Measuring Carbon Emissions from Tropical Deforestation: An Overview

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Tropical deforestation contributes about 20% of annual global greenhouse gas (GHG) emissions, and reducing it will be necessary to avoid dangerous climate change. China and the US are the world's number one and two emitters, but numbers three and four are Indonesia and Brazil, with ~80% and ~70% of their emissions respectively from deforestation. Slowing or stopping deforestation is a near-term, cost-effective option for significantly reducing global emissions, with extraordinary additional benefits for biological diversity and sustainable development in tropical nations. Carbon market incentives to stop deforestation can also help US companies and consumers control the costs of a national cap-and-trade system to reduce US emissions. Accurately monitoring and measuring emissions from deforestation is necessary to creating effective incentives for tropical countries to control and stop the process. The attached paper by remote sensing scientist Dr. Gregory P. Asner[1] shows that ***technologies and methods already in use in nearly half of the world's tropical forests accurately monitor and measure deforestation and forest carbon, and could be implemented globally now. The major obstacles to accurate global measurements of emissions from deforestation are political, institutional and budgetary rather than scientific or technical.***

Dr. Asner's paper provides an authoritative overview of current methods and technologies for measuring and monitoring GHG emissions from tropical deforestation. The paper outlines the contribution of deforestation to climate change and international standards for measuring emissions from deforestation. It also discusses existing methods and technologies for measuring large-scale deforestation events (greater than 63 acres (25 hectares)) and global deforestation mapping with mid-resolution satellite technology. The paper further examines high-resolution satellite analysis of smaller deforestation events (less than 63 acres (25 hectares)) and new methods for measuring forest degradation – logging, thinning, burning and other disturbances that damage forests and reduce their capacity to store carbon without entirely removing the forest canopy. The paper finally summarizes current methods for measuring forest carbon – along with measurement of rates of deforestation and degradation, the critical metric for estimating GHG emissions form deforestation.

International Good Practice standards for measuring forest carbon and deforestation published by the Intergovernmental Panel on Climate Change (IPCC) indicate how carbon market incentives for stopping deforestation or degradation can de designed to reward only real, verified emissions reductions. Conservative accounting of forest carbon, accurate measurement of historical deforestation rates (or "baselines") using existing satellite data, and robust satellite monitoring of deforestation rates can ensure that carbon market incentives produce real reductions in deforestation emissions.

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Summary

Tropical deforestation contributes about 20% of annual global greenhouse gas (GHG) emissions, and reducing it will be necessary to avoid dangerous climate change. Slowing or stopping deforestation is a near-term, cost-effective option for significantly reducing global emissions, with unparalleled co-benefits for biological diversity and the livelihoods of forest peoples. Accurately monitoring and measuring emissions from deforestation is necessary to creating effective incentives for tropical countries to control and stop the process. *Technologies and methods already in use in nearly half of the world's tropical forests monitor and measure deforestation and forest carbon to a high degree of accuracy, and could be implemented globally now. The major obstacles to accurate global measurements of emissions from deforestation are political, institutional and budgetary rather than scientific or technical.*

This paper provides an overview of current methods and technologies for measuring and monitoring GHG emissions from tropical deforestation. The paper outlines the contribution of deforestation to climate change and international standards for measuring emissions from deforestation. It also discusses existing methods and technologies for measuring large-scale deforestation events (greater than 25 hectares (65 acres) and global deforestation mapping with mid-resolution satellite technology. The paper further examines high-resolution satellite analysis of smaller deforestation events (less than 25 hectares) and new methods for measuring forest degradation – logging, thinning, burning and other disturbances that damage forests and reduce their capacity to store carbon without entirely removing the forest canopy. The paper finally summarizes current methods for measuring forest carbon – along with measurement of rates of deforestation and degradation, the critical metric for estimating GHG emissions form deforestation.

International standards for measuring forest carbon and deforestation published by the Intergovernmental Panel on Climate Change (IPCC) indicate how carbon market incentives for stopping deforestation or degradation can reward only real, verified emissions reductions. Conservative accounting of forest carbon, accurate measurement of historical deforestation rates (or "baselines") using existing satellite data, and robust satellite monitoring of deforestation rates can ensure that carbon market incentives produce real reductions in deforestation emissions.

