WORKING PAPER

Data and Methods to Estimate National Historical Deforestation Baselines in Support of UNFCCC REDD

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1. ABSTRACT

Global climate policy initiatives are now being proposed to compensate tropical forest nations for reducing carbon emissions from deforestation and forest degradation (REDD). These proposals have the potential to include developing countries more actively in international greenhouse gas mitigation and to address a substantial share of the world's emissions which come from tropical deforestation. For such a policy to be viable it must have a credible benchmark against which emissions reduction can be calculated. This benchmark, sometimes termed a baseline or reference emissions scenario, can be based directly on historical emissions or can use historical emissions as input for business as usual projections. Here, we review existing data and methods that could be used to measure historical deforestation and degradation baselines including FAO national statistics and various remote-sensing sources. The freely available and corrected global Landsat imagery for 1990, 2000 and soon to come for 2005, may be the best primary data source for most developing countries with MODIS or other coarser high frequency data as a valuable complement for addressing problems with cloud cover and for distinguishing larger scale degradation. While sampling of imagery has been effectively useful for pan-tropical and continental estimates of deforestation, wall-to-wall (or full coverage) assessments may be best for measuring national-level reference emissions. It is possible to measure historical deforestation and forest degradation with sufficient certainty for determining reference emissions, but there must be continued calls at the international level for making high-resolution imagery freely available, and for financial and technical assistance to help countries determine credible baselines.

2. INTRODUCTION

Deforestation and degradation in the tropics currently account for about 20% of global greenhouse gas (GHG) emissions and constitute the majority of emissions from developing

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counties (IPCC 2007; Gullison et al. 2007). In addition to their critical role in the global carbon cycle and climate system, tropical forests are home to about half of the world's species and provide a livelihood for millions of people. Recognizing the importance of tropical forests and the value of developing country participation in global climate change mitigation efforts, proposals are now being rapidly advanced to compensate tropical forest countries for Reducing Emissions from Degradation and Deforestation, or REDD as part of a future international climate agreement (UNFCCC Country submissions, 2007; Olander and Murray, 2007, Gullison et al. 2007). One of the critical questions for the adoption and success of REDD is whether the emissions from deforestation and forest degradation can be measured with sufficient accuracy.

REDD measurements will likely be based on the carefully crafted and negotiated methodologies for land use, land use change and forestry (LULUCF) under the UNFCCC, which are the 2006 The Good Practices Guidance (GPG) for Land Use, Land Use Change, and Forestry and the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. The measurement system set up in the GPGs uses three tiers that range from coarse-resolution data using general equations to substantially refined local data used in sophisticated models. The benefits of using these methods as the basis for REDD are: (1) they have been developed and reviewed by experts (2) they have already been accepted in UNFCCC negotiations, (3) they have been tested over the initial phase of the Kyoto Protocol and (4) a tiered system provides flexibility for differences in technical capability among countries. The existing methods cover all types of land-use changes and transitions and account for both carbon emissions and sequestration, while the REDD system currently under discussion focuses only on emissions from deforestation and degradation of forests (Milne and Jallow 1996).

For measuring REDD, countries will need to know: (1) the aerial extent of forest loss and forest degradation (hectares), (2) for degradation, the proportion of forest biomass lost (percentage), (3) where the deforestation or degradation occurred (which forest type), (4) the carbon content of each forest type (metric tons of carbon per hectare), and (5) the process of forest loss which affects the rate and timing of emissions (Ramankutty et al. 2007). Ultimately, the quantities of interest are units of carbon emissions avoided by reducing deforestation and degradation. This paper focuses on the measurement of historical forest change, while another paper in this issue addresses quantification of forest biomass carbon stocks (Gibbs et al., this issue). To quantify emissions it is critical that the methods for quantifying land cover change discussed herein can be effectively linked to carbon stock and flux estimates.

Measuring a reduction in emissions from deforestation and degradation raises the question of what the reduction is compared to. The terms "baseline" or "reference scenario" refer to a situation without a particular policy in place, either before the policy was enacted, or a prediction of what would have happened without the policy in place. In the case of REDD, reduction in emissions from deforestation below the baseline or reference scenario could be considered additional and eligible for compensation. For example: if the baseline emission from deforestation for country X is 20,000 metric tons of carbon per year and their emissions in their first year of accounting were 18,000 metric tons, they could receive compensation for 2,000 metric tons.

