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ASSESSING REDD+ PERFORMANCE OF COUNTRIES WITH LOW MONITORING CAPACITIES: THE MATRIX APPROACH

Note by the Executive Secretary

1. The Executive Secretary is circulating herewith, for the information of participants in the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, a document prepared by an international team of authors proposing a matrix approach for assessing the performance of countries with low monitoring capacities in reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+).

2. The document is circulated in the form and language in which it was received by the Secretariat of the Convention on Biological Diversity.

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Assessing REDD+ performance of countries with low monitoring capacities: the matrix approach

M Bucki[1], D Cuypers[2], P Mayaux[3], F Achard[3], C Estreguil[3] and G Grassi[3]

[1] Directorate-General Climate Action, European Commission, B-1049 Brussels, Belgium
[2] Unit Transition, Energy and Environment, VITO, Boeretang 200, 2400 Mol, Belgium
[3] Institute for Environment and Sustainability (IES), Joint Research Center (JRC), Via E Fermi 2749, I-21027 Ispra (VA), Italy

E-mail: Michael.Bucki@ec.europa.eu

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Abstract
Estimating emissions from deforestation and degradation of forests in many developing countries is so uncertain that the effects of changes in forest management could remain within error ranges (i.e. undetectable) for several years. Meanwhile UNFCCC Parties need consistent time series of meaningful performance indicators to set credible benchmarks and allocate REDD+ incentives to the countries, programs and activities that actually reduce emissions, while providing social and environmental benefits. Introducing widespread measuring of carbon in forest land (which would be required to estimate more accurately changes in emissions from degradation and forest management) will take time and considerable resources. To ensure the overall credibility and effectiveness of REDD+, parties must consider the design of cost-effective systems which can provide reliable and comparable data on anthropogenic forest emissions. Remote sensing can provide consistent time series of land cover maps for most non-Annex-I countries, retrospectively. These maps can be analyzed to identify the forests that are intact (i.e. beyond significant human influence), and whose fragmentation could be a proxy for degradation. This binary stratification of forests biomes (intact/non-intact), a transition matrix and the use of default carbon stock change factors can then be used to provide initial estimates of trends in emission changes. A proof-of-concept is provided for one biome of the Democratic Republic of the Congo over a virtual commitment period (2005–2010). This approach could allow assessment of the performance of the five REDD+ activities (deforestation, degradation, conservation, management and enhancement of forest carbon stocks) in a spatially explicit, verifiable manner. Incentives could then be tailored to prioritize activities depending on the national context and objectives.

Keywords: REDD, deforestation, forest degradation, conservation, fragmentation

1. Introduction

1.1. Multilateral context

The 16th and 17th Conferences of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) agreed on a framework for policy approaches and positive incentives on issues relating to five activities: reducing emissions from deforestation, reducing emissions from forest degradation, conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+, UNFCCC 2010).

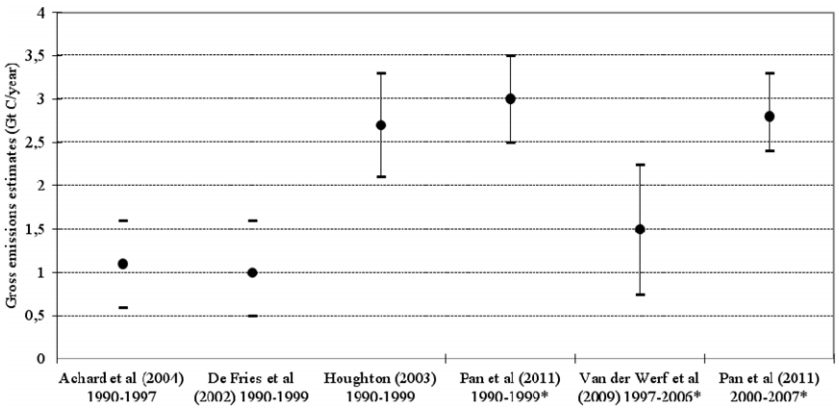

Figure 1. Gross emissions estimates (Gt C yr^{-1}) from tropical deforestation and forest degradation, with their uncertainties (Achard *et al* 2004, De Fries *et al* 2002, Houghton 2003, Pan *et al* 2011, van der Werf *et al* 2009). * = including peatland emissions.

REDD+ has three phases: (1) readiness; (2) capacity building and demonstration; and (3) performance-based payments for actions that should be fully measured, reported and verified (MRV) at the national level to measure performance vis-à-vis reference levels (RLs). Within the negotiation process, RLs are usually understood as benchmarks to be subtracted from the net emissions from REDD+ activities to calculate emission reductions (Meridian Institute 2011). It is still unclear whether and how developing countries that engage voluntarily in REDD+ should monitor and report on all activities, or if only some of them (deforestation, degradation) would be mandatory.

REDD+ requires developing countries to design: (1) forest RLs taking into account historical data, and national circumstances; (2) robust, consistent, accurate and transparent national forest monitoring systems; (3) information systems on social and environmental safeguards (UNFCCC 2010). Parties (i.e. countries) are now (i) exploring financing options for the full implementation of REDD+ and (ii) developing technical modalities for MRV of emissions and removals as well as guidance on providing information on safeguards. Given the potential contribution of REDD+ to the UNFCCC, and the necessity to ensure its cost-effectiveness and environmental integrity, UNFCCC Parties seek reliable performance indicators.

Deforestation and forest degradation together are deemed the second largest anthropogenic source of carbon in the atmosphere (van der Werf *et al* 2009), yet the range of published estimates of global emissions from deforestation and forest degradation (figure 1) illustrates the variability in methods and the remaining uncertainties.

1.2. The lack of definitions in REDD+

In the context of the UNFCCC a forest definition has been agreed for the Kyoto Protocol ('Annex-I' Parties) and for afforestation/reforestation projects under the Clean Development Mechanism (UNFCCC 2001, 2004). These definitions are based on two main parameters and implicitly leave a third one up to the countries.

