Review of Methods and Potential Role of Remote Sensing for Forest Carbon Stock Measurement: A Pilot Project for REDD+, Thailand

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Abstract
Reducing Emissions from Deforestation and forest Degradation in developing countries (REDD+) has been widely discussed as an important option to mitigate climate change. The idea of REDD+ is to reward forest-borne greenhouse gases (GHG) as an emitting agent. REDD+ is one of the potential organizations in the reducing emissions with low cost and achievable in short time frame. REDD+ also contains much potential in promoting environmental co-benefit activities such as biodiversity conservations and enhancement of soil and water qualities. At present, many REDD+ demonstrated activities are being implemented at global levels. Efforts were made to develop and apply a proper monitoring system to estimate the emissions from deforested and forest degraded lands. It had been reported that the cost-effective monitoring system in REDD+ required a balance between remote sensing and ground based measurements. The system would provide reliable and lucid area information including forest type distribution that elucidated the carbon stocks of any countries. Both ground based and remote sensing measurements of forest attributes might be converted into national carbon stock estimates using allometric relationships. In this paper, the map and updated biomass carbon databases of prominent forests were synthesized to create the first complete set of national level forest carbon stock estimates.

1. Introduction

Advances in forestry are known to provide rural people much potential in both struggling out their poverty and mitigating farm damages caused by uncontrollable weather conditions. According to IPCC Fourth Assessment Report and other documents (Moutinho and Schwartzman, 2005, Metz et al., 2007, Parry et al., 2007 and Solomon et al., 2007), growth and deterioration of tropical forests can be significantly influence the climate changes in term of greenhouse gas absorption and emission, respectively. The tropical forests provide many natural resources which are continuously destructed by rural people and can be alleviated by proper agroforestry adoptions (Smith and Scherr, 2003, Angelsen and Kaimowitz, 2004 and Montagnini and Nair, 2004). The agroforestry principal is based on the use of farmed trees in combination with indigenous trees in order to provide a variety of potential incomes from both timber and non-timber products (Michon and de Foresta, 1996, Leakey and Simons, 1998 and Simons and Leakey, 2004). In addition to the traditional products, the agroforestry also has its important role in maintaining ecosystem varieties (Jose, 2009) and climate mitigation through carbon sequestration (Sharrow and Ismail 2004, Kirby and Potvin 2007 and Nair et al., 2009). The stored carbon can possibly be released into the atmosphere as carbon dioxide (CO_2) through bio-catabolism and any type of combustion afterwards. It was estimated that around 1-2 billion tons per year of the carbon dioxide was released due to the tropical deforestation during the 1990, approximately 15-25% of annual global greenhouse gas emission (Fearnside and Laurance, 2004). The recent estimation indicated that various implemented programs in Brazil and Indonesia could counteract about 80% of the carbon emission from deforested lands, this was in line with the Kyoto Protocol (Santilli et al., 2005 and Teerawong et al., 2012). Moreover, smashing the tropical forests is also the major cause of globally important carbon sinks destroying. The sinks currently sequester the atmospheric CO_2 which are in critical condition so that this will affect future climate stabilization (Stephens et al., 2007). "Deforestation avoidance" projects were excluded from the 2008-2012, the first commitment period of the Kyoto Protocol, because of concerning it too weak in fossil-fuel reductions, sovereignty, and methods to measure the emission reductions (Niles, 2002 and Gullison et al., 2007). More recently, the importance of emission reductions due to the tropical deforestation is continuously increased and it is included in most of future climate change policies. The United Nations Framework Convention on Climate Change (UNFCCC) recently agreed to study and consider a new initiative, led by forest-rich developing countries, which calls for economic incentives to help in facilitating the Reductions of Emission from Deforestation in Developing countries (REDD+). REDD+ is a set of steps designed to use market financial incentives in order to reduce the emissions of greenhouse gases from deforestation and forest degradation. However, political cooperation and implementation of climate stabilizing policies were aimed to reducing carbon dioxide emitted from deforested lands, this requires resolutions involved in many scientific challenges. Foremost among these challenges is identifying feasible approaches to assess national-level carbon emissions from deforestation in developing countries. To estimate emissions, it is necessary to know the damaged forest areas and the amount of stored carbon in those forests. The purpose of this paper is to synthesize options to estimate national level forest carbon stocks in developing countries and propose methods to link the forest carbon to the deforestation estimates. Finally, this paper also illustrates the operation of the forestry sector based on carbon storage in Thailand.