1. Tropical Deforestation and Climate Change

Clearing and burning tropical forests accounts for about 20% of global annual Greenhouse Gas emissions, about as much as all of the fossil fuels burned in the US every year and more than the world's transportation sector. China and the US are the world's

number one and two emitters, but numbers three and four are Indonesia and Brazil, with ~80% and ~70% of their emissions respectively from deforestation.

Reducing overall emissions from deforestation in tropical nations can help avoid dangerous climate change. Most climate scientists think that greatly reducing or stopping tropical deforestation, while also substantially reducing emissions from developed and major developing countries' fossil fuels, will be necessary to keep warming under 2° C by the end of the century. Climate scientists increasingly regard the two-degree target as the maximum allowable in order to avoid potentially disastrous climate change.

Reducing emissions from deforestation in developing countries may produce emissions allowances or credits in carbon markets under the post-2012 global cap-and-trade system under negotiation in the United Nations Framework Convention on Climate Change (UNFCCC)[2].   If tropical countries reduce national deforestation below historical levels, emissions allowances from reduced deforestation could help developed countries and their industries control costs and take steeper reductions targets. Carbon market credit for reduced deforestation could also generate the funds needed to make living forests worth more in the market than dead ones, thus making large-scale, long-term tropical conservation possible.

Reducing national-level deforestation below historical rates in high-deforestation tropical counties offers the greatest potential emissions reductions from the forestry sector, although carbon sequestration or avoided deforestation projects may help tropical countries develop the capacity to control national deforestation. Measuring emissions from deforestation accurately is necessary for deforestation emissions reductions to trade in carbon markets, or for any performance-based system to compensate reduced emissions from deforestation. The UNFCCC has called on nations to begin measuring and monitoring deforestation rates so that Reduced Emissions from Deforestation and Degradation [3] – known as REDD– can be included in a global agreement to reduce emissions.

This paper discusses the methods and technologies currently available for measuring emissions from deforestation at the global, national and regional (e.g., the Amazon) scales. For further information and additional technical details, see DeFries et al. (2005), Gibbs et al. (2007), and Achard et al. (2008).

2 http://unfccc.int/2860.php

3 http://unfccc.int/methods_science/redd/items/4531.php

2. Measuring Emissions from Tropical Deforestation and Degradation: Methods and Technologies

Overview

Two kinds of measurement are needed to estimate GHG emissions from deforestation: the rate of change in the forest cover (or "deforestation rate") and the amount of carbon stored in the forest (or "carbon stock").   Forest activities that release GHGs can be divided into two categories. Deforestation is the clear-cutting and often burning of entire forest landscapes. Degradation includes selective logging, thinning, burning and other disturbances that do not completely remove the forest canopy but nonetheless lower the carbon-storing capacity of forested areas. The science community is providing methodologies for monitoring both types of activities and for estimating the carbon-storing capacity of forested areas in order to monitor forest carbon stocks. Technologies and methods for measuring deforestation and forest carbon stocks are either already operational or could be implemented on a large scale now.

Forest cover can be measured at the global, national and regional levels using satellite mapping technologies together with information from on-the-ground surveys (or "ground-truthing".) Large-scale deforestation events can easily be detected by satellite imagery, while smaller-scale events can be detected through high-resolution satellite imagery or airplane observation. Measuring forest degradation events such as selective logging or burning poses a greater challenge, but new methods show that this is also feasible.

In support of the UNFCCC REDD effort, the Intergovernmental Panel on Climate Change[4] (IPCC) provided Good Practice Guidelines[5] to support countries in developing carbon assessment systems. Assessment systems can be divided into three "tiers" according to level of accuracy.

Tier-I, the most general approach, is based on non-spatial, or non-mapping, estimates of national forest cover and on generic estimates of forest carbon density values (e.g. tons of carbon per hectare). Tier II is more detailed, and uses forest maps and forest carbon inventories that are more accurate than Tier-1 "default" values. Tier-III, the most rigorous approach, is based on very detailed landscape-specific or even species-specific carbon stock estimates with regular, ongoing reassessments. Carbon accounting for REDD will have to be conservative, so that countries cannot claim credit for more carbon and more emissions reductions than they can accurately measure and demonstrate.