(i) Land-use parameter: 'forest' land excludes land under any other (non-forest) use, in particular agricultural use, e.g. 'trees on farmland' or oil palm plantations are excluded, whilst areas that are 'un-stocked' (i.e. bare of trees) but 'expected' to regrow as forests (e.g. clear-cuts) are included.

(ii) Land cover parameter: 'forest' is a minimum area of land of 0.05–1 ha with tree crown cover (or equivalent stocking level) of more than 10–30% with trees with the potential to reach a minimum height of 2–5 m. Each country can select its own thresholds in the above-defined ranges.

(iii) The forest definitions do not consider any 'naturalness' or degradation related pattern parameters (e.g. forest plantations versus natural regeneration, intact versus disturbed) nor account for sustainability of forest management practices, leaving such stratification of forested lands to the countries themselves.

The authors take the view that these definitions are not sufficient in a REDD+ context: the borders, in space and in time, between forestry and agriculture are blurred in the margins of tropical forests (transition zones), with shifting cultivation, logging, sylvo-pastoralism and agroforestry being common practices. Land-use mapping and planning can be further complicated by overlapping claims (Childress 2010, Sundström and Mustalahti 2010, Sunderline *et al* 2009). The 'conservation of natural forests and biological diversity' is explicitly recognized under REDD+ (UNFCCC 2011), but it is not defined although their protection is a mandatory safeguard.

The REDD+ terminology can also be confusing as regards its actual implementation:

(i) Of the five REDD+ activities, only deforestation is generally considered unambiguous.

(ii) A group convened by the Intergovernmental Panel on Climate Change (IPCC) to resolve the definition of degradation (Penman *et al* 2003) was unable to produce a clear definition because losses of biomass in forest may be considered as temporary or cyclical and therefore essentially sustainable, even if on average the carbon stock remains permanently below that of intact forests.

Table 1. Estimates of carbon emissions from degradation (expressed as an additional percentage to the emissions from deforestation).

Study area	Additional emissions due to forest degradation (%)	Reference
Humid tropics	+6	Achard *et al* (2004)
Brazilian Amazon, Peruvian region	+25–47	Asner *et al* (2005)
Tropical regions	+29	Houghton (2003)
South East Asia	+25–42	Houghton and Hackler (1999)
Tropical Africa	+132	Gaston *et al* (1998)

(iii) According to Herold and Skutsch (2011), conservation of forest carbon stocks represents an effort to ensure permanence by establishing long-term commitments to preserve forests. It would imply that human activities in such areas are minimal, and in sum will result in a near zero carbon balance in the near and long-term, resulting in the continued supplies not only of carbon but also of other ecosystem services.

(iv) The concept of 'sustainable management of forests' (SMoF) is often related to commercial timber operations, although low intensity community forest management (Herold and Skutsch 2011) may also qualify; it is usually understood as sustained timber yield, i.e. the extraction rate equals natural increment but no binding standards apply. Countries with high forest cover, which have not yet started their forest transition (Rudel *et al* 2005) could therefore argue that, following the model of developed countries, their 'sustained yield' is higher than current yield, and that converting or degrading is part of their sustainable development, hence of SMoF. This would open the door for factoring some emissions out or adjusting baselines accordingly, even if monitoring and accounting of the activities 'deforestation' and 'degradation' would themselves be mandatory.

(v) Enhancement of carbon stocks (EoCS) may be understood either as afforestation and reforestation (reverse deforestation) or as restoration (reverse degradation).

1.3. On the need to MRV degradation

Given the lack of clarity and data on forest degradation in some developing countries, negotiators might, as they did in the Marrakesh Accord on Land Use, Land-Use Change and Forestry (LULUCF), consider making some REDD+ activities mandatory and others voluntary, with a risk of leakage between categories. One could then anticipate that in a country where only deforestation is well monitored and regulated, former clear-cutters figure out how to defeat detection efforts by adapting their practices towards degradation, which is less likely to be observed, as demonstrated in Brazil (INPE 2011).

Emissions from deforestation represent only part of the total emissions from forest lands, with forest degradation adding from 6 to 132% of additional emissions (table 1).

Table 2. REDD+ activities in a conversion matrix, based on IPCC land-use categories.

	To	
From	Forest land	Other land
Forest land	Forest degradation Forest conservation Sustainable management of forests Enhancement of carbon stocks	Deforestation
Other land	Enhancement of carbon stocks	

1.4. Current IPCC guidance on land use and land-use change related emissions and developing countries' monitoring capacities

The latest available IPCC guidelines for national greenhouse inventories (IPCC 2006) refer to two basic inputs to calculate emissions and removals: activity data (i.e. area) and emissions factors (i.e. changes in carbon stocks per unit of area). The IPCC classifies the land in six different land uses, and provides methodological guidance for each 'land use remaining the same' (e.g. forest remaining forest) and for each land-use change (e.g. forest converted to cropland). Applying these IPCC guidelines, the five REDD+ activities would be covered by only three broad 'categories' (table 2).

1.4.1. Activity data. The IPCC suggests three non-hierarchical 'approaches' for obtaining activity data: (1) only identifying the total area for each land category; (2) tracking aggregated land-use changes between categories; and (3) tracking land-use changes on a spatially explicit basis.

Despite sustained efforts, country reports to the latest Global Forest Resources Assessment (FRA-2010) of the UN Food and Agriculture Organisation (FAO) (FAO 2010) show that many countries still struggle with monitoring their actual forest extent. The limitations of this global dataset are known (Grainger 2008), in particular in relation to the accuracy of the data. This lack of data accuracy in current national forest reporting is thus equally relevant for REDD+ monitoring.

Approaches 1 and 2 often rely on one or two national forest inventory campaigns and linear projections over 5 or 10 years. Whilst annual deforestation rates in most countries are below 2%, in FRA-2000 there was a total difference of 22% between total tropical forest area figures from country reports[4] and the FRA-2000 remote sensing survey (FAO 2001). This discrepancy rose to 26% for the same year in FRA-2010 (table 3).