While measuring and monitoring of forest change in the coming years will be able to take advantage of new remote sensing tools, baselines or reference scenarios, which are based on historical trends, depend on existing data. In this paper we provide some general guidelines and background regarding how deforestation and degradation could be measured using existing data.

3. DEFINING DEFORESTATION AND FOREST DEGRADATION FOR MEASUREMENT

Clear measurable definitions of deforestation and degradation are essential. Current definitions may not be appropriate depending on the assessment method used. In the REDD context, deforestation has been defined as a "measurable sustained decrease in crown cover" below a 10-30% threshold (UNFCCC 2006). Deforestation defined in this manner may be difficult to measure using available data. With existing inventories and remote sensing it will not always be possible to accurately estimate percent canopy cover across a country and the different forest types and terrain that it encompasses. Degradation, defined as a decrease in crown cover that does not fall below the 10-30% threshold, is even more challenging to measure.

Specific measurement definitions may need to be developed guided by the policy goals, available data, and methods reasonably attainable by the countries. The IPCC Good Practice Guidelines contain some important rules of thumb: "…land should be categorized in such a way that is reasonably consistent with IPCC guidelines[5], robust for carbon estimates, mappable by remote sensing, and inclusive of all land area to reduce error." (Milne and Jallow 1996). Mappable by remote sensing is key for tropical nations because most lack good inventory data.

4. A FRAMEWORK FOR ESTIMATING BASELINES OR REFERENCE EMISSONS SCENARIOS

For REDD the baseline or reference emissions scenario under discussion is a national-level trend based on or projected from historical trends in emissions from forest change (UNFCCC Country submissions, 2007; Olander and Murray, 2007). These trends should be measured over multiple years (5 to 10) in order to reduce the impact of anomalous years The reference period selected will likely be determined in negotiations, but a more recent reference period (in the last 5 to 10 years) would likely better reflect current land-use trends and be most feasible given constraints in available data.

[5] So that it aligns with activities already being accounted for like those in CDM.

Because emission reductions from deforestation and degradation would be matched by financial compensation, a credible method for measurement is absolutely essential. Historical reference trends should have the following characteristics:

Accuracy and Precision –All reasonable efforts should be made to ensure that estimated changes in forest cover and greenhouse gas fluxes closely reflect what is happening on the ground. The measurement error or uncertainty need to be quantified to determine how much confidence can be placed in REDD credits. Uncertainty is unavoidable and will vary by country. The uncertainty could be used to qualify the REDD values – a discounting or grading system could adjust the values for REDD credits accordingly.

Comprehensiveness – The baseline should cover all relevant activities. For instance, if all deforestation in the country is to be included, than all sources of deforestation in a country must be represented by the data used to develop the baseline estimate. If degradation is to be included, then the data need to have high enough resolution to detect and quantify the amount of area degraded.

Environmental Integrity – For the REDD system to work in favor of climate protection, it must ensure that the corresponding greenhouse gas reductions are real. Given the various forms of uncertainty described herein, prudence suggests that baselines be set conservatively (not too high) as a safeguard against rewarding too much REDD credit and diminishing global greenhouse gas mitigation efforts.

Transparency – Minimum standards of transparency will aid in the verification and ensure fairness and integrity of the REDD system; this includes documentation of data and methods and making them available to third parties.

Flexibility – A wide range of circumstances -- including differences in data availability, dominant type of land use, terrain, and the capacity to incorporate remote sensing methods-- will apply across and within countries affecting their ability to estimate baselines. A REDD system will need to be flexible in allowing and accounting for variability in methodologies and accuracy.

Feasibility – The proposed approaches for estimating baselines must be possible with a reasonable level of effort and expense or else they will simply not be done well or done at all. Feasibility factors include data availability, analytical capabilities, cost of data collection and analysis, and institutional support for these efforts.

Compatible – The proposed methods to estimate deforestation and degradation must be compatible with methods used to estimate forest carbon stocks. Definitions of deforestation and degradation must also be measurable using available data and methods.

5. DATA OPTIONS FOR MEASURING HISTORICAL FOREST CHANGE

The data needed for measuring forest change for a historical reference period must have national coverage, reasonable spatial resolution, and acceptable error for a minimum of two time points (likely 5 to 10 years apart). The FAO estimates deforestation using national statistics for all countries, and while the data are available freely, they are of mixed quality. In many cases a better alternative may be spectral remote-sensing data. The follow sections will describe these data options in more detail.