It is likely that most – though not all – tropical forest nations would initially rely on Tier-I levels of accuracy, which would be subject to high levels of uncertainty. Carbon values for crediting should not exceed the lower limit of this range of uncertainty. However, more accurate measurement methods are already available and it is expected that forest nations would upgrade in response to clear policy signals. As the authors of a global

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4 http://www.ipcc.ch/

5 http://www.ipcc-nggip.iges.or.jp/public/gp/english/

analysis of Tier-I estimates conclude: "The future of REDD and related climate policies need not be constrained by the technical challenges of estimating tropical forest carbon stocks. A range of options exists to estimate forest carbon stocks in developing countries and will continue to improve in response to policy needs and signals." (Gibbs et al. 2007, p. 10). Developing national monitoring capacity to Tier-II and Tier-III accuracies will require better regional mapping methods, most of which are available today.

Global Monitoring of Large Deforestation Events

Direct observations of changes in forest cover at large geographic scales must be derived from satellites, in conjunction with field surveys and ground-truthing. Purely field-based observations of changing forest cover are notoriously inaccurate and unreliable. Global satellite mapping of forest cover has greatly improved in recent years, and estimation of deforestation at resolutions of about 25 hectares (63 acres) and larger is now routine (Achard et al. 2007, Hansen et al. 2008). If a deforestation event is smaller than 25 hectares, which would include nearly all selective logging of forests, then there is no guarantee that the global mapping satellite sensors and methods will detect it. Selective logging in the Amazon increases GHG emissions ~25% above emissions from deforestation (Asner *et al.* 2005). Nonetheless, the global mapping systems provide wall-to-wall coverage of enormous tracts of forest and changes in forest cover (Figure 1).
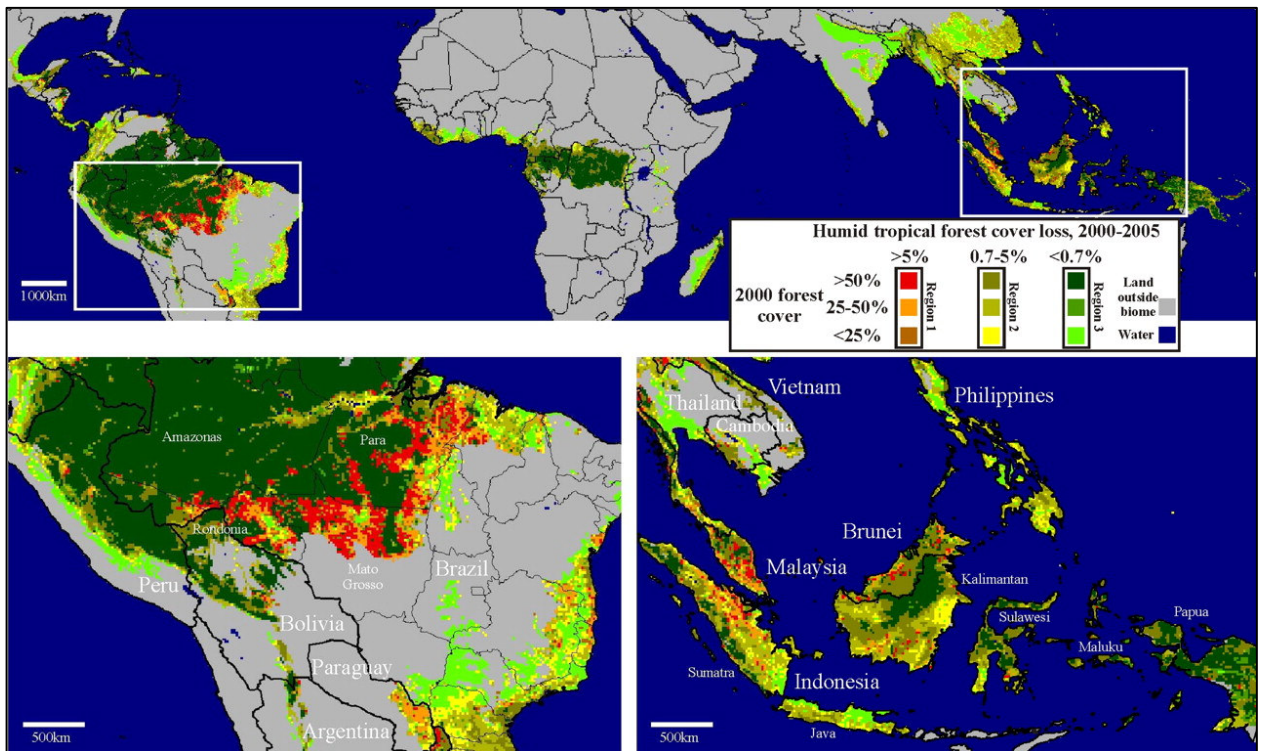

Fig. 1. Global-scale map of forest losses from 2000 to 2005 (Hansen et al. 2008).