Moving to approach 3 could track gross deforestation on a spatially explicit basis, thus addressing the shortcomings of aggregated datasets (GOFC-GOLD 2010, Ramankutty *et al* 2007). Using state-of-the-art remote sensing technologies and satellite imagery at 30 m × 30 m resolution, the accuracy currently achievable for a forest/non-forest map is around 90% (Pekkarinen *et al* 2009). Despite country-level reporting discrepancies, forest/non-forest can actually be mapped quite easily from available satellite data. Yet, parsing out degraded areas is far more challenging.

[4] www.fao.org/forestry/fra/67090/en/.

Table 3. Discrepancies in FAO tropical forest area estimates for the year 2000 between successive country reports and from the FAO remote sensing survey (in million ha).

Region	FAO FRA-2000 country statistics	FAO FRA-2000 remote sensing survey[a]	FAO FRA-2010 country statistics (revised for 2000)
Asia	289 (129%)	224 (100%)	301 (134%)
Africa	622 (129%)	484 (100%)	607(125%)
Latin America	892 (116%)	767 (100%)	950 (124%)
Total	1803 (122%)	1475 (100%)	1858 (126%)

[a] Only the results of the countries included in the FRA-2000 remote sensing survey were considered. This survey is considered as the data with which other assessments are compared (100%).

1.4.2. Emission factors. IPCC suggests three hierarchical 'tiers' of data for emission and carbon stock change factors with increasing levels of data requirements and analytical complexity: (1) Tier 1 uses IPCC default values of carbon stocks detailed per ecological zone and per continent. These values have a large uncertainty range (∼70%) even for above-ground biomass (IPCC 2006); (2) Tier 2 improves on Tier 1 by using country-specific data and by estimating forest biomass at finer scales; (3) Tier 3 typically has a higher spatial resolution, using numerical models and/or actual detailed field estimates with periodical measurements of changes in forest biomass on permanent plots.

Sasaki and Putz (2009) illustrated that Cambodian forests could lose 59% of their carbon through selective logging and would still be classified as forest. Thus there would be no change in IPCC carbon estimates unless Tier 2 or 3 monitoring was in place. IPCC default values of forest biomass stocks in Africa range from 20 to 155 tC ha^{-1}. Up to 2008, only Mexico, India and Brazil were in a position to use Tier 2, with no developing country able to use Tier 3 (Hardcastle and Baird 2008). Compared to above-ground biomass, soil carbon can be a very significant source (e.g. peat fires and peat decomposition are estimated to cause respectively 30% and 15% of land emissions in Indonesia) but it is even more difficult to monitor: it has high spatial variability and low temporal variability, making measurement impractical on anything but very small areas or very long periods.

1.4.3. Synthesis. Few developing countries have the capacity to monitor changes in forest cover and carbon stocks, and only three out of 99 had the capacity considered adequate for forest area change monitoring and forest inventories in 2009 (Herold 2009). Moreover, due to cumulative sources of errors, deforestation would need to be reduced drastically to produce estimates that would allow a clear detection of emission reductions, e.g. 50% in the case of Panama (Pelletier *et al* 2011). However, uncertainties on data from both area changes and carbon can be partly tackled through the conservativeness concept (e.g. by using the lowest end of the confidence interval of emission reductions, *de facto* applying a discount factor to the most uncertain estimates). This concept may allow for flexible monitoring requirements at the start of the REDD+ process while fostering further improvement of the accuracies (Grassi *et al* 2008).

1.5. Structure of the paper

This paper aims at informing REDD+ negotiators and national REDD+ strategies on a possible way forward as regards monitoring and accounting for all REDD+ activities even when Tier 2 or 3 is not available, but approach 3 activity data are.

- Section 2.1 introduces a binary stratification of the forest category in table 2, and gives a proof-of-concept for the rainforest of the Democratic Republic of the Congo (DRC).
- Section 2.2 proposes to frame all REDD+ activities in a land conversion matrix, based on this binary stratification.
- Section 2.3 suggests that the conversion matrices could be used as basic historical datasets for setting RLs and for assessing performance under each REDD+ activity, improving the credibility and environmental integrity of REDD+ as a whole.
- Section 3 gives blueprints and a rationale for a workable REDD+ accounting logic for early performance-based payments, either in phase 2 (demonstration activities) or phase 3 (full implementation).
- Section 4 provides a glossary that is aimed at clarifying specific terms used in this paper.

2. Method: the matrix approach

If very stringent monitoring requirements would prevent the least developed countries from accessing full REDD+ incentives, avoided forest loss and degradation in better equipped countries may simply be displaced elsewhere (Oliveira *et al* 2007). Neither the usual grouping of degradation with deforestation, nor the alternative grouping of degradation with EoCS and SMoF (Herold and Skutsch 2011), would shed as much light on actual forest trends as the full disaggregation of emissions, removals and RLs by activities. For REDD+ to be effective, the majority of forest-rich countries must therefore be in a position to set credible RLs against which progress can be measured and verified for all significant activities. Reliable and consistent time series should therefore be constructed for measuring and monitoring emissions and removals. To allow most countries to join the REDD+ mechanism in the near future, one option is to offer the possibility of simplified monitoring approaches that would:

- be in close alignment with IPCC guidance and current agreements under the climate convention;
- make a link between REDD+ monitoring, implementation and reporting;
- target the most critical drivers of deforestation and degradation;
- use reliable data that are readily available for all/most countries wishing to participate in the REDD+ mechanism;
- allow for the progressive incorporation of sub-national or transboundary datasets (e.g. obtained from demonstration activities in phase 2) to national level in a consistent framework; and
- encourage and anticipate a gradual build-up of capacities.

This section introduces three interdependent concepts which together could set the frame of such a simplified approach to MRV and RLs for REDD+. It has been successfully tested in a hypothetical REDD+ situation. For demonstration purposes only, we used the DRC as an example for which we conducted our analysis for the periods 2000–2005 and 2005–2010. As our analysis is based on existing DRC forest map products (OSFAC 2010), only negative evolutions were recorded and only two five-year periods were considered, with results giving only a partial view of the situation in DRC.

