Wetland Global Carbon Survey:

Tropical Wetlands Initiatives for Climate Adaptation and Mitigation (TWINCAM)

Final Report

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Implemented by:
USDA Forest Service

and

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International Forestry Research

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Summary

This Final Report covers the entire activities during the 2011/2012 fiscal year. At the same time it includes activities for the fourth quarter (1 July-30 September 2012). Five groups of activities listed below are described with their deliverables as expected in the objectives of the project.

The highlights of year-2 of the Wetland Global Carbon Survey Project are the involvement of the team in the IPCC processes in developing guidelines for National GHG Inventory in wetland ecosystems and the accomplishment of the wetlands global carbon map. In addition, new partnerships and networking have been conducted in Vietnam, Costa Rica and Dominican Republic.

The capacity to understand and assess wetland ecosystem C stocks was developed for numerous partners in Indonesia, Vietnam, Mexici, Costa Rica and Dominican Republis throughout the course of the project implementation. Capacity building was initiated with a training workshop to understand the role of ecosystem C in IPCC processes and UNFCCC initiatives (including REDD+) and how to implement sampling protocols for ecosystem C stock assessments. Sample and data collections have been completed in the above-mentioned countries. This ensures prolific years to come in terms of delivering scientific products through seminars, workshops, and publications of reports and papers.

Budget wise the project has been fortunate to be able to wisely spend and share the resources with appropriate partners and collaborators.

1. Introduction

1.1. Background

Wetlands have increasingly become global and national interests, especially in the arena of climate change mitigation and adaptation. The implementation of the Tropical Wetlands Initiatives for Climate Adaptation and Mitigation (TWINCAM) under the Wetland Global Carbon Survey Project supported by USAID is both relevant and timely. It is so appropriate that in a relatively short period it has gained wide attention and participation.

Global communities such as the Blue Carbon Working Group organized by Conservation International and the IUCN, who are interested in issues around coastal ecosystems (including mangroves) share common interests that require integration. The Working Group seeks further collaboration for more effective impacts on the policy community. The TWINCAM project is well positioned to foster such collaborations and facilitate science-policy dialogue at regional, national and global levels.

Moreover, the outcomes of the project could be integrated into Intergovernmental Panel on Climate Change (IPCC) activities. The IPCC is now engaging a process to supplement the existing 2006 IPCC Guidelines for National Greenhouse Gases Inventory. The Supplement is specifically targeted for the wetlands chapter and will be completed in October 2013.

At national levels, the REDD+ mechanism has been piloted in several countries including those harboring large wetland areas covering freshwater peat swamp forest and mangroves. The fact that these countries do not have the capacity to assess carbon assets has challenged the TWINCAM to be more pro-active in promoting the approach, protocol and analysis of the data. Understanding the breadth and wealth of carbon pools will certainly improve country's policy formulation and negotiation power in the global arena.

Producing information on C stocks of some of the largest terrestrial C pools on earth has been driving year-2 activities. Subsequently, the data will be made available as they are of great value to policy and decision makers related to MRV, REDD+ and land use planning for tropical wetlands. The regional and modeling approaches used in this project helps refine our methods at each stage, and will update with new developments in remote sensing technology.

TWINCAM has finished a wetlands global carbon map in this year-2. The wetlands global map has been producing by MODIS satellite images with a set of physically intelligible indexes. The developed indexes include, i) a global topographic wetness index, ii) a global surface wetness index derived from optical EOS images, and iii) a global geomorphological map. Combining information on surface wetness phenology, topographic wetness and geomorphology, a global tropical map of the likelihood of wetland occurrence was created. Present best estimates of global topical wetlands are grounded in compilations of disparate sources from studies using a variety of different techniques. The primary objective of this study was to develop a globally consistent map of global tropical wetlands.

Although the adaptation front has not been fully explored, it is now the right time to use the existing information on C-stocks and GHG emissions from wetlands to evaluate the disturbance regimes. Changing land management or development trajectories of tropical wetlands as an adaptive measure to climate change may be considered. This could lessen vulnerabilities to the adverse effects of climate change and be financed through C conservation incentives such as REDD+. TWINCAM is expected to weigh adaptation and mitigation strategies equally.

Our intensive work has mainly been implemented in Indonesia and Vietnam, and shared with other tropical countries that contain extensive wetland areas such as Costa Rica and Dominican Republic. Output has been shared through open communication, workshops, consultations and desk studies through literature review. Counterparts in these and several other Central and South American countries have been identified for the establishment of future project sites. To make the study truly global in context, the processes within IPCC will have to be backed up with ground work to assess emission factors and their underlying causes to enable development of effective mitigation strategies.

1.2. Goals and Objectives

In international policy circles, at national levels and in early demonstration REDD+ activities, monitoring, reporting and verification (MRV) of emissions reductions are major technical hurdles to the implementation of the new international REDD+ scheme. Lack of regionally and nationally appropriate default values for the IPCC equation preclude so called Tier 2 and 3 accounting and this is particularly acute in tropical wetlands.

The overall goal of this project is to support the development of the international REDD+ mechanism in wetlands and significantly reduce this constraint throughout the tropics through better characterization of C stocks in intact tropical wetlands and in the land cover types that are replacing them.