The satellite sensors commonly used for global-scale monitoring of forest cover include the NASA Moderate Resolution Imaging Spectrometers (MODIS[6]) onboard the Terra[7] and Aqua[8] satellite platforms, and the VEGETATION[9] sensor onboard the Systeme Pour l'Observation de la Terre-5 (SPOT-5[10]) platform. The data are freely available, and can yield global-scale deforestation maps such as the one shown in Figure 1 on a sub-annual basis.

Regional Monitoring of Smaller Deforestation Events

Global mid-resolution satellite monitoring approaches can miss the millions of small forest clearings that are made each year at the few-hectare (acre) scale. These small clearings are ubiquitous and thus can add up to a large fraction of the total tropical deforestation in a country. Higher-resolution satellite monitoring approaches are now widely used to measure deforestation at the regional level (e.g., the Brazilian Amazon). Some systems are fully operational, such as the PRODES[11] system used by Brazil's National Space Research Institute (INPE). This monitoring program has been providing annual mapping assessments of deforestation events down to about 0.2 hectare (0.5 acre) resolution since 2000. It is also transparent: INPE makes its deforestation maps freely available on the World Wide Web in data formats that are easily accessible to most geographers.

Regional-scale, high resolution satellite monitoring approaches such as PRODES can provide annual assessments of deforestation across countries as large as Brazil, which alone represents about 40% of all humid tropical forests worldwide. The primary workhouse for regional- and national-scale mapping of forest cover anywhere in the world is the NASA Landsat series of satellites. Landsat-5[12] was launched in 1982 and, although it is far beyond its intended mission lifetime of approximately 5 years, it continues to provide critical forest cover data in many tropical regions. Landsat-6 failed during launch, and Landsat-7[13] provided high-quality data from the time of its launch in 1999 until it suffered a partial failure in 2003. Landsat-7 continues to provide partial mapping coverage, but many in the tropical forest mapping community have turned to Landsat-5 to fill in the data gaps until a new Landsat can be built. The next generation Landsat[14] is currently under development with an intended launch date of 2012-2013. All Landsat imagery data is available online at no charge,[15] greatly enhancing the ability

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[6] http://modis.gsfc.nasa.gov/

[7] http://terra.nasa.gov/

[8] http://aqua.nasa.gov/

[9] http://www.spot-vegetation.com/home/quick/quick.html

[10] http://spot5.cnes.fr/gb/index3.htm

[11] http://www.obt.inpe.br/prodes/

[12] http://landsat.usgs.gov/

[13] http://landsat.gsfc.nasa.gov/

[14] http://ldcm.nasa.gov/

[15] http://landsat.usgs.gov/mission_headlines2008.php

of any organization or individual to map deforestation in tropical regions. Other countries have launched or plan to launch similar instruments into Earth orbit. The China-Brazil Environmental Resource Satellite (CBERS[16]), French SPOT-5[17], and Indian IRS[18] satellites are a few important examples.

Forest Degradation

To detect more subtle changes in tropical forest associated with degradation, scientists have recently developed new methods to improve the analysis of Landsat and other high-resolution satellite imagery. Degradation is caused by logging, thinning, burning and other disturbances that do not completely remove the forest canopy. Mapping forest degradation (the second "D" in REDD) is far more challenging than mapping deforestation, but these new methods are yielding reliable results. Souza et al. (2005) used advanced mapping methods with Landsat to detect forest degradation caused by selective logging and ground-level fire. Asner et al. (2005) developed the Carnegie Landsat Analysis System (CLAS), the first system designed specifically to map large-scale forest degradation, especially from many types of selective logging. The CLAS System was initially applied to five states in the Brazilian Amazon and it showed that selective logging is often found in areas neighboring deforestation zones (Figure 2, next page). CLAS was also used to map transitions between selective logging activities and full clear-cutting, showing that logged forests are 400% more likely to be completely cleared than unlogged forests (Asner et al. 2006).