2.1. Concept 1: a simple definition of degradation, based on 'natural/intact' and 'non-intact' forests

Agreeing on global definitions of forest concepts has proved extremely challenging for decades. For example, generic definitions of forest degradation (such as 'the reduction of the capacity of a forest to provide goods and service') exist for about 50 countries or specific contexts. Definitions that allude to multiple forest benefits and soil conditions may treat forest values in a comprehensive manner, but are more difficult to use for international purposes in a consistent and transparent manner. The definition of degradation developed by IPCC focuses on human induced changes in the carbon cycle but this definition has not been operationalized and has no formal status (Simula 2009). In addition, the latest decision (UNFCCC 2012) on REDD+ financing acknowledges explicitly the potential for REDD+ to deliver (and incentivize) more than mitigation (including biodiversity, resilience and adaptation benefits).

In a number of developing countries, the main source of emissions from forests beyond deforestation has originated from the conversion of unmanaged ('intact') forests into 'non-intact forests', through logging or other degradation processes (Maniatis and Mollicone 2010). The bulk of degradation could therefore be considered (in these areas) as a transition departing from intact forests (Mollicone *et al* 2007). Building upon this proposal, we suggest a stratification of the 'forest land' category (from table 2) into two subcategories, 'natural/intact forests' (IFL) and 'non-intact forests' (NIFL = all other forests).

In order to create a proxy map for 'natural/intact forests' and 'non-intact forests' we applied Morphological Spatial Pattern Analysis (MSPA, Soille and Vogt 2009). We consider thereafter the MSPA class 'core forests' (see glossary in section 4) as a proxy for 'natural/intact forests', the 'non-core' classes being considered as a proxy for 'non-intact forests' i.e. as forests possibly exposed or vulnerable to degradation. Please note the MSPA tool is just one of the many tools that could be used to distinguish between IFL and NIFL. The purpose of this paper is to suggest that based on this distinction (irrespective of how it is done), it would be possible to monitor and account for the 5 REDD+ activities in a more detailed manner.

Regarding the observation scale, the MSPA proxy captures forest degradation as a transition, the actual nature of which depends on the spatial resolution and periodicity of the input maps: for example, the MSPA of frequent, fine spatial resolution input maps would probably capture patterns of low intensity forestry, small scale subsistence farming, and traditional use by indigenous peoples. The MSPA of low spatial resolution input maps would solely capture processes due to large infrastructure (new roads) or large scale deforestation, which nonetheless usually signals the shift towards more intensive land use and severe carbon loss, and would most often lead to increasing conversion from 'intact/natural forests' to 'non-intact forests'.

The underlying assumption remains that forests that are sufficiently remote from non-forested areas (i.e. at a certain distance from roads, navigable waters, croplands, grasslands, mines, etc) are much less exposed to significant anthropogenic degradation (Mollicone *et al* 2007). Using 'non-core forest' as a proxy for 'non-intact forests' is therefore both pragmatic and result-oriented. According to a thorough literature review and a case study in Broadbent *et al* (2008), forest degradation (disturbances, logging and fragmentation related edge effects) is more prone at the edges. Broadbent *et al* (2008) further provide a list of detrimental effects of forest fragmentation: changes in forest micro-climate, increases in wildfire susceptibility and tree mortality, changes in plant and animal species composition, seed dispersion, predation, increased hunting, changes in forest structure, and resource extraction or conversion to agriculture. The distance to which these effects penetrated the forest was studied up to 2 km from the borderline. Southworth *et al* (2011) show that deforestation rates drop with distance from major roads. Numata *et al* (2010, 2011) also report that forest fragmentation is one of the major causes of forest degradation in the Amazon; the forest canopy density collapses near forest edges. The combined carbon emissions from these forest disturbances and fragmentation related edge effects may exceed 10% of deforestation-based carbon flux estimates. Numata *et al* only assumed degradation within 100 m of forest edges during the first four years, but they acknowledge that degradation can occur up to 300 m from the edge and over longer periods. The land cover part of the UNFCCC definition of forest land is now broadly accepted by parties. Moreover it has been selected by the FAO for their latest global remote sensing survey (FAO 2010) which allows benefiting from available, objective and harmonized forest information from satellites. OSFAC (2010) produced such wall-to-wall maps (using LANDSAT TM/ETM+) of forests in the DRC for the years 2000, 2005 and 2010 at 60 m × 60 m spatial resolution (i.e. 0.36 ha). We ran the MPSA tool on these maps using OSFAC's category 'primary forest' as binary raster input. The OSFAC category 'primary forest' corresponds to the IPCC biome 'tropical rain forest'. The OSFAC categories 'dry forest' and 'secondary forest' correspond to the IPCC biomes 'tropical dry forest' and to a mixture of secondary forests, plantations and rural complex. These two categories are not considered for the current analysis. Using year 2000 as the primary input map (figure 2), we tested several minimal mapping units (MMUs) and thickness values to see how they influence the percentage

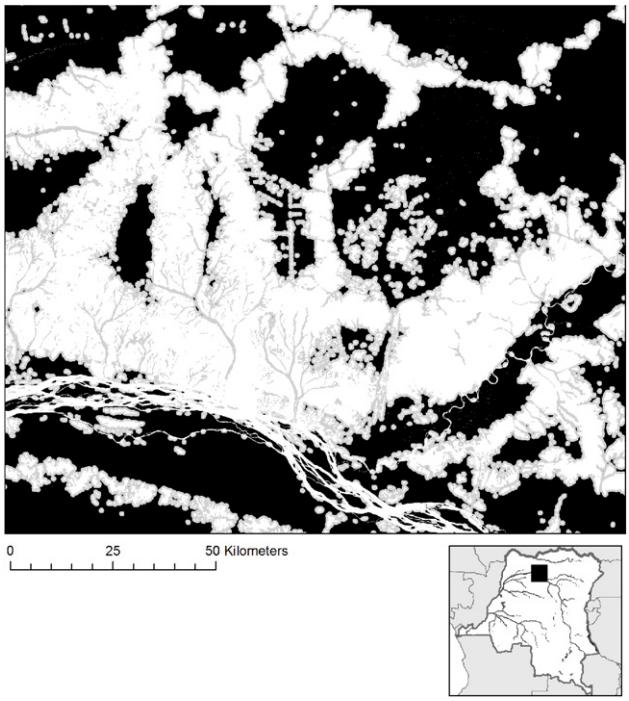

Figure 2. Sample MSPA forest map in the central part of DRC (black = natural forest land, gray = exposed forest land, white = non forest; edge size = 500 m, minimum mapping unit = 2 ha).

of forests that would be classified as 'natural forests' for this specific rain forest type (table 4).

