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LETTER

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Stéphane Mermoz¹ , Alexandre Bouvet¹, Thuy Le Toan¹ and Martin Herold²¹ Centre d'Etudes Spatiales de la Biosphère (CESBIO), Université de Toulouse, CNES, CNRS, IRD, UPS, F-31401 Toulouse, France² Center for Geoinformation, Wageningen University, Droevendaalsesteeg 3, 6708 PB Wageningen, The NetherlandsE-mail: stephane.mermoz@gmail.com**Keywords:** tropical forestry, savannahs, carbon stocks, REDD+Supplementary material for this article is available [online](#)**Abstract**

In this paper, we aim to assess the impacts of the forest definitions adopted by each African country involved in the global climate change programmes of the United Nations on national carbon emission estimations. To do so, we estimate the proportion of national carbon stocks and tree cover loss that are found in areas considered to be non-forest areas. These non-forest areas are defined with respect to a threshold on the percentage of tree cover adopted by each country. Using percent tree cover and aboveground biomass maps derived from remote sensing data, we quantitatively show that in many countries, a large proportion of carbon stocks are found in non-forest areas, where a large amount of tree cover loss can also occur. We further found that under the REDD+ framework (reduced deforestation, reduced degradation, enhancement and conservation of forest carbon stocks, sustainable management of forests), some partner countries have proposed activities related to only reducing deforestation, even when a large proportion of their carbon stocks are stored outside forests. This situation may represent a limitation of the efficiency of the REDD+ mechanism, and could be avoided if these countries choose a lower tree cover threshold for their definition of forests and/or if they were engaged in other activities.

1. Introduction

Countries that have ratified and/or are signatories to the United Nations Framework Convention on Climate Change (UNFCCC) have been involved in developing relevant policy processes that aim at mitigating the effects of climate change by protecting forests, including agreements such as the reducing emissions from deforestation and forest degradation (REDD+) agreement. The basic idea of REDD+ is simple: a developing country can negotiate for financial compensation in return for reducing its greenhouse gas emissions from deforestation and degradation of forests (Parker *et al* 2009, Mertz *et al* 2012). REDD+ goes beyond deforestation and forest degradation and includes the conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks.

Within the framework of REDD+, developing countries obtain and receive results-based finance only if emissions reductions are measured, reported

and verified (MRV) relative to forest reference emission levels (FREL). For this purpose, multi-temporal maps of aboveground and belowground biomass (AGB and BGB, respectively) generated from Earth observation and *in situ* data (Mitchard *et al* 2013, Goetz *et al* 2015) are recommended. Such maps are assumed to be directly convertible to carbon. However, multi-temporal AGB maps are currently not available, and the accuracy and spatial resolution of global AGB maps still need to be improved. Alternatively, the standard method applied in practice consists of using widely available Earth observation optical data (namely, Landsat) to assess the annual change in forest cover (Hansen *et al* 2013) together with *a priori* knowledge of the values of forest carbon per unit area in different forests to estimate carbon loss. However, compared with estimates from the Food and Agriculture Organization of the United Nations (FAO), the estimates of forest cover change for Africa from Hansen *et al* (2013) are under-estimated, although

lowering the tree cover threshold to include more change reduces this under-estimation. The lack of agreement reflects the difficult nature of mapping change in low biomass areas, which represent half of the remaining areas of natural forest in Africa. The disagreement also reflects the lack of systematic forest inventories and mapping capabilities for many African countries (Hansen *et al* 2013). In addition, countries tend to report only deforestation when using these approaches and not forest degradation, which is defined as a disturbance event leading to substantial reductions in carbon stocks, biodiversity and ecosystem services, within a forest that is not converted to other land uses and remains forest (Mertz *et al* 2012). Crucially, these estimates of forest cover and forest cover change, and the carbon emissions that are effectively taken into account, are highly dependent on the definition of a forest.