2. The Measurements Method of Forest Carbon Stock

Above ground carbon stored in the living biomass of trees is typically the largest pool which is most directly impacted by deforestation and degradation. Thus, estimating above ground forest biomass carbon is the most critical way in estimating carbon stocks and fluxes from tropical forests and measurement protocols for other carbon pools have been described (Brown and Logo, 1984, Brown, 1992, Brown, 2002; Segura and Kanninen, 2002). In many cases, widely used aboveground biomass values from look-up tables and correlations may be sufficient. For example, root biomass is typically estimated to be 20% of the aboveground forest carbon stocks (Achard et al., 2002) based on a predictive relationship established from an extensive literature review (Mokany et al., 2006). Similarly, dead wood carbon stocks (down trees, standing dead, broken branches) are generally assumed to be equivalent to about 10-20% of the aboveground forest carbon in mature forests (Houghton et al., 2001 and Achard et al., 2002). Soil carbon stock estimation was not discussed here, but it might be critical to consider for regions such as Southeast Asia's peat swamp forests where the soil was a massive carbon emission source after deforestation has taken place (Page et al., 2002 and Mokany et al., 2006). The most direct way to quantify the forest carbon stored in aboveground living biomass (hereafter referred to as forest carbon stocks) is to harvest all trees in a known area, dry them, and weigh the remained masses. The dried masses can be converted to carbon content by taking half of the biomass weight (carbon content about 50% of biomass). While this method is accurate for a particular location (such as small area with low amount of aboveground living) because this method is limited due to its time-consuming, expensive, destructive, and impractical for country level analyses. None of methodology can directly measure the forest carbon stocks across a landscape. Consequently, much effort has directed into tool and model developments. Those tools and models can "scale up" or extrapolate the destructive harvest data points to larger scales based on proxies measured in the field or from Remote Sensing instruments (Saatchi et al., 2007). Although most of the previous works usually focuses either on project level or single site approaches (Pearson et al., 2005, Saatchi et al., 2007 and Laosuwan et al., 2010) this paper reviewed and summarized a range of approaches that were able to be adapted to estimate forest carbon stocks across tropical countries (see in Table 1). Remote Sensing instruments mounted on satellites or airplanes can estimate tree volumes and other proxies be converted using statistical relationships among ground based forest carbon measurements, these approaches varies in benefits and limitations.

3. Global Estimates of Forest Carbon Stocks

Basically all emission estimates from tropical deforestation are based on a handful of biome average datasets where each one represents a value of forest carbon per area unit (tons of C per hectare) and they are applied to broader forest areas or classes (Ramankutty et al.,2007).

Table 1: Benefits and limitations of available methods and data sources to estimate national-level forest carbon stocks (Adapted from Gibbs et al., 2007)

Method	Description	Benefits	Limitations	Uncertainty
Biome Averages	Estimates of average forest carbon stocks for broad forest categories based on a variety of input data sources	- Immediately available at no cost - Data refinements could increase accuracy - Globally consistent	- Fairly generalized - Data sources not properly sampled to describe large areas	High
Forest Inventory	Relates ground-based measurements of tree diameters or volume to forest carbon stocks using allometric relationships	- Generic relationships readily available - Low-tech method widely understood - Can be relatively inexpensive as field-labor is largest cost	- Generic relationships not appropriate for all regions - Can be expensive and slow - Challenging to produce globally-consistent results	Low
Optical Remote Sensors	- Uses visible and infrared wavelengths to measure spectral indices and correlate to ground-based forest carbon measurements - Ex: Landsat, MODIS	- Satellite data routinely collected and freely available at global-scale - Globally consistent	- Limited ability to develop good models for tropical forests - Spectral indices saturate at relatively low C stocks - Can be technically demanding	High
High-Res. Airborne Optical Remote Sensors	- Uses high-resolution (~10-20 cm) images to measure tree height and crown area and allometry to estimate carbon stocks - Ex: Aerial photos, 3D digital aerial imagery	- Reduce time and cost of collecting forest inventory data - Reasonable accuracy - Excellent ground-verification for deforestation baseline	- Only covers small areas (10,000s ha) - Can be expensive and technically demanding - No allometric relations based on crown area are available	Low to Medium