Based on Broadbent *et al* (2008), intact forest maps (Potapov *et al* 2008) and visual interpretation, we consider an edge depth of 500 m as a reasonable threshold to delineate 'natural/intact' rain forests in the DRC. Further adjustment might be needed depending on biomes, resolution and ground truthing. Objects smaller than two pixels were removed from the original input maps as potential artifacts. The degradation effect of large roads remains perfectly visible.

The MSPA proxy for distinguishing IFL/NIFL can generate forest cover and forest change maps. Such maps may also be obtained from, or in combination with, other automated tools such as CLAS and CLASlite (Asner *et al* 2009). CLASlite performs automatic mapping of forest loss (deforestation), gain (secondary regrowth) or degradation (areas of persistent forest disturbance) based on spectral signatures of satellite images. However, CLASlite alone does not distinguish automatically different types of disturbance (anthropogenic versus natural; logged versus fire scars), and is more resource intensive in terms of image processing, expert interpretation and computing time (one hour for 100 × 100 km^2 to map forest compared to a few seconds for the MSPA) than the MSPA/GUIDOS tool. MSPA could for example identify 'non-intact forests' from wall-to-wall, low and medium spatial resolution forest maps (at national level) and let CLASlite estimate 'actual degradation rates' on a sampling basis, from high resolution data to obtain more accurate IFL/NIFL forest change maps.

Table 4. Effect of MMU and edge thickness on the proportion of natural forests in the DRC.

	MMU		
Edge thickness (m)	0.36 ha	2 ha	5 ha
200	83.3%	N.A.	N.A.
500	70.6%	76.0%	78.3%
2000	35.3%	N.A.	N.A.

2.2. Concept 2: the transition matrix

The stratification proposed by the first concept could spare negotiators and developing countries the need to adopt definitions for the five activities to be supported under REDD+; the stratification of the forest land category into two subcategories (IFL/NIFL) can be used to distribute—and implicitly define by their results—the five REDD+ activities in a more detailed transition matrix (table 5).

The activity 'enhancement of carbon stocks' is split in the matrix between forest restoration and afforestation/reforestation. This would allow for rewarding specifically the former (which may be considered exceptional on short time periods, i.e. over the duration of a commitment period), or factoring out the latter as appropriate (e.g. if already accounted for under the Clean Development Mechanism).

To avoid the displacement of deforestation and forest degradation to countries with high forest cover and low deforestation rates, Griscom and Cortez (2009) argue that not only 'flow activities' but also 'stock activities' (respectively white and gray cells in table 5) should be rewarded to 'provide balanced incentive payments [and] conserve forests in both historically high and low deforestation countries, while maintaining a level of environmental integrity necessary for progress towards global REDD+ goals'. The proposed matrix allows for such consideration and furthermore underlines the specific role of natural forests, which goes beyond mitigation to preserving biodiversity and maintaining essential ecosystem services. The matrix does not allow converting non-forest land into natural forests; new 'natural forests' would mechanically be requalified as NIFL for at least two commitment periods (first as afforestation/reforestation then as restoration) before being potentially considered as natural/conservation forests (if they meet the requirements for IFL). Many forest structural properties, such as deep canopies, associated with wildlife habitat in intact forests, are not likely to be regained for 30–50 years or more following disturbance (Plumptre 1996).

We applied the MSPA tool with the criteria in table 4 (filtering two-pixels objects, 500 m edge) on the forest maps of the DRC for the years 2000, 2005 and 2010. Table 6 provides the transition matrices between successive maps.

According to our analysis 0.83 million ha of the DRC rainforests were 'degraded' from IFL to NIFL status during 2000–2005 and 1.4 million ha during 2005–2010. Gross deforestation rose from 0.34 million ha to 0.65 million ha over these periods. The current assumption that 'non-intact forests' are likely to be degraded would need to be validated (using other tools and/or groundtruthing) but it can already

Table 5. REDD+ activities matrix in expanded IPCC categories.

	To		
From	Natural/intact forest land	Non-intact forest land	Other land
Natural/intact forest land	Forest conservation	Forest degradation	Deforestation
Non-intact forest land	Enhancement of carbon stocks (forest restoration)	Sustainable management of forests	Deforestation
Other Land	→→→[a]	Enhancement of C stocks (afforestation/reforestation)	

[a] The areas that would appear as 'converted to natural forest land' (plantations, restoration or land abandonment) should mechanically be requalified as 'non-intact forest' for a duration ensuring that natural structural properties, such as deep canopies, tree diversity and suitable wildlife habitat, have been regained.

Table 6. Transition matrices for rainforests of the DRC for the periods (a) 2000–2005 and (b) 2005–2010 (103 ha). (Note: IFL = natural/intact forest land. NIFL = non-intact forest land. OL = other land note: available input maps did not reflect afforestation, reforestation or restoration, for methodological purposes the shaded cells could therefore not be properly computed and were left blank.)

	(a) 2000–2005				(b) 2005–2010		
	IFL 2005	NIFL 2005	OL 2005		IFL 2010	NIFL 2010	OL 2010
IFL 2000	78 424	828	26	IFL 2005	76 950	1407	66
NIFL2000	—	24 747	316	NIFL2005	—	24 976	599
OL 2000	0	—	123 839	OL 2005	0	—	124 182

be noted that the bulk of deforestation does occur in NIFL areas. Additional layers of ground-based data (protected areas, logging concessions, soil type, etc) could be added to the IFL/NIFL maps over time to improve the delineation of forest types and categories.

2.3. A simplified reporting for performance-based implementation of REDD+ activities

Our third concept suggests structuring the early national REDD+ MRV in a four-step approach.