Defining what constitutes a forest is not easy. Forests characteristics differ widely both spatially and temporally, due to factors such as temperature, rainfall patterns, solar insolation, terrain elevation, soil composition and human activity. How a forest is defined also depends on who is doing the defining and for which purpose. In fact, a forest can be viewed through different lenses (e.g., as an ecosystem, an agricultural system, a landscape component, a socio-ecological system or land managed for timber), which leads to specific forest definitions. However, policies dealing with a broad range of forest issues are often based on definitions created for the purpose of assessing global forest stocks (Chazdon *et al* 2016). In this case, the definitions are generally very broad and are based on a small set of parameters derived using remote sensing and/or *in situ* data. This set of parameters, used in this carbon-oriented study, typically includes tree cover (TC—canopy density determined by estimating the percentage of ground area covered by the vertical projection of trees crowns), tree height (H) and the minimum mapping unit (MMU). TC is a major forest definition component that has been used for decades by FAO (Sasaki and Putz 2009) and by the remote sensing community because it can be readily monitored using standard remote sensing techniques. Note that TC is not necessarily correlated with AGB, particularly in dense forests. The UNFCCC lets each country select their national forest definition (NFD) using values for these three parameters, which are chosen within the following ranges: 10%–30% for minimum TC; 2–5 m for minimum H at maturity; and 0.05–1.0 ha for MMU. However, in the context of REDD+, countries can select an NFD outside these ranges of values as long as they justify their choice if it differs from other definitions used, for example, by the FAO.

Because the choice of NFD impacts the estimation of changes in forest cover and hence the estimation of carbon emissions (Saatchi *et al* 2011, Sexton *et al* 2016), we can examine the impact of NFD choice. There have been calls for stricter definitions of forests that qualify for

credits to help reduce greenhouse gas emissions from forest degradation (Sasaki and Putz 2009). For example, Sasaki and Putz (2009) proposed an extension of the minimum TC to at least 40% and the minimum H to 5 m, in relation to the definition of forests adopted in 2001 under the Marrakesh Accord of the Clean Development Mechanism, thereby allowing more disturbances to qualify as deforestation rather than degradation (Broadbent *et al* 2008) (e.g., disturbance with associated TC decreases from 80% to 35%). This new definition, which would result in less carbon loss in forest areas that would go unaccounted for in non-forest areas, appears to be relevant to countries that are mostly covered with dense forests. Indeed, forest degradation is found to be a key emission source (GFOI 2016) and can exceed the emissions from deforestation in countries with dense forests such as the Democratic Republic of Congo (Zhuravleva *et al* 2013).

However, using a minimum TC of at least 40% may lead to major consequences for areas with sparse or low TC. In this paper, such areas will be referred to as ‘savannahs’, as understood in the broadest sense, i.e., a subtropical or tropical grassland region with scattered trees ranging from open plain to woodland. The term ‘savannah’ therefore represents any kind of mixed tree-grass ecosystem, including woodlands and most dry forests. The definition of forests is as important for savannahs as for forests (Chazdon *et al* 2016). Indeed, savannahs are increasingly becoming recognized for their essential ecosystem services, including the provisioning of water, production of livestock forage and carbon storage, the last of which is comparable to that of forests when AGB and BGB are considered (Overbeck *et al* 2015). Recognition of these ecosystem services is particularly relevant in Africa, where savannahs account for approximately half of the total above-ground carbon (Bouvet *et al* 2018). Nonetheless, savannahs are currently impacted by anthropogenic activities including afforestation and deforestation. The afforestation of open ecosystems, generally referring to the conversion of savannahs into plantations, may aid in the storage of carbon in the long run but represents an ecological disturbance and a potential ecological disaster that results in massive loss of biodiversity (Fernandes *et al* 2016). In addition, the deforestation rates in African savannahs have been found to be higher than those in tropical rain forests, where extensive deforestation has been avoided thus far in favor of selective logging (Ciais *et al* 2011). Contrary to expectations, Ryan *et al* (2012), for example did not find evidence that clearance in African woodlands was targeted towards areas of high biomass. Note that some studies have cast doubt upon deforestation rates reported in Africa. Fairhead and Leach (2003), for example, argued that the rate and extent of deforestation in Western Africa have been massively exaggerated and presented strong evidence to support a rethinking of deforestation history. In countries that are mostly covered by savannahs and even countries