5a FAO National Statistics

The FAO has been conducting global forest assessments every five to ten years since the first survey in 1947. National statistics are largely based on forest inventory data, models, and expert opinion (FAO 2000). The national statistics provide estimates of forest area and net deforestation rates by country for 1990, 2000, and 2005 (FAO 2005). While valuable for their coverage over time and in country capacity building, the FAO data have been cited for their lack of consistency between countries and between assessments - changing definitions of forest, different methods to assess deforestation, and for unreliable and missing data in some cases (Grainger, 1996; Matthews, 2001). Further, the published country-level estimates provide no detail on degradation and are difficult to validate.

5b Remote Sensing Data

Remote sensing instruments mounted on satellites provide images of the Earth's surface and its forest cover starting as far back as the 1970s and in most cases are the most reliable data source for REDD. However, remote sensing imagery can be expensive and technically challenging to analzye, and the error and uncertainty in the data and analyses are not always well characterized.

Numerous satellites sensors that can be used to detect land cover change are run by India, Brazil, Australia, Nigeria, the EU (and many of its member nations), the United States, and Japan. See Table 1 for an overview assessment of the data types and their benefits and limitations. Existing Landsat data products that have pre-processed and aligned remote sensing imagery globally (Tucker *et al* 2004) may provide a good first cut and reduce the cost, technical expertise, and time needed to develop baselines for a REDD system. These corrected and compiled Landsat data are, or shortly will be available, free with global coverage for multiple time periods (1990, 2000, and 2005 underway), and may be the best option for first assessments by most countries. Data from other satellite sensors can be used to fill gaps from cloud cover in the Landsat database, to help assess forest degradation, and to validate and determine the uncertainty in the Landsat measurement.

Table 1. Types of remote sensing data that can be used for measuring baseline forest change

DATA TYPE	SCALE	BENEFITS	LIMITATIONS	COSTS
Spectral	Coarse Resolution (e.g. AVHRR, MODIS, SPOT-VEGETATION) For Example: *~1km resolution* *~2300km Image width*	- Image processing can be automated and completed quickly for rapid assessment - Daily coverage helps overcome	- Small areas of forest change (i.e. small – scale agriculture) likely missed biasing estimates of deforestation -Unlikely to detect	Free to low cost

DATA TYPE	SCALE	BENEFITS	LIMITATIONS	COSTS
	~Daily Frequency	issues of cloud cover	forest degradation	
	Moderate to High Resolution (e.g. Landsat, ASTER, IRS, CBERS) For Example: *~30m resolution* *~180km Image width* *~Biweekly Frequency*	-Possible to conduct regional/country scale assessments -Possible to detect some types of degradation - Image processing automation is possible - Global pre-processed Landsat available	- Smaller area covered per image, thus slower and more expensive to fully cover a region -Cloud coverage is a problem, especially in humid tropics	Free to moderate cost
	High Resolution (e.g.,.IKONOS, Quickbird) For Example: *~4m resolution* *~11 km Image width*	- Excellent validation of large scale assessments - Possible to detect degradation -Good for validation	- Covers very small areas - Country coverage not available - Demanding to process - Only collects targeted or tasked locations	Expensive – must be tasked
Radar	Radar (e.g. ERS, JERS, Radarsat) For Example: *~ 30m resolution* *~ 75 m image width*	RADAR signal penetrates through cloud cover; existing data may be able to enhance other data options, but not sufficient by itself	Requires high level of expertise, may not work well in mountainous regions	Moderate to expensive
Aerial photography	For Example: *Variable high resolution*	Good for validation of forest change and degradation	Usually not large areas covered, requires time and expertise	Moderate

Data options for 1980s and 1990s

Landsat and AVHRR (Advanced Very High Resolution Radiometer) are the only satellite data options for estimating forest change baselines for the 1980s and 1990s. The daily coverage and long-term record are major advantages of AVHRR data. However, sensor degradation, inter-sensor calibration problems, geo-location errors, and noisy pixels limit AVHRR to identifying large-scale deforestation or rough, initial estimates of forest change (Agbu and James 1994). Hansen et al. (2004) concluded that AVHRR data likely result in a systematic bias underestimating deforestation. Thus, the best option during this period is data from the Landsat series of satellites, which provide an imagery archive of good quality starting in 1972. Landsat imagery has been used to identify forest clearings as small as 1 hectare or sometimes less in size (Steininger, et al. 2001; Leimggruber, et al. 2005).