There are three sub-goals that will contribute to achieving the overall success of the project:

1. Advance the science and knowledge of MRV and GHG emissions specific to tropical wetlands by facilitating scientific consensus, conducting collaborative research, and sharing expertise for mapping and spatial data analysis in support of measuring and reporting. This will include intensive activities such as developing more accurate and efficient methods and analytical approaches for wetland forest and mangrove inventories, as well as field and remote sensing studies to determine temporal and spatial dimensions of tropical peat forest dynamics needed for effective MRV.

2. Creating regional networks of permanently delineated and established forest plots and professional staff to conduct collaborative field research targeted to fill critical gaps in knowledge of wetland carbon stocks in the Southeast Asia region. Other key knowledge gaps to be addressed are the factors that influence the quantity and composition of GHG emissions from wetland conversion. These networks and activities are targeted to identify and address information deficiencies of carbon inventories, baseline assessments, and monitoring needed to implement REDD+ strategies.

3. Build capacity of regional academic and research counterparts for scientific inquiry and research related to climate change. Inform the general public and policy makers on the interrelated issues of carbon stocks, climate change, land use land cover change, and adaptation/mitigation approaches of tropical wetlands, as well as developing global wetlands carbon map.

Specific objectives:

1. Develop efficient and accurate approaches to the quantification of carbon stocks of tropical wetlands.

2. Establish a series of permanent forest plots in tropical wetlands where C stocks can be monitored through time in order to quantify changes due to LULUCF and global climate change. This has strong potential in capacity building and education.

3. Quantify C stocks of other common land uses (e.g. oil palm plantations, agriculture, aquaculture, Acacia plantations, etc) in tropical wetlands in order to establish past carbon emissions as well as baselines for the future.

4. Based upon intensive field studies and quantitative modeling scale C stocks of tropical wetlands to regional/global levels. Map ecosystem C stocks of wetlands in the targeted global of interest.
5. Quantify dynamics of peat C and non-CO2 GHGs associated with land cover change at the plot scale in intact, degraded, and converted wetlands. The research will focus on the effect of water table level and nutrient dynamic changes on soil organic C losses and N2O emissions.
6. Generate timely scientific and lay reports to promote a better global appreciation of GHG dynamics in tropical wetlands, their role in the global C cycle, and potentials for effective climate adaptation and mitigation planning.

2. Activities and deliverables

To meet the objectives, the activities reported here are grouped into categories that were implemented in the regions where capacity building and networking have been established.

2.1. Field campaign

After covering important sites of Indonesian and Mexican wetlands in year-1 and the first half of year-2, we continued to carry out GHG flux measurements from peatlands in Indonesia. We also conducted field measurement campaign in Vietnam, Costa Rica, and Dominican Republic in mangroves ecosystems.

Vietnam

Following a three-day class work attended by 30 participants representing government agencies, civil societies, and academia, field works were organized to collect samples using the Sampling Potocol adopted by TWINCAM (Kauffman and Donato, 2012). The participant were divided into two groups for hands-on training experiences with 15 members on each group. The first group worked in the Can Gio Biosphere Reserve, and the second group worked in the Ca Mau Protected Forest (see Figure 1).

Figure 1. Study sites in Can Gio and Ca Mau provinces

Field sampling in Can Gio was conducted in six transects and nine transects in Ca Mau sites to measure tree diameter and collect woody debris and soil samples. Indoors training was conducted for data tabulation, soil pH measurement, soil color determination, wood density measurement, sub-sampling the litter samples as well as calculating the aboveground carbon pools in the transects.

To reach the sampling sites boat rides (Figure 2) were very efficient to determine the transects that have to be perpendicular to the river embankment.

(a) (b)

Figure 2. Can Gio mangrove biosphere reserve (a); Kien Vang protected forest, Ca Mau province (b) (Photo: Sigit Sasmito)

The preliminary results of live trees carbon stock showed in Table 1. Soil carbon analysis is being carried out in soil laboratory of Bogor Agricultural University, Indonesia.

Table 1. Live trees and roots C-stocks

Pools	Can Gio Biosphere Reserve C-stocks (MgC ha^{-1})	Kien Vang Protected Forest, Ca Mau C-stocks (MgC ha^{-1})
Aboveground (trees)	95.4 (11.0)	91.4 (14.6)
Belowground (roots)	34.2 (3.2)	34.3 (5.3)

Costa Rica

Working with partners from the Costa Rican government, NGOs , CATIE and the three major universities in Costa Rica we sampled tall mangroves and abandoned shrimp ponds (converted from mangrove) of the Pacific Coast of Costa Rica. This was working field training where students, National Park employees and faculty worked with me to learn the methods of measuring carbon stocks necessary for the measurement and monitoring of stocks and emissions.

In this study we established plots and sampled composition, structure, and Carbon stocks of 5 mangroves and 2 abandoned shrimp ponds (in mangrove sites Figure 3). The mangrove plots were established throughout the Estero Damas mangrove along a gradient from the upland edge to the estuarine fringe on the Pacific. This was significant as these were the first mangroves sampled on the Pacific Coast of Latin America and this was the first study where carbon stocks of shrimp ponds has been quantified.

