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A ranking of net national contributions to climate change mitigation through tropical forest conservation

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A R T I C L E I N F O

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A B S T R A C T

Deforestation in tropical regions causes 15% of global anthropogenic carbon emissions and reduces the mitigation potential of carbon sequestration services. A global market failure occurs as the value of many ecosystem services provided by forests is not recognised by the markets. Identifying the contribution of individual countries to tropical carbon stocks and sequestration might help identify responsibilities and facilitate debate towards the correction of the market failure through international payments for ecosystem services. We compare and rank tropical countries' contributions by estimating carbon sequestration services vs. emissions disservices. The annual value of tropical carbon sequestration services in 2010 from 88 tropical countries was estimated to range from $2.8 to $30.7 billion, using market and social prices of carbon respectively. Democratic Republic of Congo, India and Sudan contribute the highest net carbon sequestration, whereas Brazil, Nigeria and Indonesia are the highest net emitters.

1. Introduction

Deforestation in tropical regions causes 15% of global anthropogenic carbon emissions (Van der Werf et al., 2009). Reduction of deforestation related emissions and mitigation through carbon sequestration have been identified as among the most cost-effective interventions to mitigate climate change (Stern, 2007). Carbon sequestration is a public good because it is nonrivalrous in consumption and nonexcludable (Stone, 1994). Public goods are associated with the tragedy of the commons and market failures as the market does not capture the actual value of the service, leading to an undesirable shortage of supply. In this case, as the value of standing forests is not recognised, excessive deforestation occurs and causes a shortage in supply of carbon sequestration services. International payments for ecosystem services (PES) such as carbon sequestration can correct this market failure by compensating countries responsible for generating the service (Bishop and Hill, 2014). Once payments are introduced and the service value internalized, service undersupply—avoided carbon emissions and carbon sequestration—is expected to be mitigated.

In 2005, at the eleventh Conference of the Parties in Montreal, a mechanism for reducing deforestation emissions in developing countries through PES was proposed and widely supported. This mechanism, abbreviated as REDD, was subsequently expanded to REDD + to include carbon stock enhancing activities, sustainable forest management and conservation (Peskett, 2008).

Technical limitations of historical and projected deforestation reference levels made REDD + controversial at the United Nations Framework Convention on Climate Change negotiations. Partly due to this controversy, REDD+ was prevented from joining other clean development mechanism projects—such as renewable energy introduction—as certified emission reduction credits (Grondard et al., 2008). Rather than the expected large-scale implementation of REDD + at the global and national level, which would have occurred if REDD + had joined global carbon credit markets, REDD+ is currently slowly growing, supported by project level international donors. There are currently over 300 subnational REDD + projects under implementation (Kshatriya et al., 2013) representing only 0.4% of the CO_2 traded in carbon markets globally in 2008. Given these circumstances, further international level discussions on international PES strategies for carbon services through conservation could be necessary to accelerate agreements on financial mechanisms and establish strong global carbon markets.

Quantifying the contributions from each country on carbon sequestration services could be an important first step to catalyse further discussion on international PES. For high-income countries, this clarifies which countries could be potentially compensated and how much, facilitating the generation of responsibilities and information. Information about the problem and potential solutions,

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in this case contributions to tropical forest preservation, are key to avoid global commons tragedies for tropical forests (Ostrom et al., 1999).

To this end, here we identify the carbon sequestration services and emissions from deforestation by tropical nations and rank net sequesters and emitters.

2. Methods

2.1. A ranking of contributions based on net carbon sequestration services

Contributions are based on the balance of CO_2 sequestered from forest stock and carbon emitted from deforestation and degradation activities. If a country has net carbon sequestration, potential compensation is calculated by multiplying net sequestration by the price of carbon sequestered, i.e. the country contributes the actual services provided in a given period of time and such contribution occurs when the services of carbon sequestration are greater than the disservices from emissions due to deforestation. If the country is a net emitter of carbon, the contribution is negative. The value of the net contributions is:

$$\text{value}_i = (S_i - E_i)p \qquad (1)$$

where value_i is the value of the net contribution by country i (USD/year); p is the carbon price (USD/tons of CO_2 emitted or sequestered); E_i is the annual emission from deforestation for country i (tons of CO_2 emitted); and S_i is the annual sequestration from forests for country i (tons of CO_2 sequestered).

2.2. Application of the mechanism at the pantropical level to identify contributions

We are not aware of geographic information system (GIS) maps of changes in primary, secondary and plantation forests at the pantropical level. Instead, to distinguish different sequestration rates for different forest types, the Global Forest Resource Assessment 2010 (FAO, 2010) was employed. We used this as a source for the area changes in primary, secondary and planted tropical forests in each country in the years between 1990 and 2010.