Data options for late 1990s and 2000s

Due to its higher resolution and relatively good availability Landsat still provides the most viable data option for REDD, but Landsat 7 (most recent satellite) has experienced technical difficulties since 2003[6]. Corrections have been made and much of the Landsat 7 imagery is still usable. The older Landsat 5 satellite has continued to collect imagery up through most of 2007, but data acquisition was recently suspended according to the United States Geologic Survey. Imagery from new coarser resolution sensors (MODIS, SPOT-VEGETATION) and new moderate to high resolution (i.e. ASTER, CBERS) sensors that came on line in the late 1990s will likely be necessary to supplement the Landsat data (reviewed in DeFries et al. 2005; 2006).

The coarser resolution imagery from MODIS and SPOT-VEGETATION provide global coverage for the current decade. As is the case with AVHRR data, these data are best for less precise and more frequent measurements. They are helpful for finding and assessing areas with the greatest rates of change and for filling in temporal and spatial gaps where the higher resolution data is unavailable or insufficient. This data can be very helpful for cloudy regions, seasonal forests, and measuring degradation (e.g. Hansen et al. 2006). For seasonal forests it may be necessary to have imagery for certain times of year (wet season) or for multiple seasons during a year to distinguish degradation and management from normal seasonal variability. For degradation, it can be very helpful to have frequent imagery to assess trajectories of change.

Compiled Landsat Data for 1980-2005

NASA has made global Landsat data for ~1975, ~1990 and ~2000 freely available[7] (Tucker et al. 2004) and 2005 data should be available in 2008 or 2009 (Tucker personal communications). These dates make measurement of a 1990 to 2000, 10 year reference possible now, or a 5 or 15 year reference out to 2005 possible in the relatively near term. These of Landsat images are available in “raw” form or in global mosaics that have already been orthorectified and merged together. The library of unprocessed Landsat imagery used in the global mosaics are freely available and provide a good option for measurements of historical forest change.

However, clouds cover significant areas in imagery for the very humid or coastal tropics. These are some of the same areas critical for countries that may be interested in joining a REDD system. To find imagery with the least cloud cover, images from different years are used. For example, looking at the imagery for Ecuador, that was used in the 1990 global Landsat mosaic, one image is from 1987, and the image that covers this same location in the 2000 mosaic is from 2001 (Table 2). For this image location we are measuring a 14 year reference period using the images in the mosaics, instead of the expected 10. Annual deforestation rates should be used to normalize baselines to a standard time period. For Ecuador, individual images range from 1999 to 2001 for the 2000 mosaic, and from 1986 to 1991 for the 1990 mosaic.

Table 2. Dates and estimated cloud cover for Landsat images for Ecuador that were used in the 1990 and 2000 mosaics (MDA federal 2004).

[6] On April 2003 the failure of the Landsat 7 ETM+ scan line corrector resulted in data gaps outside of the central portion of acquired images, seriously compromising data quality.
[7] http://glcf.umiacs.umd.edu/data/mosaic/

Image	1990 Mosaic	Cloud Cover	2000 Mosaic	Cloud cover
(Path\Row)	(Image date)	%	(Image date)	%
08\060	12-22-1989	0	08-30-2000	0
08\061	12-22-1989	0	08-30-2000	9
09\060	08-07-1989	0-10*	09-09-2001	13
09\061	08-23-1989	0-10*	09-11-2000	22
09\062	09-11-1987	0-10*	08-10-1999	0
10\060	03-23-1986	50-60	11-14-1999	30
10\061	03-26-1987	10-20	09-16-2001	40
10\062	03-26-1987	0-10*	05-11-2001	40
10\063	02-11-1986	0-10*	10-31-2000	10
11\060	03-14-1986	40-50	03-31-2001	16
11\061	02-21-1990	20-30	11-23-2000	0
11\062	04-29-1991	0	11-23-2000	0

Data is pulled from the original single image metadata.
*visual estimates suggest that these images all had a least 5% cloud cover

Clouds cover portions of many images in the humid regions even when images are selected from a range of dates to avoid clouds. For example, again using Ecuador as an example, the imagery metadata show that 2 to 3 images used in each of the mosaics has more than 30% cloud cover (Table 3). It will be impossible to determine a reference trend in forest cover change for regions that have cloud cover on either end point (impossible to determine if there was a change). Overlaying the 1990 and 2000 mosaics for the northwest portion of Ecuador, which is typical of a troublesome cloudy spot, we found that only 44% of the area was cloud free (Figure 1). That means 1,364,029 ha of forest are not accounted for in this region because of clouds.