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[16] http://www.satimagingcorp.com/satellite-sensors/cbers-2.html
[17] http://www.satimagingcorp.com/satellite-sensors/spot-5.html
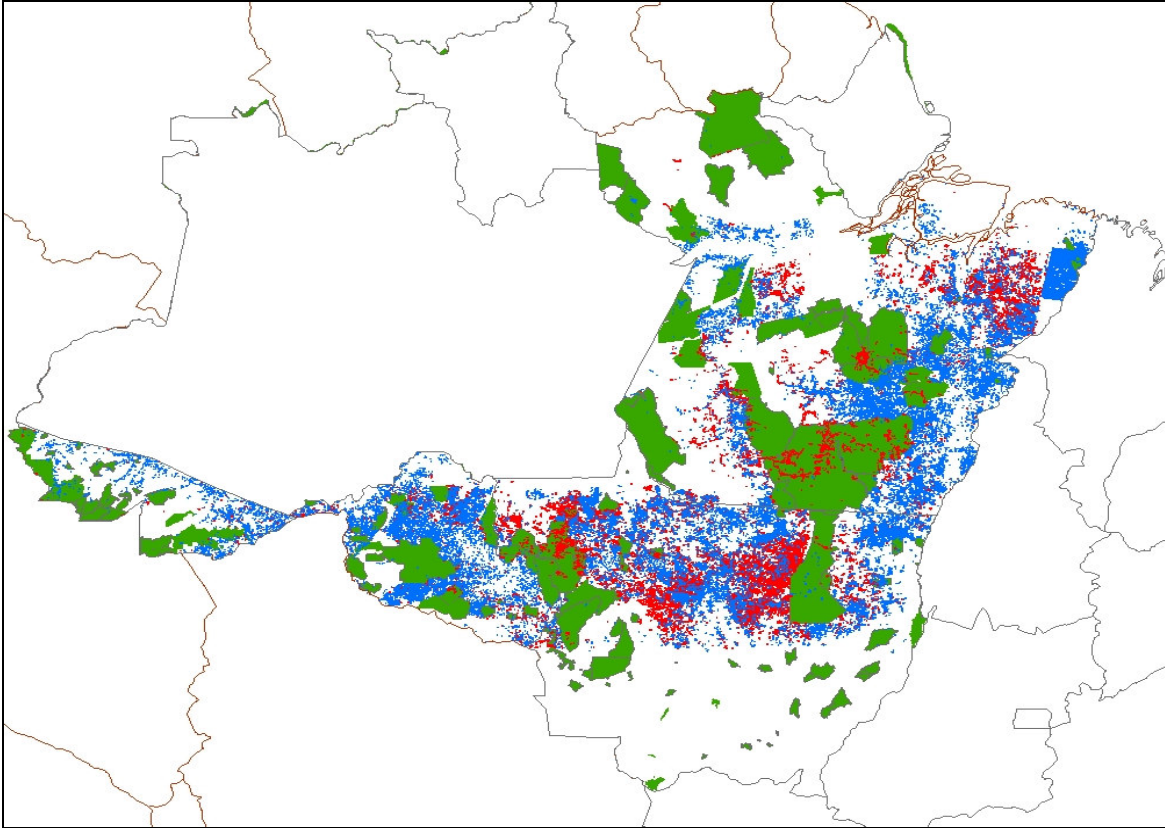[18] http://www.isro.org/

Fig. 2. A map of deforestation (blue) and selective logging (red) in the Brazilian states of Para, Mato Grosso, Rondonia and Acre covering the years 1999-2002. Green areas indicate federal forest reserves, indigenous lands, and protected areas (Asner et al. 2006).

A new simplified system called CLASlite[19] was subsequently developed with the specific goal of providing non-profit government and non-government organizations in South America with monitoring software. The CLASlite Capacity Building project is currently underway, with Peru, Bolivia, Ecuador, Colombia, Brazil, Surname, and Guyana all targeted to receive the software and training in its use.

Monitoring Forest Carbon Stocks

Satellite imagery from optical sensors, regardless of resolution, does not measure forest carbon directly. Any map of forest cover will consequently need to be "painted" with carbon density values (e.g., tons of carbon per hectare) in order to geographically map forest carbon stocks. Painting a satellite forest cover map with plot-scale data is a considerable improvement over the IPCC Tier-I level of reporting. However, the only field-based carbon density values currently available for this crucial step are derived by analyzing only a small fraction of a given landscape. For example, such plot-based

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[19] Asner, GP and DE Knapp. CLASlite User's Manual. Carnegie Institution for Science, Stanford, CA 94305

biomass estimates for the Brazilian Amazon are derived from the analysis of just one millionth of the area (Phillips et al. 1998).