Soil carbon analysis was conducted in the CATIE analytical laboratory under the direction of Dr. Miguel Cifuentes, CATIE. Data analysis in the final phases and publications are forthcoming. The ecosystem carbon stocks showed in Figure 3. The first five communities are intact mangroves and the last 2 are abandoned shrimp ponds. From these data we can begin to calculate total emissions from Land use via a stock change approach. If we assume that the C stocks of the shrimp ponds were equal to that of the intact mangroves before conversion, then a mean of 469 Mg C has been lost due to land use change. This is in equivalent to a loss of 1720 CO_{2e}/ha.

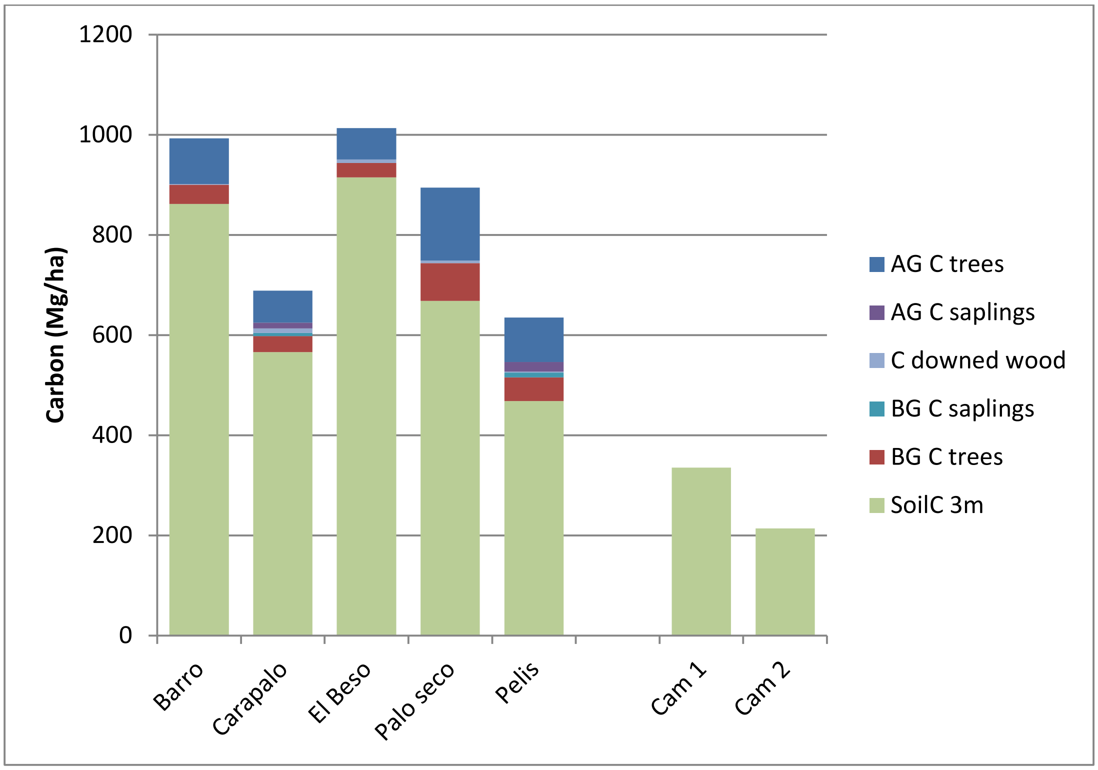

Figure 3. Ecosystem carbon stocks of pacific mangrove communities of Estero Balsa, Costa Rica.

Dominican Republic

We conducted a workshop and sampled carbon stocks of the mangroves of the *Parque Nacional Monte Cristi*, Dominican Republic. The description of the ecosystem structure is shown in Table 2. This is among the largest remaining mangroves in Hispanola and threatened by numerous coastal land uses. In total, we sampled 9 mangrove sites (three distinctive types) and three abandoned shrimp ponds. This was the first study to quantify carbon stocks in the Caribbean islands. Data are in the process of being analyzed.

In this study we sampled the three dominant structural types of mangrove in Latin America. Mangroves in the Caribbean are classified on the basis of structure and we were able to quantify c stocks of tall, medium and short mangroves. The depth of the organic horizons were always >1m in depth and in some plots as deep as 2.5 m. We found that soils in abandoned shrimp ponds had lost a mean of 99-154 cm of the organic soils.