Large data gaps caused by clouds will need to be filled with other sensor data, such as frequently acquired coarse resolution spectral (e.g., MODIS, or SPOT-VEGETATION) or radar data (e.g., ERS or Radarsat), which may increase the costs of analysis and imagery (in the case of radar data) particularly for countries with continuous cloud cover (Hansen et al. 2006).

The final issue to be aware of when using the mosaic data is the range of seasons in which the images were captured. The images for Ecuador range throughout the year (Table 3). While this is not so critical for a consistently wet tropical forest region like Ecuador, it becomes much more important in countries with areas covered by seasonal forests.

Despite these considerations, freely available Landsat imagery used in the periodic global mosaics may be the best data available for providing a spatially explicit and transparent assessment of changes in forest cover in the short-term. If these data are supplemented with other remote sensing data and ground inventories in the next few years they can provide reliable historical reference assessments for deforestation and degradation for determining baseline emissions.

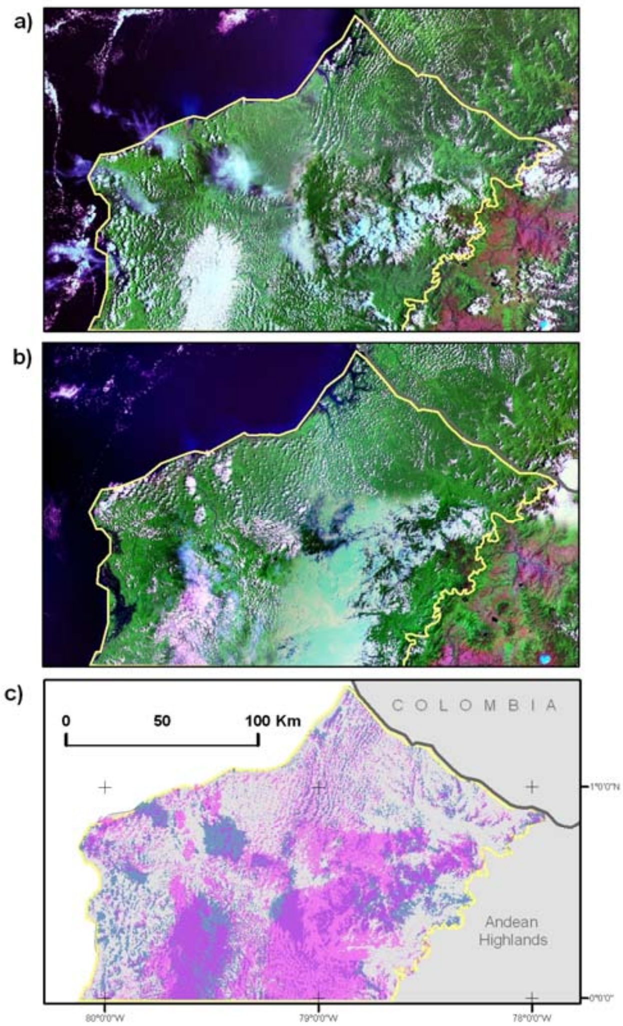

Figure 1. Landsat GeoCover Mosaic data for Northern Ecuador for a) 1990, b) 2000, and c) cloud cover for both images overlaid.

6. METHODS FOR USING REMOTE SENSING TO MEASURE FOREST CHANGE

To detect a change in forest cover (deforestation or degradation) with existing data, images are needed for two or more time periods. By overlaying the images and determining the differences between them, the change between the two dates can be determined. This "difference" image can then be classified to show loss of forest, degradation of forest or other changes.

The two major approaches used to assess deforestation over large scales are "wall-to-wall" and sampling methods. In wall-to-wall methods, images covering an entire country or region are analyzed. Sampling approaches use systematic sampling where a regularly spaced grid to identify plot locations across an entire region (Mayaux et al. 2005) or random sampling which are usually stratified by topography, soil type, broad forest type, or degree of disturbance (hot spots), and the intensity of sampling can vary by strata with more sampling in areas of greater interest (FAO 2001, Achard et al. 2002). Wall-to-wall sampling has primarily been used for sub-national or national level assessments while sampling approaches have primarily been used for continental or global scale assessments.