Table 1. For each of the 30 African REDD+ and/or UN-REDD partner countries: total surface, proportion in savannahs, national definition of forest (minimum tree cover TC; mapping unit, MMU; and height), total aboveground biomass stocks from the Bouvet *et al* (2018) map, proportion of biomass stocks in areas considered to be non-forest areas, national tree cover loss from 2001 to 2016, proportion of tree cover loss below the respective tree cover values when using the tree cover map from Hansen *et al* (2013), and REDD+ activities as described in UNFCCC FREL (D means deforestation, DD deforestation and forest degradation, + enhancement and/or conservation of forest carbon stocks and/or sustainable management of forest)

Countries	Surface 10 ³ km ²	Savannah %	TC %	MMU ha	Height m	Biomass Mt	Biomass <TC %	TC Loss 10 ³ km ²	TC Loss <TC %	D	DD	+
Benin	116.8	99.5	—	—	—	360	—	4.7	—			
Burkina Faso	280.5	100	10	0.05	2	502	79.4	2.3	6.6			
Cameroon	467.7	60.4	10	0.5	3	6785	7.9	8.5	0.1			
Central African Republic	623	89	—	—	—	5166	—	7.1	—			
Chad	1315.8	100	—	—	—	1017	—	5.7	—			
Congo	341.2	38.2	30	0.5	3	6715	0.2	6.2	5.2	✓	✓	
Côte d'Ivoire	3238	94.8	30	0.1	5	1888	33.9	24.8	23.1	✓		✓
Dem. Republic of Congo	2332.3	58.1	30	0.5	3	35 493	1.9	100.2	2.2	✓		
Equatorial Guinea	27	28.5	—	—	—	632	—	0.9	—			
Ethiopia	1142.3	98.2	20	0.5	2	4520	67.5	3.6	17.5	✓		✓
Gabon	264.1	16.4	30	1	5	6753	0.7	2.3	1.6			
Ghana	240.1	95	15	1	5	1043	17.2	7.4	11	✓	✓	✓
Guinea	248.2	76	—	—	—	2523	—	13.7	—			
Guinea-Bissau	34.5	79.2	—	—	—	187	—	1.8	—			
Kenya	580.9	99.6	15	0.5	2	1955	86.4	4.2	19.3			
Liberia	96.3	49.4	30	1	5	1757	0.6	9.9	0.5			
Madagascar	625.5	86.7	30	1	5	3882	32.1	27	8.3	✓		
Malawi	121	100	10	0.5	5	307	66.8	1.5	1.1			
Morocco	4841	99.9	25	1	2	520	96.8	0.5	14.6			
Mozambique	822.8	98.6	30	1	3	3928	48.4	34	23.2	✓		
Namibia	887.2	100	15	0.5	5	1243	99.5	0.1	62.9			
Nigeria	919.2	94.8	10	0.5	5	3529	21.4	14.6	3.1	✓		
South Sudan	635.6	99.9	—	—	—	1838	—	2	—			
Sudan	1945	100	—	—	—	1040	—	0.1	—			
Tanzania	946.1	99.8	10	0.5	3	3601	11.2	26.6	1	✓		
Togo	57.5	99.8	10	0.5	5	151	12.9	0.9	0.8			
Tunisia	185.9	97	—	—	—	113	—	0.2	—			
Uganda	241	97.7	30	1	4	842	40.4	4.6	6.9	✓	✓	✓
Zambia	770.8	100	10	0.5	5	3285	6.9	19.4	1	✓		
Zimbabwe	411.8	100	—	—	—	1214	—	5.2	—			