While applying field-based carbon inventory data to satellite forest covers maps improves national forest carbon stock estimates, more accurate methods are currently being developed. These include an expanding network of forest inventory monitoring sites representing major forest types and conditions (reviewed by Gibbs et al. 2007). Several approaches have been demonstrated that promise even more accurate and timely results. One important line of research focuses on deriving information on forest structure from aircraft and satellites. Compared to previous forest cover maps, these newer maps of forest structure provide more robust information about actual carbon stores. Using spaceborne radar, Saatchi et al. (2007) mapped the vegetation carbon stocks across the Amazon; radar provided an index of forest volume, which was then converted to carbon storage estimates using field-based conversion equations ("allometrics") that relate volume to carbon mass per hectare.

Another fast-developing approach for carbon mapping uses airborne and spaceborne Light Detection and Ranging (lidar) technology (reviewed by Lefsky et al. 2002). Lidar provides detailed 3-D imaging of forest canopies, and the 3-D structure can be directly linked to biomass levels (Figure 3). Most lidar demonstrations have been done with aircraft, which can typically sample up to 10,000 hectares (25,000 acres) per day, too small an area for national-scale mapping. The airborne approach however provides a powerful means to "mega-sample" a region that goes far beyond what was possible using field plots or forest inventory networks. There is also one spaceborne lidar called NASA GLAS,[20] which provides spot measurements of 3-D forest structure. Although the data are not in image form (it is a spot or profiling system), the measurements can be collected over time to sample a region. Additional spaceborne radars and lidars are being planned with estimated launch dates of 2013 and beyond.

Conclusions – Current methods and technologies for measuring emissions from deforestation are adequate for REDD

Tropical deforestation occurs in "hotspots" – 55% of global deforestation takes place in only 6% of the tropical forest biome (Hansen *et al.* 2008) Large part of this deforestation is currently accurately and regularly monitored. The Brazilian Amazon from 2000 – 2005 accounted for almost ½ of the world's deforestation, and this is monitored and analyzed by several governmental and independent programs – annual high-resolution analysis to measure annual deforestation (PRODES); monthly mid-resolution monitoring of clearings over 25 ha (63 acres) to detect new deforestation for enforcement purposes (DETER); yearly analysis of forest degradation (DEGRAD); and daily monitoring of fires using NOAA and other low-resolution satellites. Accurate and transparent measurement of deforestation contributed to substantial reductions in Brazil's deforestation after 2003. Peru, Bolivia, Columbia and Ecuador are in process of installing

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[20] http://glas.gsfc.nasa.gov/

capacity to monitor and measure both deforestation and degradation, which will cover an additional ~12% of global annual deforestation. Technically, both deforestation and degradation could be measured globally by the US or the EU today, but tropical countries understandably want the capacity to measure their own deforestation. The obstacles to global monitoring and measuring of emissions from deforestation are political, institutional and budgetary rather than scientific and technical.

Conservative carbon accounting, appropriately designed deforestation baselines, and rewarding reductions once they are achieved and demonstrated with robust technologies can ensure that carbon credit goes to real reductions in national deforestation rates. Peer-reviewed estimates of carbon values in closed forest in the Amazon, for example, range between 120 and 350 tons/Carbon per hectare (Saatchi *et al.* 2008). Brazil's Amazon Fund uses 100 tons/C/hectare to calculate emissions reductions. Rules for national forest carbon accounting for countries that want access to international carbon markets must specify minimum standards (e.g. the IPCC Good Practice Guidelines) that only allow credit for carbon that can be accurately measured, both in the past, for purposes of creating baselines, and after reductions over a period of years are achieved, when credit is claimed. Countries using IPCC Tier I methods for estimating forest carbon would only be able to use lower-limit estimates, no higher than the lower end of the range of uncertainty, for establishing baselines and claiming credit. At the other end of the spectrum, a country with the installed capacity and willingness to invest in measuring, and reducing, forest degradation in addition to deforestation, would have a much more detailed, higher-emissions baseline, and would be able to claim credit for greater reductions if it achieved them. Policy – and price – signals will drive continued improvements in technologies and methods for measuring emissions from deforestation and degradation.

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