A major motivation for using a sampling approach is to reduce costs and time associated with processing wall-to-wall imagery. While a 10% sampling rate, like that used by the FAO, would be sufficient for continental and global assessments, it is not sufficient for national level assessments (Tucker and Townshend, 2000; Czapleweski, 2003). Another concern about sampling is that any stratified sampling for the baseline may constrain future monitoring so that it must be consistent with the originally selected stratification. Given this, full wall-to-wall processing may be the best option for determining national reference period baselines.

Accuracy in Deforestation Measurement

For an individual Landsat scene or local area, forest vs. non-forest determination can have an accuracy of 90% to 95% (Roy et al. 1991, Sader et al. 1991, Steininger, 1996). Patches of forest clearing of around 1.0 ha can be detected. At the national level with variation in topography and forest type across the landscape, accuracies can be a bit lower, ranging from 85% to 90% (e.g. Steininger et al. 2001; Leimgruber et al. 2005). The minimum patch size usually detected at the national scale is around 2 to 5 hectares. For coarser resolution forest cover change detection using MODIS data, recent modeling approaches in the tropics produced errors as low as 7 to 11% for annual changes at 250 and 500m resolution (Hayes and Cohen 2007, Hayes et al. in press).

For validation or accuracy assessment of a given map, much finer resolution data must be obtained. For maps created from moderate to course-scale remotely sensed data (e.g. Landsat) this would consist of field surveys or high resolution aerial photos or imagery. For many countries, conducting national ground surveys of current deforestation extent is not feasible. Aerial photos, traditionally used as a source for map assessment, have become more accessible with the advent of digital cameras or airborne videography, though still remains expensive. High resolution imagery such as IKONOS or QuickBird is costly and only covers a small land extent. An excellent source of free viewable data, where available, is the high resolution imagery from Google Earth. The imagery is continuously updated and improved to higher resolutions (as fine as 50cm), and is available across many portions of the world. While the imagery cannot be fully linked into image processing packages, it has great potential for map validation in some areas.

Accuracy in Degradation and Managed Forest Measurement

Measuring the extent of forest degradation and forest management is much more difficult than measuring deforestation. Within areas considered "tropical rainforest" there are a range of canopy densities and ecosystem types. This natural variation in forest cover can be due to underlying biophysical elements (e.g. semi xeric, semi-deciduous, shrublands, limiting soil conditions such as the white sand forests of the Amazon). These ecosystems, to many satellite sensors, appear similar to degraded areas of neighboring forest. Human intervention in these more open canopies is very difficult to distinguish. This type of confusion could be alleviated to a degree by having an accurate and detailed vegetation map of these various natural canopy types (e.g. Josse et al. 2007, Navarro and Ferreira 2007), something that many rainforest nations lack. Rapid forest growth in moist tropical areas can lead to a perceived dense forest cover, a few years after selective logging or in a forest made up of low density early successional species. These perceived 'in-tact' forests have less biomass and thus their deforestation or degradation will result in lower carbon emissions than a truly 'in-tact' forest.

An ideal way to identify degradation is to analyze annual time series of Landsat imagery to see the transitions. Unfortunately this is very difficult to do with existing data because high-resolution imagery like Landsat is not recorded frequently enough to provide the needed cloud-free imagery. Even light clouds or haze over tropical forests can be a problem because it is often confused with degraded forests during satellite image classification. Coarse resolution data like MODIS has imagery taken on a sufficient temporal frequency to have enough good images for a frequent time series (ideally multiple images per year to distinguish degradation from effects of seasonality). However, at coarse resolution much forest degradation, which is often small scale, can be missed.

It is even more difficult to determine the carbon emissions to assign to different types and degrees of forest degradation and the accuracies of such an effort, but efforts are underway to improve this (Gibbs et al., this series). It seems plausible that degradation be included in a REDD system but would only be credited in countries that can demonstrate credible measurements with clearly determined uncertainty. This may be more difficult to do, but worth it for countries where forest degradation is the dominant land-use change.

7. EXISTING ANALYSES OF DEFORESTATION AND DEGRADATION USING REMOTE SENSING

A number of pan-tropical or country level analyses of deforestation have been done using remote sensing data. We will briefly discuss some of the main efforts and their limitations for developing national level reference period baselines.