We estimated potential emissions from carbon (E in Equation (1)) aboveground, belowground, in soil and in dead organic matter in each country. GIS maps of aboveground tropical forest biomass were obtained by overlaying maps from Ruesch and Gibbs (2008) with the distribution of tropical forests (Hansen et al., 2010). Biomass was transformed to tons of carbon per hectare, multiplying by a 0.49 carbon fraction of biomass (Feldpausch et al., 2004; IPCC, 2006). Belowground carbon was estimated using IPCC (2006) shoot-root ratios for tropical forests, applied to aboveground carbon maps. IPCC Tables 2.3 and 2.2 (Feldpausch et al., 2004; IPCC, 2006) were employed to derive estimates of carbon stored in soil and dead organic matter. All carbon estimates were expressed as tons of carbon dioxide per hectare and the maps were used to estimate the average emissions per hectare of tropical forest deforested for each country.

The exact size and location of carbon sinks is uncertain and depends on the type of forest and level of degradation (Pan et al., 2011). Given these limitations, we used a power law model of variation in the pools of living biomass, organic soil horizons, soil and coarse woody debris in tropical forests as a function of forest age (Pregitzer and Euskirchen, 2004) to estimate carbon sequestration (S in Equation (1)) for different types of forests. The model ($\text{MgC/ha} = 53.7 \cdot \text{age}^{0.26}$), derived through fitting existing literature estimates of carbon sequestration in the tropics, allowed prediction of carbon sequestration rates for different forest ages (Pregitzer and Euskirchen, 2004). We considered three different forest types consistent with the Global Forest Resource Assessment 2010 and used their expected average age to estimate sequestration rates: (i) *primary intact tropical forests* for which sequestration rates ranged from 0.46 Mg C/ha•year (for 100 year old forests) to 0.33 Mg C/ha•year (for 200 year old forests). Note that the equation was fitted to age stages of up to 200 years and was hence not used to extrapolate beyond that age. These results are conservative with respect to sequestration of 0.63 Mg C/ha•year (95% CI 0.22–0.94) in intact African forests (Lewis et al., 2009) and 0.62 ± 0.23 Mg C/ha•year in intact Amazon forests (Baker et al., 2004); (ii) *secondary forests* that were assumed to range between 30 and 90 years old with corresponding sequestration rates ranging from 1.1 to 0.5 Mg C/ha•year respectively. These estimates resemble biomass accumulation of 1–2 Mg C/ha year in forests greater than 60–80 years old (Lugo and Brown, 1992); and (iii) *planted forests* that were assumed to range between 5 and 20 years old with corresponding sequestration rates of 3.9 and 1.5 Mg C/ha•year. These estimates agree with sequestration rates of 1.9–7 Mg C/ha•year in 12–13 year old native tree plantations in Costa Rica (Redondo-Brenes and Montagnini, 2006).

We employed two carbon price scenarios (p in Equation (1)): (i) USD$2.31/tC, the average of the market settlement prices per tonne of carbon from 2003 to 2010 in the Chicago Climate Exchange (CCX, 2013); (ii) USD$25/tC, a social carbon price based on the certainty equivalent of the mode of peer-reviewed estimates with a 3% of pure rate of time preference, without equity weights and a risk premium (Tol, 2009). Countries included were low income, lower-middle income and upper-middle income countries (as classified by the World Bank in July 2013) where the majority of the country lies between the tropics of Cancer and Capricorn and information on primary, secondary and plantation forest were available, resulting in a total of 88 countries.

3. Results

3.1. Global carbon sequestration and emissions during 2005–2010

We estimate that a total of 1.2 billion tons of CO_2 were sequestered annually between 2005 and 2010 by forests in the 88 countries. In total, these 88 countries also emitted an annual average of 1.1 billion tons of CO_2 through deforestation in the same period. The average annual value of carbon sequestration services during this period were USD2.8 and USD30.7 billion for current market values of CO_2 and the social price of carbon respectively.

3.2. Contribution at the national level

Despite this global trend of greater sequestration than emissions, the comparison between emission and sequestration from deforestation is very different at the national level. In the proposed system, emitted tons of carbon carry the same weight as the service provided by tons sequestered. Under these conditions, most countries (66 of 88 countries) produce net contributions, i.e. their sequestration is greater than their emissions (see Supporting Information for a ranking of the countries per net contribution). Countries contributing the most are those with low deforestation rates and relatively large forest stocks which produce notable carbon sequestration services. For instance, the highest average annual contributors are the Democratic Republic of Congo (USD1.7 billion per year, Fig. 1) and India (USD1.7 billion per year, Fig. 2). The high contribution from India is due to a large forest stock, combining preserved primary forests and increasing planted forests (from 9.4 to 10.2 million hectares) which provide higher sequestration rates. In countries producing a net carbon contribution, reforestation is common, and