The term "biome" refers to a broad of forest categories (tropical evergreen broadleaf, tropical dry forest). Biome averages, however, are freely and immediately available and currently provide the only source of globally consistent of forest carbon information. For these reasons, despite exited uncertainties, biome averages are still the most routinely used forest carbon stock data source. The biome average carbon stock estimates from prominent data sources were compiled. Therefore, attempts were made to trace the original source data and explain all modifications made by the biomass data set producers, but that was not possible in every instances. Assumptions about carbon storage in different pools were standardized to allow practically precise comparison. Gibbs and Brown (2007a, 2007b) estimates account for variations within forest classes such as human disturbance and natural ecological conditions. Accurate assessment is impossible until additional field data are collected across the tropical areas, so determining which dataset provides the most certain estimate is also impossible and these are only estimates of the country level forest carbon stocks to date. It provides an important reference point for policy discussions. The estimates are based on the IPCC (2006) default values provide IPCC Tier 1 estimates of national carbon stocks that can be used instantly. The ground-based and Remote Sensing approaches described in next section will help in forest carbon stocks estimate refining REDD+ and other incentive mechanisms to reduce emissions from deforestation.

4. The Forest Measurement in Inpang Community Network (ICN), Thailand

The conceptualization in forest measurement and inventory data investigate two corresponding meeting and training of farmer (APN, 2009). The method based on two main components described in detail follows; 1) developing of a survey instrument, data collection, and database creation and 2) developing of the carbon sequestration management applications. (Samek et al., 2011). A survey instrument was developed into English and Thai language in order to be suitable for basic small holder agroforestry data collection. The collected dada included ownership, location, farm size, and use history in farm area, and tree data (species, number of trees planted, age of trees, and use). The survey forms were distributed to ICN members in October 2007 and total of 957 forms were completed (Laosuwan et al., 2011).

4.1 Developing of a Survey Instrument

The data was inserted into an access database and organized in three related tables; ownership (name, address, size of farm area, land use history data), list of tree species (Latin and local names), and an agroforestry table (owner id, specie planted, age of trees by species, number of trees planted by species, and use of tree species) (see Figure 1). This is primary data first developed to be ICN information system which still lacks in carbon counting or registration. Conversely, the data can allow the researchers to stratify the ICN diversity of agroforestry practice in multiple ways such as by geographical, by species diversity and by the size of area views. By using the location information from developed database, an ICN GIS was successfully developed.

4.2 Developing of the Carbon Sequestration Management Applications

Firstly, the implementing procedure for small farm carbon offset project has been developed by researcher team who are working in a program at Michigan State University called Carbon2Markets (www.carbon2markets.org) lead by Prof. Dr. David L. Skole and Dr. Jay H. Samek from the Department of Forestry, Michigan State University. The Carbon2Market (Figure 2) approach was evolved by linkages among international organizations, various institutes, and local and national work groups. The approach employs Geoinformatics technology (i.e. Remote Sensing: RS , Geographic Information System: GIS and Global Positioning System GPS) and is manipulated its GIS content via internet system (a mash-up or web application hybrid) through various operating systems, software, and scripts (i.e. Arc GIS Server, Windows Server, Microsoft SQL Server2005 RDBMS, ASPX, JavaScript Object Notation, Micxrosoft.NET Framework and KML/KMZ.

5. Satellite Remote Sensing Methods

The forest changes can be monitored by remote sensing, at least in part, or by systematic forest inventories with large enough sample size to detect any significant changes in the forest according to the forest types. Monitoring the area changes due to forest degradation (i.e. the change from intact forest to disturbed forest) is much more challenged for remote sensing than deforestation monitoring. Deforestation can be easily detected from space, particularly when it exists in large scale. However, forest degradation, such as the removal of a few trees per hectare (selective logging) or undergrowth (by fire) or taking out of branches and small trees (for fuel wood) is very difficult to observe remotely.