7.1 Sampling approaches

The FAO conducted a remote sensing analysis by sampling Landsat data stratified by broad forest types to estimate deforestation in the 1980s and 1990s (FAO 2001). The Landsat scenes were classified visually and included a number of different land cover types from which it may be possible to distinguish degradation in addition to deforestation. This was a pan-tropical analysis and the sample size was sufficient only for continental level estimates. A more intensive sampling scheme would be necessary for national-level analysis (Tucker and Townshend 2001; Czapleweski, 2003).

The European Union's Joint Research Center in its most recent global assessment used coarse resolution satellite data from 1990-1997 to create a base map upon which experts selected regions of greatest deforestation, "hot spots", across the tropics (Achard et al 2002, 2004). The tropics were then stratified into "hotspot" and "non hotspot" regions, and Landsat scenes were sampled more intensively in the hotspot areas. As with the FAO analysis, these scenes were classified visually and included a number of different land cover types from which it may be possible to distinguish degradation in addition to deforestation. The stratification by hotspots means that greater accuracy in the areas of greatest change may be achieved. Achard et al. (2002, 2004) estimate continental-scale carbon emissions from deforestation and degradation, but the sampling scheme was not designed and is not sufficient for national-level assessment.

7.2 Wall-to-wall assessments with Landsat and AVHRR

A pan-tropical wall-to-wall global assessment of deforestation in the 1980s and 1990s was conducted using coarse resolution data (8km AVHRR; DeFries et al. 2002, Hansen and DeFries 2004). As the authors acknowledge, the precision of these data is not appropriate for determination of country level deforestation. It provides only an indication of areas of greatest forest change.

There are numerous country level wall-to-wall assessments of deforestation, most of which have used Landsat or Landsat-like data. At the national-level, Brazil and India have conducted comprehensive, high-resolution estimates of forest change. Brazil estimates deforestation annually using this technique. In other cases, international NGOs or academic institutions have conducted these assessments with local collaborators. Examples of countries that have completed wall-to-wall analyses are provided in Table 3 below. In addition to these, a regional assessment of the Congo Basin was completed (Hansen et al. 2006). This assessment provides a helpful example of country-level assessments using a combination of remote sensing data (MODIS, SPOT, and Landsat). The coarser resolution but more frequently acquired data allowed them to have greater temporal resolution to help account for cloud cover and assess large scale degradation. Additional regional efforts are currently underway in the tropical Andes and non-Brazilian Amazon including Bolivia, Colombia, Ecuador, Peru and Venezuela. At this time most of these wall-to-wall efforts only measure change in forest and non-forest, not degradation.

With additional data and analysis (and thus additional time and cost) wall-to-wall analysis can be used to assess degradation by using imagery with greater temporal frequency and by classifying the imagery to a greater level of detail. These measurements will have greater uncertainty than those for deforestation and this uncertainty will need to be quantified. A few regional, satellite based studies of selective logging in the Brazilian Amazon have tested automated wall-to-wall detection of forest management and shown it is possible in regions without substantial topography (Souza et al. 2005; Asner et al. 2005; Oliveira et al. 2007).

In summary, all of the sampling remote sensing efforts to date are pan-tropical assessments that provide estimates of deforestation on a regional basis, not by country. Wall-to-wall efforts have been completed for a number of countries showing the viability of this method for deforestation. More work will be required to include forest degradation in these assessments. Verification with high resolution data or ground truthing will be needed to determine the accuracy of these different wall to wall assessments.

At this time the only country level data available comes from these wall-to-wall assessments and FAO national statistics data. Table 4 below pulls together a number of existing studies of country level deforestation from wall-to-wall assessments that used moderate to high resolution data as compared to FAO data for comparable years. As expected, there are significant differences between the two methods as well as among the different wall-to-wall methods. A similar comparison was done for the Congo Basin assessment that used a variety of different remote sensing products (Hansen et al. 2006).

Table 3. Comparison of annual deforested area as reported by FAO to that determined by various wall-to-wall assessments of remote sensing data. The FAO data used are from the Global Forest Resources Assessment for the year 2005 (FAO, 2006).

