsat reflectance data to extrapolate the biomass measurements of above and below-ground biomass across Kalimantan.

Remote sensing analyses for the oil palm and peat mapping efforts have also progressed (see Original Approach section below).

Original Approach: Remote Sensing Analyses

Oil Palm

The three major aims to the remote sensing portion of the oil palm analysis are to 1) delimit areas of extant oil palm across Borneo on the 2000-era Landsat Geocover product, 2) within each of the plantations delimited in 1), use the 1990-era Geocover product to map the cover types that were present before the conversion to oil palm and 3) compare the area of land that has already been converted to oil palm plantations with that still slated for conversions. The outputs from the remote sensing component will then be integrated with field-derived estimates of biomass for the different pre- and post-conversion cover types to model carbon implications of the observed and planned conversion.

Good progress has been made in the first phase. Supervised and unsupervised classifiers have been evaluated and rejected in favor of visual interpretation and digitizing by hand.

Issues

This decision was taken because, although digital classification of oil palm is limited by its spectral confusion with secondary regrowth, plantations can nevertheless be delimited visually through their diagnostic patterns of management roads. These roads are diagnosed by their recti-linear pattern in areas of low topography and by their pattern that follows contour lines in areas of more rugged relief. Only plantation activities in Kalimantan creates these patterns of roads.

- Therefore, visual delineation of oil palm is being informed through use of the roads layer digitized across Borneo from the 2000-era geocover product.

However, this reliance on diagnostic road networks does allow for the possibility of confusion with other vegetated plantations (e.g., rubber, pulp and paper). Therefore to ensure the correct interpretation of plantations, it will be vital to conduct field-based validation.

- We plan to validate the resulting oil palm layer through field visits with our Indonesian counterparts in the new year. Field checks will allow refinement of our mapping technique, and will ideally allow reliable identification of non-oil palm plantations as

well.

A major challenge pertaining to the oil palm analysis has been to compile spatially explicit coverages of the area still slated for conversion to oil palm. The problems stem from a lack of coordination between the relevant agencies, inaccuracy in mapping methodologies used, and unwillingness of map holders to share their data. We have addressed these challenges through working closely with our Indonesian counterparts who have provided vital inroads to the desired information.

Peat Study

The Jan-October field campaign of 2005 yielded aerial surveys across many land cover types in western West Kalimantan, and field surveys that derived the key measures of peat depth and above- and below-ground biomass.

The above-ground biomass estimates are being analyzed to test for empirical relationships that will permit the use of ETM+ and MODIS reflectance measurements to extrapolate above-ground biomass across Borneo. So far, predictive relationships between reflectance and above-ground biomass have been tested using multiple regression and decision trees, coupled with a preliminary assessment of forward-propagating neural networks (after Foody *et al*. 2003). No single method appears highly promising, for example, multiple regression is found to give low R^2 values (highest ~ 0.3). Furthermore, achieving this level of correlation requires the inclusion of the SRTM DEM as a proxy for tree height; a method that is only valid in topographically flat areas proximal to the coast. Decision trees are found to contain substantial error. We are in discussion with collaborators at Woods Hole toward strengthening predictive relationships through applying their procedures to correlate biomass directly with MODIS data rather than ETM+; the rationale behind this is that, compared to ETM+, MODIS reduces unwanted noise that is introduced due to heterogeneity of the canopy.

Below-ground biomass estimates derived during the field surveys are being compared with peat phasic zones classified from ETM+ data using a K-means unsupervised classification to test phasic zone information as a predictor of peat depth. Work underway is testing for significant differences in above-ground biomass within the zones classified from the ETM+ data. This analysis is being used to test the hypothesis that the zonation of peats that is observable on ETM+ images relates to distinct phasic zones. Assuming a successful outcome, the next step will be to test the hypothesis that peat phasic zone (as mapped using ETM+) can be used as a predictor of peat depth.

A further analysis of the peatlands is being conducted to delimit the extent and condition of peat forest that was present in Borneo circa 1990 as compared to its extent and condition circa 2000. This analysis is based on the classification of peat extent and condition from the 1990 and 2000 Landsat TM and ETM+ geocover products. We are evaluating both basic heritage approaches (as used by Skole et al. 2004 – e.g. ISODATA) and intend to also test for improvements in classification transferability and accuracy that can be realized using more advanced recent methods (e.g. Machine Vector Learning). The results of the Landsat-based analysis will be merged with our digitized roads layer to create maps that reveal how the suceptability of

Kalimantan's peatlands to fire changed between 1990 and 2000 and will allow us to develop 'business-as-usual' scenarios of future susceptibility of peat to fire.

Issues

There are three recurrent challenges to the work. The first is the highly heterogeneous nature of the canopy, which may weaken our capacity to extrapolate field estimates of biomass using Landsat reflectance data. In particular, the logging of much of the peat forest during several different pulses of extraction during the last 20 years has created a highly heterogeneous canopy whereby woody biomass can vary by an order of magnitude within just a few meters. This poses serious problems with scaling field-derived measurements of biomass up to the scale of even 30m Landsat pixels, particularly in the context of imperfect co-registration between datasets. A second possible reason for a weak correlation between field-derived biomass and reflectance is the time elapsed between the latest SLC-on ETM+ image of our peat field sites (28 August 2002) and the date of our peat biomass surveys (summer 2005). This time difference may mean that the biomass measured during the 2005 field surveys has been reduced from the biomass that was actually present at the time of our latest ETM+ image (2002), particularly because we know that the peat forests are being logged so rapidly.