Table 2. Generalized descriptions of tall, medium, and dwarf mangroves (mangle alta, media, and enano) of the mangroves of the *Parque Nacional Monte Cristi*, Dominican Republic

Feature	Tall mangrove	Medium mangrove	Dwarf mangrove
Canopy Height	>10m	3-10m	<3 m
Diameter of canopy trees	>5cm	Most <5cm	Most <2 cm
Canopy Tree Density	Dense (>700/ha)	Extremely dense (>30,000/ha)	Extremely dense (>12,000/ha)
Downed wood	Abundant	Scarce	Practically absent
Geomorphic position	Fringing/Riverine edge	Basin/Interior zones	Basin, tidal flats – Interior zones
Salinity	Relatively Low	Moderate	Relative high
Composition	Rhizophora, Laguncularia, Avicennia	Rhizophora, Laguncularia	Rhizophora, Avicennia

There are two very significant preliminary findings and observations from the Dominican Republic study. The first is that the organic rich soils of the low mangroves clearly demonstrate that coastal non-forest marine ecosystems contain among the largest carbon stocks ecosystems on earth. Second, the conversion of coastal ecosystems results in remarkable emissions of greenhouse gasses. The loss of 99 to 154 cm of organic rich soil suggests a huge loss. Further, the C concentration of surface soils of the shrimp ponds was an order of magnitude lower than that of intact mangroves.

The unique structure of the ecosystems requires different approaches to their measurement. Efficient means of measurement is significant accomplishment of the TWINCAM study. While the dwarf and medium mangroves are low in stature, they still contain remarkably high carbon stocks; among the highest of any ecosystem on earth.

Figure 4. Tall, medium, and dwarf mangroves of the Caribbean

Indonesia

This year we have established a large interdisciplinary study to examine carbon fluxes, carbon stocks and environmental changes associated with land use land cover change in tropical peat forests of Central Kalimantan. A study to examine carbon fluxes have been established where trace gas emissions (greenhouse gases-GHGs) of CO_2, CH_4 and N_2O are being quantified in intact peat swamp forests and in oil palm plantations. The intact forests are located in Tanjung Puting National Park and oil palm locations are in adjacent villages. The soil respiration is partitioned into its autotrophic (root respiration) and heterotrophic (microbial respiration) components using the trenching method and laboratory incubations. In addition to trace gas measurements we are sampling water table depth, soil redox potential, litter fall, and decomposition as well as climatic variables. These are important parameters necessary to develop better models of emissions from peat forests and disturbed sites.

In June 2012 a field trip was carried out with the purpose of establishing at least a three year study that will be the dissertation research of Nisa Novita – an OSU graduate student funded by TWINCAM/CIFOR. Reza Nugroho, an MSc. Student registered at IPB-Bogor will at the same sites monitor soil respiration and its components over a 1 year period. Further this is one of the sites where TWINCAM-funded UNH student Sofyan Kurnianto collected peat samples for age characterization.

This year we located the intensive forest and palm plantation study sites and have established the trace gas emissions study. In the future we will quantify carbon stocks in the sites of trace gas emissions as well as in other forests and plantations of the area. In total, we hope to measure C stocks in at least 10 intact forests and 10 oil palm plantations of varying age since establishment.

Figure 5. Intact peat swamp forests, Tanjung Puting National Park, Central Kalimantan, Indonesia and the adjacent oil palm plantations provide research sites for a comprehensive greenhouse gas measurements and carbon stock studies.

2.2 Workshops and meetings

Workshops and meetings have been effective avenues to disseminate the results, get the feedback and comments, and improve the methodology and analysis of sample/data collected with partners. were attended by TWINCAM scientist to presenting TWINCAM data.

Numerous presentations have been reported in the previous Quarterly Report and they may be accessed at http://www.slideshare.net/CIFOR/. The list in Table 3 indicates the events in the last four month. Most of them are by invitation.

Table 3. List of workshop and meetings attended by TWINCAM team members

No.	Venue and date	Activities	Organizer	Staff involved
1	Bonn, Germany May 2012	Technical and scientific aspects of sources, sinks and reservoirs of all GHGs for coastal and marine ecosystems.	UNFCCC/SBSTA	J. Boone Kauffman
2	Orlando, USA 4-8 June 2012	International Wetland Congress: Exceptionally high carbon stocks of mangroves and their potential conservation through global carbon markets.	International Ecological Society	J. Boone Kauffman, Maria Fenanda Adame and Daniel Donato
3	Orlando Florida June 4-8, 2012	International Wetland Congress: Tropical peatlands of Southeast Asia: Functions, threats and the role of fire in climate change mitigation.	International Ecological Society	J. Boone Kauffman, M. Warren, and D. Murdiyarso
4	Nadi, Fiji 18-22 Jun 2012	Regional Workshop of Forest Carbon Assessment and Monitoring in Pacific Countries.	Secr. Pacific Community (SPC), GIZ, JICA	Chris Heider and J. Boone Kauffman
5	Can Gio, Vietnam June 2012	Training Workshop on Field Sampling Protocol for C-Stocks Assessment in Tropical Wetlands Ecosystems	CIFOR, USFS, Nong Lam University	D. Murdiyarso, J. Purbopuspito, Sigit Sasmito, R. Mackenzie
6	Stockholm, Sweden June 2012	14th International Peat Congress	Intl. Peat Society	Kristell Hergoulac'h
7	Washington DC, 10 July 2012	Better REDD than dead: how climate change mitigation of mangroves can save biological diversity though reduced deforestation and degradation.	Counterpoint International	J. Boone Kauffman
8	Dublin, Ireland 17-19 July 2012	IPCC 3rd Lead Author Meeting, Wetlands Supplementary Guidance	IPCC	J. Boone Kauffman Lou Verchot
9	Bucharest, Rumania July 2012	The COP-11 to the Ramsar Convention on Wetlands of International Importance	Secretariat of RAMSAR Convention	Joko Purbopuspito
10	Semarang, Indonesia July 2012	Reorientation Policies of Coastal and Seas Thematic Geospatial Information Workshop	Geospatial Information Agency	Sigit Sasmito
11	Santo Domingo, Dominican Republic 6 Sep 2012	*El Potencial Del Carbono Azul Y La Conservación De Manglares En La República Dominicana*.	*Universidad Autonoma de Santo Domingo*	J. Boone Kauffman
12	Bogor, Indonesia 13-14 Sep 2012	International Symposium on Wild Fire and Carbon Management in Peat-Forest in Indonesia	Japan Sci. & Technological Agency/JICA	D. Murdiyarso