Annual Deforestation Rates

	Brazil		**Paraguay**	**Bolivia**		**Argentina**		**Liberia**	**Myanmar**	**Peru**
DATES	1990-2000	2000-2005	1990-2000	1990-2000	2000-2005	1990-2000	2000-2005	1990-2000	1990-2000	2000-2005
FAO ha/year	-2,681,000	-3,103,000	-179,000	-270,000	-270,000	-149,000	-150,000	-60,000	-466,000	-94,000
Date Variations				*1992-2001*	*2001-2004*	*1998-2002*	*2002-2006*	*1986-2000*		1999-2005
Wall to Wall ha/year	-1,700,300	-2,214,868	-254,603[i]	-150,600	-224,700	-195,483	-298,302	-22,857	-120,000	-64,700

Study Methods

Area Included in Assessment

	Brazil	**Paraguay**	**Bolivia**	**Argentina**	**Liberia**	**Myanmar**	**Peru**
FAO	Entire Country						
Wall to Wall	Amazon Only	Entire Country	Only Bolivian Amazon (Eastern lowland) Does not include Dry Chaco Vegetation area	Only Eastern Chaco forest in 6 provinces with highest deforestation rates	Entire Country	Entire Country	79% of Amazon

Definition of Forest and Deforestation							
FAO	Forest is defined as trees higher than 5m stands spanning 0.5 sq ha with tree cover greater than 10% Definition excludes tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems.						
Wall to Wall	Same as FAO	Deforestation is conversion of forest to non-forest	Deforestation is conversion of humid/semi-humid forest cover to non-forest. Analysis excludes secondary forest growth, plantations, and dry montane forests	Deforestation defined as loss of native forest. Analysis excludes degradation and secondary regeneration.	Deforestation is loss of forest. Forest is defined as closed-canopy cover greater than 80% Anything less is labeled as non-forest	Deforestation is loss of forest. Forest is defined as closed-canopy cover greater than 50% and tree height greater than 5 m.	Same as FAO
Method							
FAO	Submitted by countries, varied						
Wall to Wall	Landsat TM	Landsat TM	Landsat TM	Landsat TM	Landsat ETM+	ASTER	Landsat ETM+
Sources							
	http://www.obt.inpe.br/prodes/	Kim, S., et al. "Assessment of Paraguay's Forest Cover Change Using Landsat Observations." 2007, *In Press.*	Killeen, TJ, et al. "Thirty Years of Land-Cover Change in Bolivia" 2007, *In Press*	UMSEF, "Mapping Native Forest Land in Argentina" June 2007. http://www.ambiente.gov.ar/archivos/web/UMSEF/File/2006_monitoreo_bosque_nativo_preliminar.pdf	Christie, W.T., et al. "Fragmentation and Clearance of Liberia's Forests: 1986-2000." *In Press.*	Leimgruber, P, et al. "Forest cover change patterns in Myanmar (Burma) 1990-2000." *Environmental Conservation* 32(4): 356-364, (2005)	Paulo J. C. Oliveira, et al. "Land-Use Allocation Protects the Peruvian Amazon" Science 317, 1233 (2007)

8. CONCLUSIONS

As the discussion above demonstrates, there are a number of important technical issues and decisions to resolve before a REDD program can be put in place. However, we believe all of these issues are resolvable.

Assessments of historical trends in deforestation are limited to data that have been collected back in time at least a decade. Field inventory data on tropical deforestation are sparse and inconsistent and the time required to acquire more data makes this approach infeasible for measuring reference forest change in the near term. Landsat images used in the global mosaics are a good option for initial measurements of forest change. Especially if they are complemented with other data such as coarser resolution MODIS data to fill gaps caused by clouds and shadows, to address questions of seasonality, and for measuring degradation and forest management. New research by DeFries et al. (in review) suggests another possible method by which existing data can be used to measure historical emissions from deforestation. Since this method uses different data, it can provide a complementary assessment or alternative to the methods suggested here.

To conduct these assessments, there is an on-going need to provide free or low cost high-resolution imagery. It may be helpful to establish standardized methods for the analysis of remote sensing data, and it will be necessary to establish transparency and verification requirements that include some assessment of uncertainty. More pervasive field inventories and surveys can be used to measure and validate remote sensing results providing key "reality checks" to the overall system of land cover classification and change detection. These same surveys can be used to enhance existing data on greenhouse gas emissions associated with deforestation, which is greatly needed (Gibbs et al. this issue). Methods for assessing accuracy/error must be transparent and widely accepted. Ideally basic information on country-level baselines would be available through some type of internet based interface.

Many developing countries have limited capacity to operate and manage the technical components needed to develop credible REDD baselines. Grant programs to help countries set up national remote sensing assessments and training technicians should be a priority for international and bi-lateral funding agencies.

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