Tree Species	Number of Plantation	Years	DBH (cm.)	H (m.)	GPS	Used (kgs.)								Growth
						Fruit	Woodfire	Sap	Constructi	Spice	Herb	Seed	Other	
Pterocarpus macrocarpus Kurz	12	17	27.36364	14.30	N 17 04 841 E 103 46 043		/		/		/	/	Food for	Slow (plantation /natural)
Irvingia malayana Oliv. ex A.W.Benn.	16	15	8.590909	5.80	N 17 04 836 E 103 46 044	/	/		/			/		Slow
Xylia xylocarpa (Roxb.) Taub. var. kerrii (Craib & Hutch.) I.C.Nielsen	20	25	0.480455	20.80	N 17 04 853 E 103 46 057	/	/		/		/	/	Leaf for	Well (plantation /natural)
Adenanthera pavonina L.	13	8	14.31818	9.80	N 17 04 849 E 103 46 052		/		/		/	/		Well
Irvingia malayana Oliv. ex A.W.Benn.	1	50	1.170909	24.60	N 17 04 828 E 103 46 073	/	/		/		/	/	Food for	Slow
Hopea odorata Roxb.	60	12	16.86364	9	N 17 04 856 E 103 46 097		/	/	/			/		Well

Figure 1: Example data collection form

Figure 2: Illustrate carbon2markets system (www.carbon2markets.org/project)

Table 2: Type of remote sensing data and their monitoring (Adapted from DeFries et al. 2007)

Sensor	Resolution	Example	Benefits	Limitations	Cost
Optical sensor	Fine (< 5 m).	Ikonos, Quickbird, Aerial photos.	Validation over small areas of results from coarser-resolution images.	Country coverage not available, and demanding to process.	High to very high (2-30/km2).
	Medium (10-60m). Landsat TM, SPOT HRV, AWiFs LISS III, CBERS.	Primary tool to identify deforestation at regional/ country scale, possible to detect some types of degradation.	But only small area covered per image so work- and costintensive to cover a region. Less suitable for cloudy areas.	Landsat and CBERS free from 2009.	Low (< 0.00 1/km2) for historical to medium (0.5/ km2) for recent data.
	Coarse (250-1,000m). Terra-MODIS (2000-).	SPOT Vegetation (1998-).Envisat MERIS (2004-).	Consistent pan-tropical annual monitoring to identify large clearings and locate hotspots rapid assessments and daily coverage helps overcome issues of cloud cover and seasonal forests.	Unlikely to detect forest degradation and small-scale deforestation.	Low or free.
Radar sensor	High (~30m).	ERS, JERS Radarsat, ALOS PALSAR (2007-).	Radar can penetrate through cloud cover and complement other data options (e.g., full pan-tropical ALOS data for 2007).	Requires high level of expertise; limited applicability in areas with significant relief	Ranging from expensive to free.

These activities only least affect the covering canopies but they can affect the forest carbon stock significantly (Samek et al., 2011). Remote sensing methodology has been a successful tool in measuring carbon stocks of boreal and temperate forests including young stands with lower carbon densities. The optical satellites, such as LANDSAT, ASTER, and MODIS, cannot be used in tropical forest carbon stock estimating with any degree of certainty. Many attempts have been made to estimate forest carbon stocks indirectly by developing statistical relationships between grounds based Normalize Differential Vegetation Index (NDVI), but this method tends to underestimate the tropical forest carbon stocks. The optical satellites are lesser effective in dense closure canopy forest and has been unsuccessful in generating broad or transferable relationships (Laosuwan et al., 2011). Nonetheless, the optical remote sensing systems can effectively operate at the global scale and with some satellite systems (LANDSAT and ASTER) so that it can provide globally consistent records for last 30 years. The Remote Sensing data is available in wide range (Table 2).