For each broad forest category within the country (as defined in the IPCC guidelines, i.e. tropical rain forest, tropical dry forest, etc):

(a) parties agree on an incentive scheme;
(b) before the start of the commitment period, each country proposes RLs (in hectares) for each REDD+ activity (disaggregated as in the transition matrix of table 5), to be reviewed and agreed at UNFCCC level;
(c) at the end of the commitment period each country would report for each REDD+ activity the difference between its RLs and the actual area changes observed during the commitment period; to obtain emission and removal estimates, the differences in area for each cell of the transition matrix should be multiplied by default emission factors associated to each activity (until better estimates become available);
(d) based on the information provided in (b), as well as supplementary data if appropriate, each country would apply for performance-based payments.

2.3.1. Step 1: agreeing on an incentive scheme. The relative weight of incentives targeting the different activities and ecosystems will ultimately determine how REDD + impacts forest management practices. REDD+ incentives should therefore prioritize the activities that would best achieve the REDD+ objectives in a given context. For instance, in countries such as Indonesia where forest carbon stocks still decrease while deforestation rates drop, it could mean specifically encouraging reduced degradation and sustainable management of forests (FAO 2010).

Yet, REDD+ should also direct incentives towards actions which maximize potential benefits in poverty alleviation and biodiversity, including strengthening ecosystem resilience and services (Council of the European Union 2008, UNFCCC 2012). In order to maximize the long-term benefits of REDD+, it would need to focus on conserving existing natural forest, especially intact primary forest (Cotter *et al* 2010, Gibson *et al* 2011); it should also maintain traditional forest use, agroforestry and community forestry which provide a wealth of socio-economic benefits for little carbon price. Brun *et al* (2006) found that in Malaysia carbon density decreased by less than 10% as forest was converted to swidden agriculture. However, further intensification into permanent agriculture depleted stocks by almost 50%.

Different incentive schemes (price per ha or per ton of carbon, baseline adjustments, biodiversity premiums, payments for ecosystem services) should therefore be set for different contexts, to reflect country situations and the relative benefits of REDD+ activities in terms of mitigation, adaptation, food security, poverty alleviation and biodiversity, and the trade-offs and synergies between managing forests for local people and for global climate. For example, over-logged forests with high biodiversity values could receive specific support to avoid further conversion into cropland (Berry *et al* 2010, Edwards *et al* 2011). In practice it would require the effective consultation of affected stakeholders and setting fair benefit sharing arrangements, based on actual efforts and so-called co-benefits.

Given the proposed transition matrix and the results shown in table 7, different incentive schemes could have been developed to prioritize different goals; take the following, for example.

- If the goal were to increase the credibility of emission reductions, especially in the initial phases of setting MRV systems and especially where Tier 1 (i.e. very uncertain) carbon stock change factors are used, the evaluation process may involve multiplying the results by conservativeness factors to take into account the uncertainty of input data. This approach could follow the mechanism which is already in place for adjusting annex-1 GHG inventories under the Kyoto Protocol (UNFCCC 2006) and be applied to the uncertainty of the emission trends (Grassi *et al* 2008). If the same Tier 1 carbon stock change factors are used in both RL and in the accounting period (which means that the errors of emission factors are fully correlated), the required conservativeness factors to be applied to emission reductions would involve relatively small discounts (i.e. potential credits would be discounted by 10%–30%, depending on the uncertainties of input data). In this way, the conservativeness principle would help broaden participation in REDD+ while incentivizing increases in the accuracy of the estimates.
- If priority were to be given to the preservation of 'natural forest' (e.g. safeguard 2e in appendix 2 of UNFCCC (2001), a positive result for 'conservation' activities in the commitment period as compared to RL (e.g. 221 000 ha in table 7) can be set as a precondition for other activities to be eligible for support.

2.3.2. Step 2: establishing reference levels. The 'forest transition curve' (Rudel *et al* 2005) offers a good theoretical backdrop: it foresees the relative loss of forest below 'natural carrying capacities'. With development, forest cover decreases, reaches a trough, then rises and stabilizes at a 'sustainable level'. The overall mitigation priorities of REDD+ are first stopping and reversing carbon loss in the forests (by making the curve bottom-out sooner and rise higher than 'normal') and second, recapturing carbon faster (i.e. raising the curve's final slope). However, the forest transition curve is not predictive, it does not say when a country will reach the next stage nor defines where the sustainable end result of the conversion would stand.

In the case of the DRC, assuming that values in table 6(a) are used as a historical REDD+ dataset, its position on the curve would be a solid and transparent basis for negotiating the RLs of each activity for 2005–2010. The DRC could for instance anticipate that their agriculture and timber production would expand at the expense of natural forests, and thus forecast, for example, an increase of deforestation and degradation rates. For illustrative purposes, we assume they would have built their RL based on +50% and +100% increases respectively.

In this specific case, it would mean the DRC might temporarily increase its forest emissions and still apply for REDD+ support. However, for REDD+ to fulfil its mitigation purpose, the sum of all RLs of all participating countries should amount to a significant global reduction/inversion of forest emissions over time. This would imply that developing countries should not enter the full implementation phase of REDD+ until a number of them (covering a high percentage of global forests) are ready to do so.

2.3.3. Step 3: reporting on the difference between RLs and actual transitions. Table 7 provides transparent and consistent information for each REDD+ activity, based on simple metrics. This table is flexible in the sense that it first allows for sub-performance in one activity to be compensated elsewhere (here deforestation rates higher than expected are compensated by degradation rates lower than expected).

Second, the basic metrics (activity areas) may be easily combined with various sources of information on emission factors (i.e. C stock change/ha). In the example of table 7, Tier 1 data are used but Tier 2 country-specific values of carbon stocks or carbon stock changes would increase the accuracy. At present default Tier 1 values of carbon stocks/ha for EFL (per each broad forest category and continent) are lacking in the IPCC guidelines. Broadening this approach would require asking the IPCC to produce carbon stock estimates (average and uncertainty, by biome) for 'non-intact forests' based on a screening of literature. This would allow deriving estimates of C stock changes and uncertainty estimates for each REDD+ activity.