2.3 Outreach

Through their participation in the UNFCCC/SBSTA, IPCC, and other international meetings, CIFOR scientists have been able to disseminate the information gathered in this study as soon as it is available for dissemination. The numerous presentations delivered this year in highly visible forums as listed above is strong evidence of this.

Information Briefings

No.	Venue	Activities
1	Bonn, Germany	Briefings on work to climate change delegations at SBSTA
2	Brussels, Belgium	Briefings to the European Union Parliament
3	Washington, DC USA	Interview with National Public Radio (NPR), USA on various aspects of mangroves in Southeast Asia for people and the environment
4	Jakarta, Indonesia	Briefings to the REDD+ Task Force on the significance of peatlands and mangroves to be included in the National REDD+ Startegy
5	San Jose, Costa Rica	Television interview with the largest TV station in Costa Rica Briefings on Blue carbon and TWINCAM activities to Ministry of Environment leadership and leading Costa Rica foundations
6	Santo Domingo, Dominican Republic	Briefings to the Ambassador and Negotiators/ Ministry officials, NGOs and University on Climate Change
7	Da Nang, Vietnam	Media briefings on Mangroves for the Future: challenges and opportunities for Southeast Asians
8	Can Gio, Vietnam	Briefings to the leaders of Can Gio and Ca Mau Districts on mangroves and climate change

Intergovernmental Panel on Climate Change (IPCC) Processes

Four of TWINCAM research team members (Kristel Hergaualch', Boone Kauffman, Daniel Murdiyarso, and Lou Verchot) are involved in the development of the Supplement to the 2006 IPCC Guideline as Convening Lead Author, Lead Author and Contributing Author. The Guideline is especially dedicated for wetlands. Several Author Meetings have been attended to scrutinize the published articles on wetlands related issues to develop methodologies for the National Greenhouse Gas Inventory.

In addition to the methodologies, the emission factors (EFs) and activity data were assessed to be included in the guidelines regarding the options for the Tiers. The Second Order Draft is being prepared by the authors after receiving numerous comments on the First Order Draft. The Supplement to rhe 2006 Guideline on Wetlands is due in May 2013.

Indonesia Forest and Climate Support (IFACS) Processes

Building on the success of TWINCAM efforts in Indonesia, affiliated USFS post-doc Matt Warren has been working with parallel USAID and US State Department programs focused on peatland issues in Indonesia. In a series of meetings in 2012, opportunities and benefits of the capacity building workshops on climate mitigation and C stock assessment following the TWINCAM model were presented to the USAID Indonesia Forest and Climate Support (IFACS) program.

The training opportunities and baseline data generated from TWINCAM were recognized by the IFACS program, and IFACS has committed to support workshops and field sampling in five targeted landscapes: Ketapang and Kayong (W. Kalimantan), Aceh Singkil (Sumatra), and North and South Papua. Data generated from these efforts will contribute to the overall TWINCAM dataset, and almost double current data for Indonesian freshwater peatlands. Data collected during the initial ecosystem C stock training and survey will be applied to estimate peatland C stocks at the landscape scale with additional spatial analysis and measurements of peat depth and bulk density. The project aims to apply methodologies and training developed by TWINCAM to estimate carbon storage in the extensive peatland and mangrove areas in each landscape.

Indonesia Climate Change Center (ICCC) Involvement

Matt Warren has also been committed to providing consultation, program development, and technical support to the Indonesia Climate Change Center (ICCC). The ICCC seeks to bridge peatland science and policy to assist “climate smart” policy development for sustainable peatland management in Indonesia. ICCC efforts are consistent with Indonesia’s commitment to voluntarily reduce greenhouse gas emissions 26% by 2020, largely targeting emission reductions from peatlands. The activities of the ICCC Peatlands and Peatland Mapping Cluster include: supporting the development of a peatlands data layer for a unified national land cover map, a comprehensive peatland policy assessment and recommendations to meet GHG reduction targets from peatlands, organization of an international meeting on peatlands science and policy in conjunction with the Asia Carbon Forum Carbon Update 2013, and a review of the current status of Indonesian peatlands with projected future states under competing policy and management scenarios. The experiences, lessons learned, and scientific contribution of TWINCAM activities are highly valued by the ICCC, who rely on expert consultation from both USFS and CIFOR TWINCAM scientists.