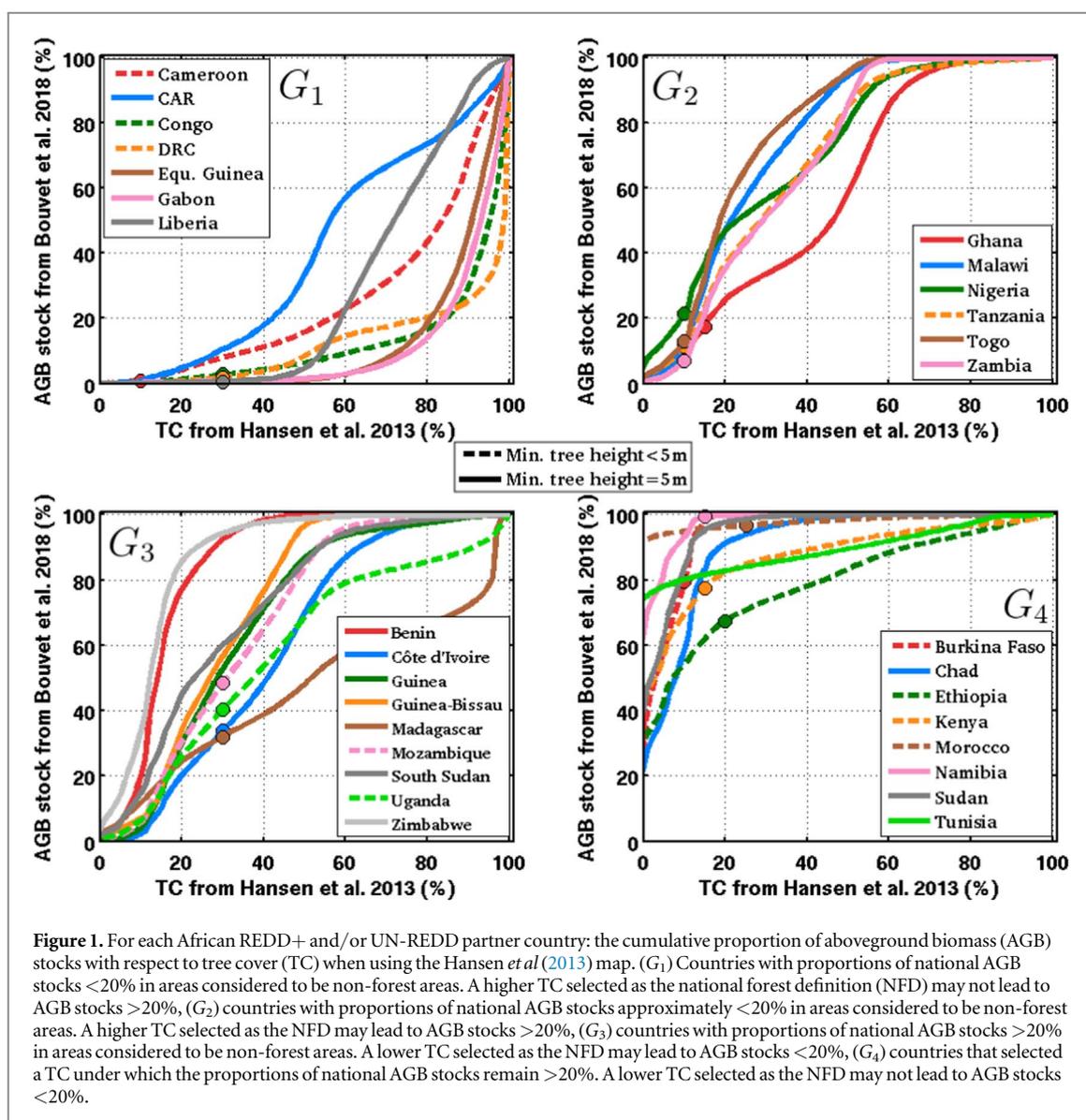
covered by dense forests, the minimum TC value that maximizes the payments to a country (but not emission reductions) is the higher value (i.e., 30% TC or higher). In fact, this value allows an increase in the area available for internationally financed afforestation and reforestation projects associated with the Clean Development Mechanism of the UNFCCC (Verchot *et al* 2007). Uganda, Ghana and the Democratic Republic of Congo increased (or were pushed to increase) the threshold of TC in their NFD for that purpose (Chazdon *et al* 2016).