6. The Pilot Project Carbon Credit in Forest Sector, Thailand

Samek et al., (2011) was developed "Biotic Carbon Sequestration in small scale agroforestry system in Inpang Community Network northeast Thailand (ICN)". The pilot project works by cooperation among researchers from Michigan State University of United State (MSU: USA); National Resource Council of Thailand (NRTC, Thailand); Faculty of Science, Mahasarakham University (MSU: Thailand) and the farmer groups in the ICN (illustrate location in Figure 3). The Figure 4 was shown carbon sequestration of ICN in 20 years. In this work, an online Measurement, Reporting, and Verification system (MRV) system have been developed by twinning emerged internet earth observation technologies and location based technologies led by Prof. Dr. David L. Skole, (APN, 2009). The project builds upon the following current trends:

- Satellites are now offering global, near real time data with high spatial resolution which allows accurately land uses, land use changes and forestry tracking of all around the world.
- Satellite imaging is decreasing in cost while more extremely high-resolution imaging systems have been launched into orbit. The internet enabled GIS mapping is now available for integration of multiple geospatial data layer types, including land cover, land ownership, population, infrastructure, and other features. The geospatial content management software is increasingly available.
- GPS enabling and location-based services are available on widely spread internet GIS.
- Telecommunications, wireless hand held devices, and increasing internet connectivity enable information flow from the field to central databases.
- Increasing of hardware's computing power with lower cost as well as ability to manage larger and more complex data sets such as remote sensing images.

This project has been developed to be a baseline reference, which is used as a reference point in assessing the reduction amount and baseline greenhouse gas emissions. This reference is important for REDD+ operating mechanism to identify baseline reference patterns that will provide maximum benefits to Thailand situation and will advance the greenhouse gas emitting reduction assessment serving the REDD+ mission.

7. Development of REDD+ Project in Thailand

Reducing Emissions from Deforestation and Degradation (REDD+) also mitigates climate change by changing the amount of carbon dioxide emissions to the atmosphere from the existing forest carbon stocks. REDD+ twins emission reductions (from changing the rate of deforestation and forest degradation over time) with carbon sequestration activities that include social and ecological co benefits (Anglesen et al., 2009). The purpose of this research project is to understand and document the methods required for integrating community based carbon measurement and monitoring with satellite Remote Sensing and GIS for implementing MRV system (REDD+ Project, 2011).The MRV system for forest carbon emission reduction or carbon sequestration project is required for project developers, stakeholders and project participants (including local people), policy-makers, and project funders (including potential buyers of carbon through emerging Greenhouse Gas Financial Markets). The study area is Kok Phuk kud-Pong Deang community forest located in Maha Sarakham province. Covers 3 districts as Wapi prathum, Borabu, and Nacheuk districs (see in Figure 5). The goals of the project are to 1) demonstrate and document the potential opportunity to realize community-based participation in carbon management activities being called for under forest carbon emission reduction and sequestration activities, 2) to link community-based carbon measurement and monitoring with remote sensing and GIS tools for MRV system, and 3) to support policy maker initiatives at national and local levels in implementing sustainable forest and land management through forest carbon management efforts (REDD+ Project, 2011).

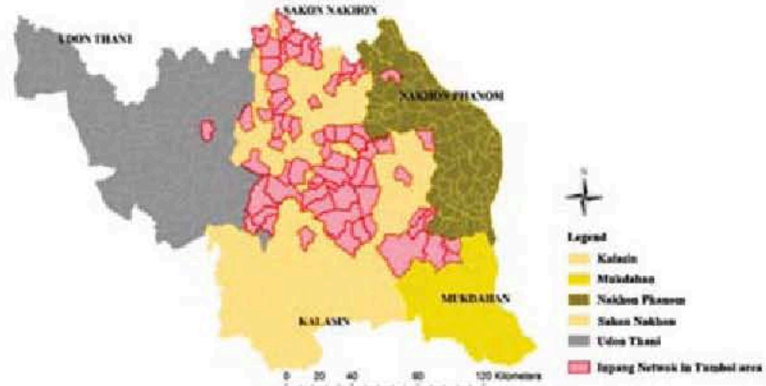

Figure 3: Map of Inpang Member's locations by sub-district in 5 Provinces in Northeast Thailand