2.4 Capacity building

Costa Rica

Groups of stakeholders in Costa Rica were engaged through various ways and means of capacity building. Among others:

- Instructed four Costa Rican graduate students, four Costa Rica University faculty and three Costa Rica Environment (National Park) employees on approaches to determine carbon stocks in Mangroves
- Three presentations (in Spanish) on our work to different policy and professional groups
- Meeting of policy and decision makers in Costa Rica (Spanish)
- Costa Rica National Park Service managers (Spanish)
- Ecotourism guides of Estero Damas mangrove (Spanish)

Indonesia

Mentorship to three Indonesian graduate students was provided by TWINCAM team. It is also combined with training in the field at Tanjung Putting National park. The students are:

- Nisa Novita, graduate student under the direction of Kauffman at Oregon State University, co-supervised by K. Hergoualc’h at CIFOR;
- Reza Nugroho, MSc. Student registered at IPB-Bogor under the direction of Iswandi Anas (IPB) and K. Hergoualc’h (CIFOR);

- Sofyan Kurnianto, MSc. Student registered at the University of New Hampshire supervised by Steve Frolking and co-supervised by Boone Kauffman.
- Sigit Sasmito CIFOR's research assistant attended training and presented a poster in 2nd Advanced International Summer School on GIS and Islands: Climate Change and Coastal Environmental Planning, University of Azores-Portugal in August 2012.

In addition to the students, hands-on exercises were exercised with the staff and technicians of Tanjung Puting National Park, Orangutan Foundation International, and interested local villagers. They were involved in the measurement and accounting of carbon stored in peat forests and oil palm plantations.

With USDA/USFS funding and TWINCAM affiliation, Prof. Frolking and MS student Sofyan Kurnianto are developing a tropical version of the Holocene Peat Model (HPM; Frolking et al. 2010). HPM was developed and has been applied to northern peatlands systems, operating at an annual time step for 1000 - 10,000 year simulations. The goal in Kurnianto's MS Thesis research is to modify HPM for tropical systems, providing a first capability to estimate tropical peat carbon dynamics over long periods, and further developing the model to simulate the impact of drainage/disturbance on C dynamics. Modeling efforts included an intensive field campaign during June and July 2012, where peat sampling was completed at TWINCAM study sites in Tanjung Puting and Berbak National Parks. Peat samples were collected for ^{14}C dating which will allow Kurnianto to calibrate and verify the ecosystem C model. Together with ongoing TWINCAM carbon flux measurements at these sites, Kurnianto's data will provide a more detailed understanding of ecosystem C dynamics.

Dominican Republic

More general audience in Dominican Republic was involved in activities conducted by Boone Kauffman:

- Workshop on *Metodos de la inventario y medicion, monitoreo y reporte de los manglares de la Republica Dominicana*. This was a field-based workshop where Boone Kauffman instructed 15 students from Dominican Republic universities, the government, and NGOs and methods needed for participation in REDD+ and other NAMAS.
- Seminars (in Spanish) on our work and its relevance to different policy and professional groups.

Vietnam

After approaching senior faculty member of Nong Lam University in Ho Chi Minh City, Daniel Murdiyarso led a field based workshop on Field Sampling Protocol for C-Stocks Assessments in Tropical Wetland Ecosystems.

- Both class and field works were supported by Richard MacKenzie (USFS), and CIFOR's Joko Purbopuspito and Sigit Sasmito. The workshop participated by 30 people from a large variety of 24 organizations including five universities, three research agencies, five forest reserve management boards, two institutes, seven forest services, and two international organizations.
- Presentations by participants on various issues related to mangrove and coastal zone management have been valuable experience to assess the capacity of Vietnamese scientists. It is possible the wealthy data set the possess may be of invaluable for future publications following writing exercise and training by professional writer
- Follow up discussions and briefings collaboration to the Vice Chancellor of Nong Lam University were conducted. There are opportunities to involve graduate students. Large bright student body may be seen as Vietnam future in science.

2.5 Wetlands global carbon mapping

Wetlands mapping

Wetlands are almost universally identified on topographic maps. As topographic maps originate from military needs of terrain information, knowledge of the distribution of wetlands was important. The wetland classification in topographic maps is hence usually of good quality. But topographic maps only cover parts of the tropics, and very restricted areas are available for open access in digital form. Thematic maps, and generalized maps at smaller scale than traditional topographic maps, more seldom include information on wetlands, even if they are easier to access. Many remote regions, including the world's largest tropical forests in the Amazon Basin (South America) and the Congo Basin (Africa) have never been properly ground surveyed. Recent studies using satellite images show that both the Amazon Basin (e.g. Lähteenoja et al., 2012) and the Congo Basin (Bwangoy, Hansen, Roy, Grandi, & Justice, 2010), contain large areas of wetlands. These studies indicate that the total wetland area of the tropics might be larger than hitherto estimated.