Third, while in principle all C pools should be reported, a simplified reporting could be allowed (e.g. reporting only above ground biomass) if evidence can be provided that this simplified reporting produces conservative estimates of emission reductions/sink increases.

2.3.4. Step 4: incentives. This last step in the MRV process should leave room for parties to review/validate the estimates, and to provide additional information on e.g. participative monitoring, recalibrations, safeguards, soil types, protected areas, peatlands, fires, force majeure and relevant policies and measures. It could also include adjustment factors based on overall national development to reflect the principles of common but differentiated responsibilities and respective capabilities.

3. Discussion and conclusions

3.1. The cost-effectiveness of REDD+

Until now, countries wishing to participate in the REDD+ mechanism have allocated a major share of readiness efforts into MRV systems for forest carbon stocks. An analysis of the 'Readiness Preparation Proposals' to the World Bank and to the UNREDD (Simula 2010) shows that designing and setting up a national monitoring system represents about 40% on average and up to 80% of readiness costs. The negotiating mandate of the UNFCCC is to agree on the most effective and efficient way to prevent anthropogenic interference with the climate system. Measuring emission reductions

Table 7. Result of a virtual REDD+ commitment period 2005–2010 for the DRC, based on a hypothetical RL that would have been adopted in 2005. (Note: IFL = intact/natural forest land. NIFL = non intact forest land. OL = other land.)

	Deforestation (in 5 yrs)		Degradation (in 5 yrs)	Enhancement of carbon stocks[a]		Sustainable management of forests	Conservation	Total
	IFL to OL	NIFL to OL	IFL to NIFL	NIFL to IFL	OL to NIFL	NIFL to NIFL	IFL to IFL	
Area (10^3 ha)								
Historical 2000–2005	26	316	828	—	—	24 747	78 424	228 180
Ref. Level 2005–2010[b]	+50% = 39	+50% = 474	+100% = 1656	—	—	25 101	76 729	228 180
Actual 2005–2010	66	599	1407	—	—	24 976	76 950	228 180
Difference (actual−RL)	27	125	−249			−125	221	0
C losses (−) (tC ha^{-1})[c]	−150	−73	−78					
C increment (+) (tC ha^{-1} yr^{-1})[d]				—	—	16	05	
Cumulated credits (+) or debits (−) in 2010, MtC[e]	−41	−91	193	—	—	—10	06	85

[a] Due to technical limitations in the input maps, these categories could not be properly computed for the case at hand but, in principle, they should also return positive figures and would have contributed to higher forest removals. This table is therefore for illustrative purposes only.

[b] Assuming for the RL an increase of 50% for deforestation and of 100% for degradation as compared to 2000–2005 (see section 2.3.2). As the total land area is constant, and two categories were missing, these three virtual RLs were enough to set the bar for five activities. In practice five RLs would be required.

[c] Assuming the following values of biomass carbon stocks: IFL: 155 tC ha^{-1} (IPCC 2006); NIFL: IFL/2 (or 50% degradation on average in non-intact forests, (Mollicone *et al* 2007); OL: 5 tC ha^{-1}.

[d] Values for NIFL to NIFL are from IPCC (2006), values for IFL to IFL are from Lewis *et al* (2009).

[e] Calculated as the difference in area (actual minus RL) multiplied by the C stock gain or loss of each activity over the five year period.

compared to arguable scenarios, fraught with very complex macroeconomic assumptions (on energy and commodity markets, demographics and exchange rate volatility) might not be the first priority to achieve this objective. On the other hand, tackling the socio-economic drivers of deforestation might deliver significant emission reductions, even though they remain difficult to quantify accurately.

Delaying performance-based payments would undermine the commitments of countries wishing to participate in the REDD+ mechanism. Phases 1 and 2 should help these countries build capacity to provide regular, complete and meaningful information. The matrix approach would make it easier for some of these countries to participate in the mechanism. The metrics and terminology of the matrix approach are transparent and would enable informed choices on forest management. The simplicity and low technical requirements would allow resource savings which can be reallocated to tackle the drivers of deforestation.

Whatever the future of REDD+, prioritizing exhaustive and comparable area measurements from remote sensing (i.e. promoting IPCC Approach 3 while allowing the use of default carbon stock change factors until better alternatives become available) over better carbon stock change factors (moving from Tier 1 to Tier 2/3) in the MRV of REDD+ would reward early action and enable a gradual build-up of capacities. It took countries such as Brazil and Europe several decades to develop operational forest monitoring systems; other countries will need time to catch up. Meanwhile priority should be given to specific and concrete actions.

- Focusing readiness on 'accurate MRV' might lead to a REDD+ mechanism that would work only for a few countries in the medium term. Global operational MRV systems would then only pick up limited emission reductions in a distant future.
- Developing instead 'inclusive MRV' (simple, robust, replicable, responsive to actual changes, consistent) and addressing directly the drivers of forest loss and degradation (fragmentation) could be a more effective way to actually reduce emissions in the near term.

3.2. REDD+ and carbon conservativeness

IPCC guidance requires Tier 2/3 methods for 'key categories' (i.e. the major sources of emissions in a country, likely including deforestation and forest degradation in most developing countries), which involve country-specific carbon stock change factors. For those countries with limited capacity to develop country-specific carbon stock change factors, if the proposed matrix for activity data is combined with Tier 1 (i.e. very uncertain) default carbon stock change factors, the high uncertainties of the resulting emission estimates can be taken into account through the conservativeness factors, i.e. applying a discount to those estimates of emission reductions which do not fully follow IPCC guidance (e.g. when Tier 1 is used for a key category).

The approach proposed here, that the same Tier 1 carbon stock change factors are used in RLs and in the accounting period, means that the errors from carbon stock change factors are fully correlated in both the RL and accounting period, and thus the uncertainty of trend is considerably lower than the uncertainty in the level of emissions (Grassi *et al* 2008). This means that applying the conservativeness factors to the uncertainty of the trend will not dramatically impact the estimates of emission reductions. In this way, the participation to REDD+ could be broadened while maintaining strong incentives for further increasing the accuracy of the estimates.