In this paper, for each of the 30 REDD+ and/or UN-REDD African partner countries, we assess the proportions of national carbon stocks and tree cover loss in areas considered to be non-forest areas, which are mostly savannahs. We also discuss the implications of the various NFD choices. To do so, we use the first published AGB 2010 map of African savannahs at a high resolution (25 m) from Bouvet *et al* (2018), fully adapted to this study, and the global TC 2010 and

TC loss 2000–2016 maps at a 30 m resolution from Hansen *et al* (2013).

2. Results

Table 1 summarizes the total surface and the proportion in savannahs; the minimum TC, MMU and minimum *H* values chosen for the NFD; national AGB stocks and the proportion of AGB stocks below the respective TC values; national TC loss from 2001 to 2016 and the proportion of TC loss below the respective TC values; and REDD+ activities, as described in UNFCCC FREL, for each country. Twenty-two of the 30 countries investigated here show a proportion of savannah >80%. To our knowledge, 20 out of 30 countries have reported an official NFD. Eight countries use a TC of 30% to define forests and 12 countries officially employ a lower value. Eleven countries have proposed, in their FREL, activities related to deforestation. Among these 11 countries,



three have proposed activities related to forest degradation and four have proposed activities related to the conservation of forest carbon stocks, sustainable management of forests and/or enhancement of forest carbon stocks. Table 1 shows that at least 20% of national AGB stocks are located in areas considered to be non-forest areas in 11 out of 20 countries that have official NFDs. Six of these 11 countries exhibit a proportion of national TC loss equal to or higher than 15% in non-forest areas.

Figure 1 shows for each country the percentage of national AGB stocks contained in areas with TC values lower than 1%, 2% ... 100% (refer to the supplementary information section for more details available online at stacks.iop.org/ERL/13/104014/mmedia). We organized the countries into four groups. The first two groups, called G_1 and G_2 (top left and right, respectively, in figure 1) comprise the countries for which most of the carbon is stocked in forest areas. Group G_3 (bottom left in figure 1) comprises the countries for which a large part of the carbon is liable to be stocked in non-forest areas,

whereas group G_4 (bottom right in figure 1) comprises the countries for which a large part of the carbon is stocked in non-forest areas. Figure 2 shows for each country the percentage of TC loss contained in areas with TC values lower than 1%, 2% ... 100%. We organized the countries in figure 2 as in figure 1. In both figures, the dots indicate the minimum TC selected as an NFD (when known), solid lines indicate that the minimum H is 5 m and dashed lines indicate that the minimum H is lower than 5 m.

Group G_1 comprises seven countries (Cameroon, the Central African Republic, Congo, the Democratic Republic of Congo, Equatorial Guinea, Gabon, Liberia). These 7 countries contain a large proportion of dense forest, ranging from approximately 84% of total surface (Gabon) to 40% (Cameroon), with the Central African Republic being the exception (11% of dense forest). Savannahs with TC < 40% represent a small proportion of the national AGB stocks and TC loss in these countries. In Gabon, which is the country with the highest proportion of dense forest in this study, 0.7% of AGB is stocked and