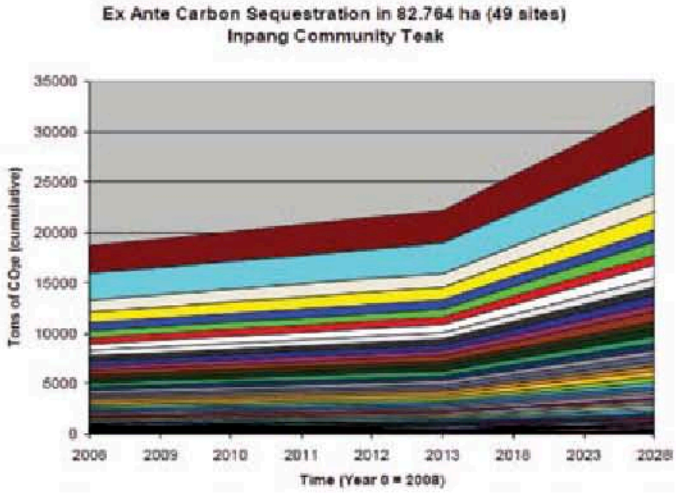

Figure 4: Estimated Carbon Sequestration in ICN from 2008-2028 (20yrs.)

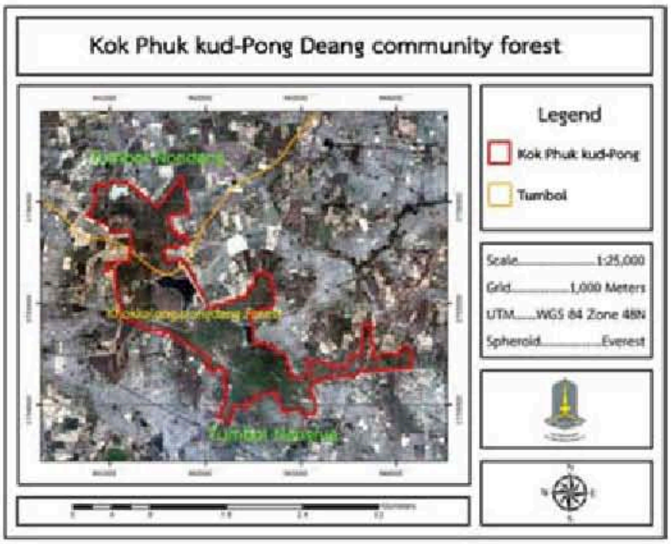

Figure 5: Kok Phuk kud-Pong Deang community forest located in Maha Sarakham province

8. Conclusion

Remote sensing technology is especially appropriate for large scale monitoring, particularly deforestation. Satellite-based forest carbon stock estimations are likely to become more accessible over next decades as new emerged technologies and their technical capacities are strengthened. Still, ground based measurements are important, principally to monitor carbon stocks until emergence of effective satellite based estimation takes place so that to verify the results obtained from interpreted image of deforestation and degradation can be mapped. Key constraints of monitoring in many developing countries especially for REDD+ purpose are accessed to the data at a reasonable cost, appropriate technical infrastructures, consistent capacities and transparent data analysis and management. Providing the accessibility to free or low cost fine resolution imagery is the key, as it helps the countries to set up national REDD+ monitoring infrastructures including technician training. Regional partnerships formed to acquiring and developing appropriate methods, as proposed by (DeFries et al, 2007; Samek et al, 2011), can also help to address some needs. Sharing experiences from Annex I-member countries on their approaches to monitoring validating, and reporting the forest carbon stock changes could be further avenue to provide additional insights and assistance to developing countries. The establishment of an independent international forest carbon monitoring institution, according to the REDD+ purposes could be another avenue to overcome remaining capacity and shortcomings. Monitoring for carbon crediting purpose needs explicit objectives set up from reliable processed information. Leaving these tasks to single REDD+ supplier country may risk from bias monitoring i.e. exaggerated emission reductions to reap the carbon benefits. Independent third party monitoring and certification, for example in form of an international forest carbon monitoring institute, may therefore be a more suitable proposal. Centralizing this task at global level can further benefit from smaller scale economy and render the monitoring at far more cost effective than ensuring coherent monitoring by each separately country. Furthermore, the task centralizing also provides more coherent time-series of deforestation data for baseline reference purposes. Beneficial capacity consists not only in the availability of technical equipments or costly satellite imageries, but also assists often more importantly in knowhow. This refers to the expertise in processing, analysis, and ultimately, the use of resulting data in the political process. The latter implies that the capacity building needs to be occurred not only at the technical level (i.e. in the forest monitoring agencies whether national or international), but also at the political and institutional levels. For example, it is necessary that at least the policymakers have to understand how alternative changes in forest carbon effects the national REDD+ arrangements and how they interrelate with other sectoral policies.

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