Global mapping of the Earth's land surface from Earth Observing Satellite (EOS) images has mainly focused on land-cover and topography. Global thematic maps that include wetlands are still dominated by data compiled from national surveys, and are usually at scales of 1:1M or coarser. The most consistent map of the global land surface might still be the Digital Chart of the World - the 1: 1M operational navigation chart developed by the United States Defense Mapping Agency (DMA). DCW does contain wetland classes, but they are not reliable and can not be used as a basis for estimating global tropical wetlands. Some of the global land cover maps developed from EOS images do contain wetland classes. These global maps, however primarily focus on vegetation classes, and hence most tropical wetland areas are categorized as forests, shrub-lands or grass-lands. Figure 6 shows the Moderate-resolution imaging spectroradiometer (MODIS) global land-cover product (MCD12Q1) (Friedl et al., 2010). The present version of the MODIS land cover product (v051) uses a decision tree classification algorithm that is iteratively improved by comparing results against a validated set of training data.

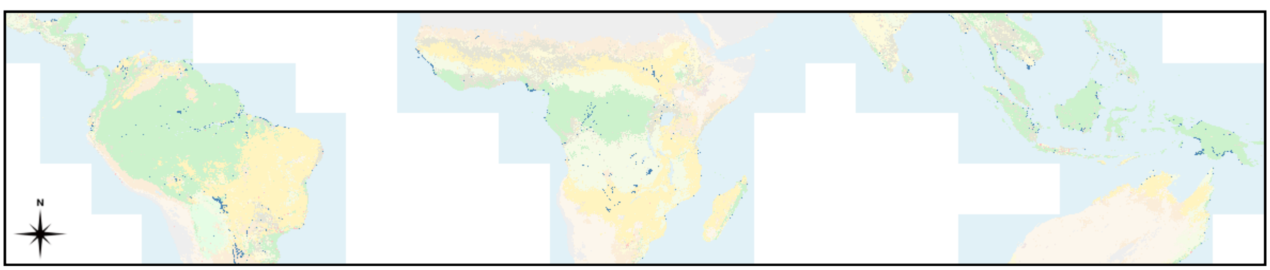

Figure 6. The standard MODIS land cover product (MCD12Q1 version 051) for 2010 permanent wetlands have fully saturated (blue) color, other land cover classes have the default hue used for the IGBP classification scheme of MCD12Q1, but with faded saturation.

The European Space Agency GlobCover map in 300 m resolution, attempts also to map global tropical wetlands (Bontemps, Defourny, Van Bogaert, Arino, & Kalogirou, 2010). GlobCover is primarily done from time-series data from the Medium Resolution Imaging Spectrometer (MERIS) sensor onboard the European Space Agency ENVISAT satellite. GlobCover is done from a combination of more traditional image analysis techniques, relying on extensive ground control points. The wetlands classes are partly derived from combining the MERIS classification scheme with ancillary data. A third global land-cover map is the ESA Global Land Cover 2000 map, but is rather a compilation of various efforts, and has not been used in this study. The only global consistent map of wetlands available, is the global mangrove map recently published by (Giri et al., 2011).

Comparing the global land cover maps for Africa, (Kaptué Tchuenté, Roujean, & De Jong, 2011) conclude that large scale features are well captured, but that heterogeneous landscapes deserve more attention. They suggest that considering timing and phenology could improve the classification of heterogeneous landscapes.

The global land cover products have been directed towards identification of vegetation classes, and though they include wetland classes, the soil substrate has been largely ignored. Global soil maps on the other hand lack detailed information from many parts of the globe (FAO, IIASA, ISRIC, ISSCAS, & JRC, 2012)�, and is too generalized to use for identification of global tropical wetlands (cf Figure 1).

Approaches

Tropical wetlands change in size both due to natural climatic fluctuations, and as a consequence of human management. Mapping global tropical wetlands, adoption of EOS image data is the only feasible possibility. As discussed above, traditional statistical image classification techniques cannot be used for mapping wetlands due to the large seasonal variations in time and space of flooding and vegetation phenology. Existing global land-cover maps are based on more advanced (iterative) statistical approaches relying on large sets of verified ground control data points. For wetlands, the lack of globally relevant and verified ground control points prevents (iterative) statistical approaches for generating a global wetland map. As wetlands are "lands transitional between terrestrial and aquatic systems", they are almost per definition heterogenous, and the results of global-scale land cover maps are more error-prone in heterogenous areas. Further, wetlands and peatlands are defined based on soil, not vegetation, conditions. Taking this into consideration, an alternative approach was developed for mapping global tropical wetlands in this study.

The first stage includes development of a set of physically intelligible indexes and maps that have logical relations to the distribution of wetlands. The developed indexes include, i) a global topographic wetness index, ii) a global surface wetness index derived from optical EOS images, and iii) a global geomorphological map. A third surface wetness index derived from radar data was also developed, but not adopted due to geometrical position errors in the radar data-set. From the optical surface wetness index the phenology (annual cycle) of surface wetness was extracted. Combining information on surface wetness phenology, topographic wetness and geomorphology, a global tropical map of the likelihood of wetland occurrence was created.

The second stage includes traditional image classification, but using a chrono-sequence of images for extracting phenological relevant reference signals to use for image classification in defined spatial and temporal domains. Due to lack of verified reference sites, the second stage could only be tested for selected regions and then only for a limited number of wetland classes. And even for these restricted area, no ground referenced verified data were available.