Given this latter issue, a second challenge has been to secure 30m imagery that is temporally coincident with the field biomass surveys conducted in 2005; particularly given the failure of the ETM+ Scan Line Corrector.

- To this end, we have extensively searched the Thai ground station's collections of Landsat 5 data, and have located an August 2005 scene with little cloud contamination. Having just received this crucial image, we will now be able to re-run the biomass correlation analysis described above to test the possibility that the poor correlations were due to land cover change having occurred in the time elapsed between the ETM+ image used in the analysis (2002) and the field campaign that collected the biomass information (2005).

A third important challenge is to sample the full depth of peat in the field. With peat depths of up to 20m possible, coring becomes extremely challenging.

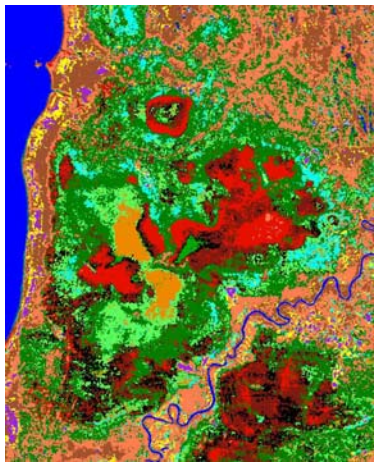
- As such, we are exploring the potential of low cost geophysical methods such as ground penetrating radar and vertical hammer-blow seismics.

Additionally, illegal logging and other disturbance continues – in our focal peatland, in our experimental burn peat site. Conditions can change rapidly. With efforts underway to map and take repeated measures of tree stem growth of all trees >20cm dbh, we have modified our initial sampling design to minimize our chances of data loss through disturbance to the study plots.

- We have decided against using dendrometer bands, as we fear that the bands would be stolen/tampered with. Instead, a clear mark or line at exactly 1.3 meters on each tree will be made to remeasure growth. In trees with buttresses or belimbings, the mark will be made above the buttresses.

Narrative: Project Progress

Database development has been furthered by the compilation of essential data layers, such as spatially explicit village to district-level GIS census data, GIS lithology data, detailed GIS land cover data, and Landsat-derived 1990-era roads, 2000-era roads, and oil palm plantation extent. The field campaign of 2005 yielded several aerial surveys across many land cover types in western West Kalimantan. Field surveys (180 person days) mapped 25 X 2km transects over four peat sites that derived the key measures of peat depth, coarse woody debris, forest use and condition (e.g., fires, logging) and above- and below-ground biomass. The above-ground biomass estimates are being tested to derive empirical relationships that will permit the use of ETM+ and MODIS reflectance measurements to extrapolate aboveground biomass across Borneo. The below-ground biomass estimates are being compared with peat phasic zones classified from ETM+ data (as illustrated) to test phasic zone information as a predictor of peat depth. Preparations are also underway for our experimental peat burn (planned for 2006). A further project component is using ETM+ data coupled with field survey to assess the carbon implications of the widespread conversion of residual forest stands to oil palm plantations. Relationships derived from field parameters will assist time-series analysis of change and carbon model development; regional analyses will serve as the basis for scaling up mapping and modeling efforts.



Next Steps

- Field validate oil palm layer generated from 2000 Geocover
- Within 2000-era plantations, map 1990-era land cover types before conversion to oil palm
- Produce best estimate of lands slated for oil palm conversion, compare 2000-status to possible future extent, and estimate biomass changes
- Utilize August 2005 Landsat 5 scene and field measures of biomass, peat depth in effort to derive relationships between above-ground biomass, reflectance; peat depth/below-ground biomass with peat phasic zone
- Map peat extent and condition across Borneo for two eras: ~1990 and ~2000
- Complete plot measures in experimental burn site; finetune burn procedures and schedule

Significant Results

Nothing that needs instant communication to the LCLUC community; we hope to report on new correlations soon, as we have reached the stage of meshing our remote sensing data with our field datasets.

Conclusions

The project is progressing well. As planned, this first year has succeeded in the initial tasks of: collecting intensive field measurements of above and below-ground biomass necessary to parameterize carbon models; assembling essential GIS and remotely sensed data sets; performing preliminary analysis of the suitability of ETM+ reflectance data to extrapolate field-derived biomass estimates; and furthering the mapping and assessment of the extent and changes in two important carbon stocks - and potential sources of carbon into the atmosphere. The project has resulted in four publications during this performance period (see below). The next major landmark will be to present substantive results to date on the peat analysis early in 2006 to a workshop on Vulnerability of Carbon Pools of Tropical Peatlands in Asia to be held on 24-26 January 2006 in Pekanbaru, Riau Province, Sumatra.