3.3. REDD+ and biodiversity, natural versus managed forests?

The effects of intensified forest management (to produce more timber, fuel wood and other forest commodities) is one of the most direct causes of variations in forest carbon stocks, yet the substitution benefits of using a larger share of forest biomass does not always compensate the loss of forest carbon (Hudiburg *et al* 2011). In table 7 for instance, it is implied that net carbon removals from disturbed/managed forests are 1.1 tC/y higher than net carbon removals from natural/intact forests. Yet it does not say what happens to the biomass extracted (instantaneous oxidation or longer term use in harvested wood products), which would change the overall carbon balance of forestry operations. If we assume instantaneous oxidation (like with biomass for energy), then degrading natural/intact forests towards more intensive forest management is a bad idea mitigation-wise: the 78 tC ha^{-1} that are lost with degradation will take roughly 70 years to be compensated by higher removals.

The underlying message in the matrix approach is that there might be legitimate trade-offs between forest management strategies (for climate and biodiversity purposes) and human development needs, and that these choices are not carbon neutral. They should be properly accounted for, which is only possible if REDD+ results can be disaggregated by biomes and by REDD+ activities. Most often though, high biodiversity, high carbon and high social benefits can be obtained together if due attention is given to local population needs and ecosystems' resilience.

The MSPA tool can provide an indicative distribution of 'natural/intact' forests and 'non-intact forests'. Over time, it could objectively allow the monitoring of transition processes associated with fragmentation and related to forest degradation. It could also contribute to the objectives of the UN convention on biodiversity. Each country has to define how to include biodiversity in its national REDD+ strategy but this decision is strongly influenced by the availability of information (Pistorius *et al* 2011). The seven pattern classes of the MSPA tool can contribute to cost-effective monitoring of landscape level forest biodiversity indicators. It is in a sense a 'Tier 1 for forest biodiversity monitoring' (Gardner *et al* 2011).

3.4. Drawbacks of the matrix approach and further research

Designing credible RLs and efficient/effective incentive schemes for REDD+ activities *ex-ante* remains challenging.

Current and future experience with REDD+ demonstration activities will tell whether it is a viable path.

MSPA is solely based on geometric concepts and depends on the availability and quality of the input forest land cover maps. Other tools should be tested and/or combined at country level to identify more accurately IFL/NIFL.

DRC is unique in that it contains extensive forests that have historically experienced low deforestation rates, further experimentation in other country situations is needed to test the suitability of the concepts to different country contexts.

Forest degradation is not necessarily a transition from intact/natural to managed/non-intact forest—rather, intact forests can be highly managed (e.g. national parks) and degraded forests can be unmanaged (e.g. understory fires from deforested lands escaping into unprotected forest edges). To what extent IFL → NIFL is a valid proxy for degradation should therefore be further tested.

4. Glossary

For the purposes of this paper, the following definitions have been used.

- Non-hierarchical 'approaches' versus hierarchical 'tiers': the IPCC provides guidance on the use of three generic 'approaches' for representing land areas and three 'tiers' for estimating emissions and removals. For the areas, the IPCC does not provide detailed guidance on the methods to estimate land areas and changes in land area associated with LULUCF activities. In practice, countries use a variety of sources including agricultural census data, forest inventories and remote sensing data, but definitions that different authorities use in assembling the data are not always consistent. IPCC therefore provides guidance on the use of three generic 'approaches' for representing land areas and three 'tiers' for estimating emission and removals. The approaches do not imply any increase or decrease in accuracy. They are not mutually exclusive, and the approach(es) selected by a country should reflect emission estimation needs and national circumstances (IPCC 2006). Similarly to current requirements under the Kyoto Protocol, it is likely that under REDD+ land-use changes would be required to be identifiable and traceable in the future. This would imply that Approach 3 would be required in any case for the full implementation of REDD+ (GOFC-GOLD 2010). By contrast, the tiered structure of methods for estimating emissions and removals is hierarchical: higher tiers imply increased accuracy in the estimation of the emissions and removals. Moving from Tier 1 to Tier 2 or 3 would increase the accuracy of the estimates of carbon stock change, but would also significantly increase the costs of monitoring as compared to Tier 1 (UNFCCC 2009). The requirements of the matrix proposed in this paper are basically 'Approach 3 + Tier 1' (or better).
- IFL 'intact forests' are defined in Potapov *et al* (2008) as: '... an unbroken expanse of natural ecosystems within the zone of current forest extent, showing no signs of significant human activity, and large enough that all native biodiversity, including viable populations of wide-ranging species, could be maintained'. We take the view that monitoring IFL would not only enable using the matrix approach for estimating emissions but could also operationalize further the safeguard on the 'conservation of natural forests and biological diversity', as set in the REDD+ legal framework (UNFCCC 2011). Therefore we used 'IFL' and 'natural forests' as a single concept.
- NIFL 'non-intact' forests: by definition, NIFL cover all the forests that would fall under the national forest definition and that would not qualify as IFL.
- Forest reference levels: benchmarks for assessing each country's performance in implementing REDD+ activities. They shall be established transparently taking into account historic data, and adjusted for national circumstances, and maintaining consistency with anthropogenic forest related greenhouse gas emissions (UNFCCC 2012).
- MSPA classes: the software GUIDOS requires raster binary ('forest'–'non-forest') maps as input, with a focal class (forest) for which the geometry and connectivity (spatial pattern) components are retrieved using an automated sequence of mathematical morphological operators. This methodology automatically maps and classifies the focal class ('forests') into the seven mutually exclusive generic MSPA classes: 'core' and six non-core classes ('islet', 'perforation', 'edge', connectors as 'loop' and 'bridge', and 'branch'). The edge depth (we used 500 m) is the only entry parameter set by the operator; it represents the distance to the (forest–non-forest) borderline and enables the delineation of the core (interior) part of patches (beyond this distance). The six non-core classes identify different types of forest areas within this distance to the borderline; they were merged together as a single NIFL class for the purposes of our analysis. Please see Soille and Vogt (2009) for further details.

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