Present best estimates of global topical wetlands are grounded in compilations of disparate sources from studies using a variety of different techniques. The primary objective of this study was to develop a globally consistent map of global tropical wetlands.

Outputs

The core of the data compiled for this study consists of products from the Moderate-resolution imaging spectroradiometer (MODIS) sensor. A range of pre-defined products derived from the MODIS sensors are available over the internet with free FTP access. All MODIS products used in this study are delivered in a pre-defined tiling system. Each tile represents approximately 10 degrees by 10 degrees. For this project 83 tiles, representing the tropical land surface of the Earth, were selected. The study area includes the region between 25 degrees north and 25 degrees south. This is equivalent to vertical tiles 06 through 11 (see Figure 7).

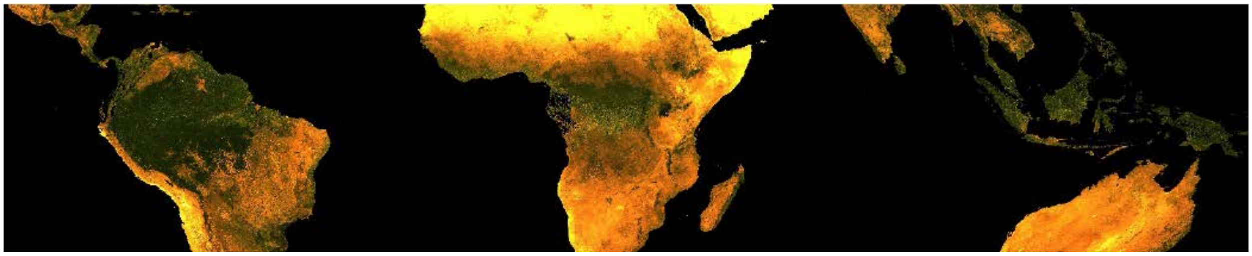

Figure 7. Tropical region included in this study (color composite of MODIS reflectance data for the peak of the dry season)

The MODIS products native sinusoidal grid has a wall-to-wall coverage of the entire Earth surface, and is an equal area projection. This is highly advantageous when processing tiled images, and especially when modeling water balances. All processing was hence done using the MODIS sinusoidal grid. All non-MODIS datasets where cut and reprojected into the MODIS pre-defined tiling system.

The extent, volume and carbon content of global tropical wetlands are not well known. The best estimates are based on disparate sources, and hitherto un-known wetlands are continuously reported in the scientific literature. Traditional classification methods, as well as more advanced methods adopted for global land-cover (vegetation) mapping, are extremely difficult to adopt for wetland mapping. The high variation in wetland appearance, the typical fragmented pattern of wetland soil and vegetation conditions, and the varying timing of wetland flooding, inundation and vegetation phenology, all contribute towards the difficulty in mapping global tropical wetlands from Earth Observing Satellite imagery.

Compared to other land-cover classes, there is also a lack of adequate and verified ground reference sites for wetlands. These problems prompted a novel approach for mapping global tropical wetlands, relying primarily on biophysical relevant indexes with indirect influence on wetland distribution. Existing indexes on topographic wetness developed for temperate regions were reviewed and a novel Global Topographic Wetness Index (GTWI) was formulated. Optical multi-spectral image data was transformed into biophysical eigen vectors, in line with the well established Tasseled Cap components. The eigen vectors were defined from global spectral end-members representing the global tropics. From the biophysical eigen vectors representing soil brightness and wetness, a novel surface wetness index was developed. Taking a full annual time-series of this surface wetness index, the annual flooding and inundation phenology of the global tropics was estimated. The bio-physical eigen vectors were also used for spectral un-mixing of vegetation and soil. This was done for a full annual time-series of MODIS reflectance images (23 tiles per annum) for the entire tropics. The soil spectral signal was used to test a chrono-sequence of automated Spectral Angle Mapper classification of wetlands in regions with adequate reference data. The classification is stratified spatially and temporally, and reference sites are only used for classifying wetlands in the same region, and in corresponding climatic phenological phases. The reference data even for these restricted regions (Indonesia and Botswana) are, however not verified at a pixel scale.

To test the potential of the developed classification scheme, verified ground reference data is needed. Existing data have only allowed visual comparisons. A third wetness index was developed for radar (L-band) data, but the available global dataset was plagued by positional errors precluding its adoption.

Several of the techniques and methods developed in this study can potentially be improved, and hence lead to a better prediction of the distribution of global tropical wetlands. All further development efforts are hampered by the lack of verified (space and time relevant) ground reference data. Without such data none of the suggested improvement can be done. The suggested improvements are listed in what is felt to be the order of importance and feasibility to achieve an improvement, with the most important first, and the least important last.

3. Budget Summary

A separate Financial Report is prepared alongside with this Technical Report. In general, it is categorized in the following items:

- Coordination
- Field Implementation
- Research Collaboration
- Tech Transfer/ Institution Strengthening
- Equipment/ Supplies/ Services
- Administration Support
- Administration Fees

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