Publications during Performance Period

Paoli, G. D., L. M. Curran, D. R. Zak. 2005. Phosphorus efficiency of aboveground productivity along a nutrient gradient in Bornean lowland rainforest: A test of the unimodel nutrient response efficiency hypothesis. *Ecology* 86:1548-1561.

Santilli, M., P. M. Moutino, S. Schwartzman, D. C. Nepstad, L. M. Curran, C. Nobre. 2005. Tropical deforestation and the Kyoto Protocol. *Climatic Change* 71:267-276.

Paoli, G. D., L. M. Curran, D. R. Zak. 2006. Soil nutrients and beta diversity in the Bornean Dipterocarpaceae: Evidence for niche partitioning by tropical rain forest trees. *Journal of Ecology.*

Trigg, S., L.M. Curran, A. McDonald. 2006. The changing role of Landsat satellite data in monitoring forest loss in and around tropical protected areas. *Singapore Journal of Tropical Geography.*

Collaborative Exchange with LBA with Borneo project

Soares-Filho, B., D. C. Nepstad , **L. M. Curran,** G. C. Cerqueira, R. A. Garcia, C. A. Ramos, E. Voll, **A. McDonald,** P. Lefebvre, and P. Schlesinger. 2005. Amazon conservation scenarios. *Nature*. Supplementary Online Materials. *To be published December 2005*

Teaching and Outreach

Yale University

2005 FES604b Linkages in the Landscape: Effects of Land Use Change on Ecosystems 3 credits New graduate course developed that integrates new satellite technologies and applications of land use change to address questions of NPP, biogeochemistry, carbon, watersheds, biodiversity and human health with synergistic effects of climate change. Several NASA sponsored researchers provided guest lectures: Simon Trigg (UMaryland) Roni Avissar (Duke University), Nadine Laporte (WHRC) and Britaldo Soares-Filho (U Minas Gerais, LBA-WHRC). Extensive

review of NASA LBA programs using special volumes from *Ecological Applications* and *Remote Sensing and the Environment* with over 20 graduate students

2005 FES 620a: Leaves, Livelihoods, & Landscapes: Ecology, Socio-Economics and Politics of Development across Borneo. With A. Doolittle. New interdisciplinary capstone course developed, 3 credits.

Yale Master's Students Supported in Indonesia – summer field research:
David Butman, Jesse Grossman, Michael Lichtenfeld
Post-doctoral Fellows: Gary Paoli
Research Technician: Alice McDonald

Field Courses Taught in Indonesia

June-July 2005	Principal Instructor**,** Carbon and Biodiversity Assessments in Peat and Lowland Dipterocarp Forest*s*, for University of Tanjungpura students, West Kalimantan NGOs and Park Management Staff with Yale FES masters students. West Kalimantan, Indonesia
July 2005	Principal Organizer**,** GPS, GIS and Field Mapping Training for West Kalimantan Agricultural Department, West Kalimantan, Indonesia
April 2005	Principal Organizer, GPS, GIS and Field Mapping Training for West Kalimantan Forestry Department, West Kalimantan, Indonesia

Policy Change and Governance

Global

EIA- Greenpeace RAN – Chain of custody of wood. J.P. Morgen – change in socially responsible investors in the wood-based sector importing timber to Indonesia

The Forest Dialogue "Illegal Logging in Asia", Hong Kong, China

Within Indonesia

Formed Indonesian NGO: **SIMPUR**, a clearing house for forest and land use information for local non-governmental organizations based in Pontianak, West Kalimantan

Land use change – participatory land use spatial plans for Ketapang District where Gunung Palung National Park is located – building on Curran et al 2004 Science results
Extended analyses to include the district of Ketapang working with local government

New environmental guidelines developed for monitoring oil palm plantations and peat swamp development and habitat conversion. Working closely with BAPPADALDA the Indonesian Agency for Environmental Monitoring to develop field based assessments of peat forests, oil palm plantations and logging. Training courses in GPS, GIS and field monitoring for staffs in West Kalimantan are scheduled for January 2006

Martin Hardiono (RS-GIS Indonesian expert) – continues to volunteer in Post-Tsunami relief efforts in satellite and aerial mapping in Banda Aceh – He began on Dec 28th 2004– two days post-Tsunami to assist in relief efforts- status of infrastructure and road networks before UN and other missions could distribute food, water and medical supplies. Now Martin continues to work in Banda Aceh every three months coordinating with CARE relief efforts and then returning to Kalimantan to work on our NASA funded program.

Curran and Indonesian team works closely with human rights campaigns, anti-illegal logging and anti –corruption groups in both the US and Indonesia, Curran serves on the Transparency International's board of the Forest Integrity Network –

Presentations and Workshops within Asia on LUCLUC Policy Issues

University of Singapore, "Protected Areas of Malayan Archipelago Symposium", Singapore

BAPPADALDA Indonesian Agency for Environmental Monitoring, Curran Keynote Speaker

USAID-Forest Dialogue: "Forest Conflicts in Asia" Curran Presenter on Indonesia

Global Peatlands Conference "Vulnerability in Carbon Pools of Tropical Peatlands in Asia" Riau Sumatra 24 January 2006 – both Curran and Trigg will attend and present at this three day symposium.