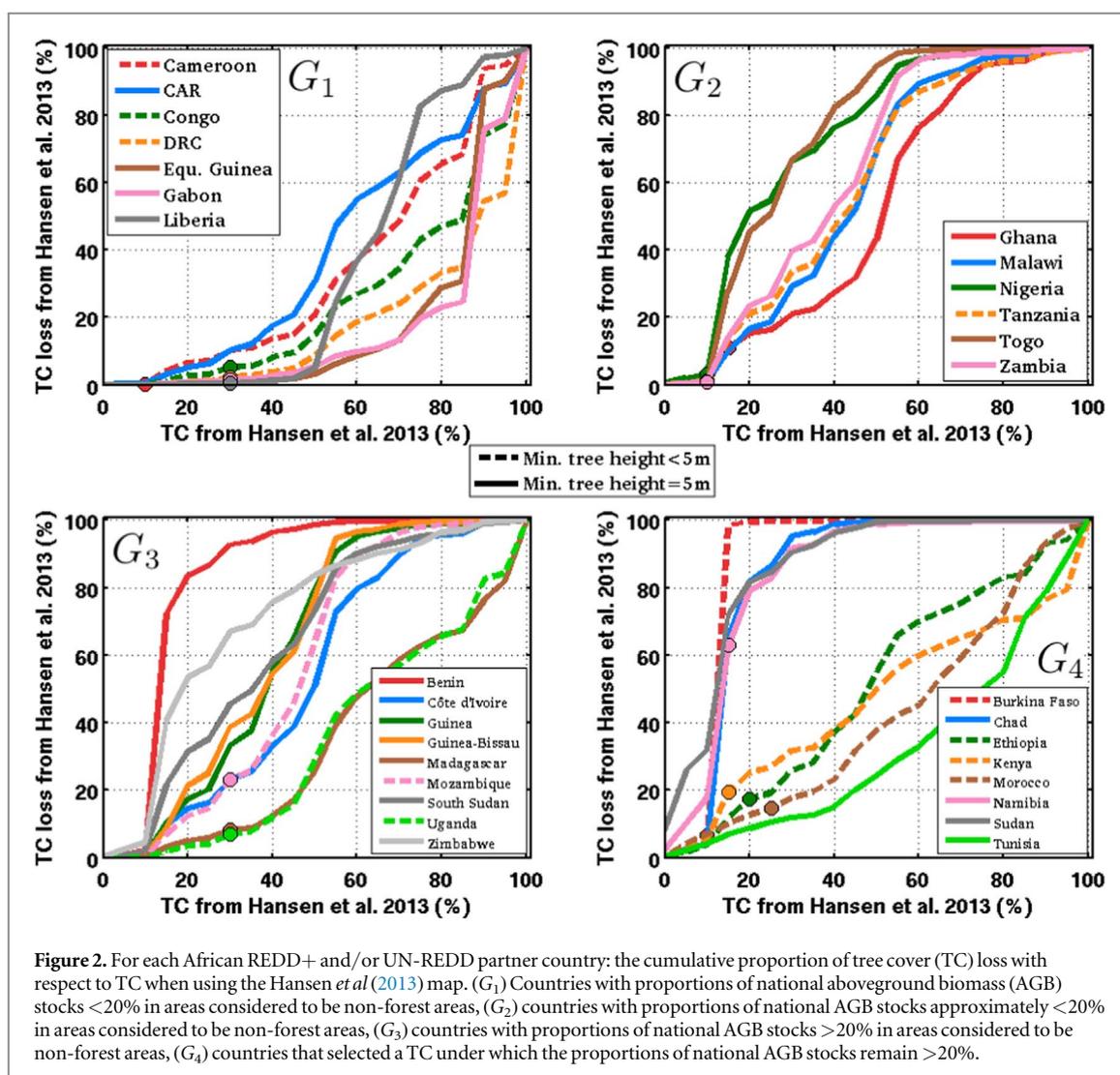


Figure 2. For each African REDD+ and/or UN-REDD partner country: the cumulative proportion of tree cover (TC) loss with respect to TC when using the Hansen *et al* (2013) map. (G_1) Countries with proportions of national aboveground biomass (AGB) stocks $<20\%$ in areas considered to be non-forest areas, (G_2) countries with proportions of national AGB stocks approximately $<20\%$ in areas considered to be non-forest areas, (G_3) countries with proportions of national AGB stocks $>20\%$ in areas considered to be non-forest areas, (G_4) countries that selected a TC under which the proportions of national AGB stocks remain $>20\%$.

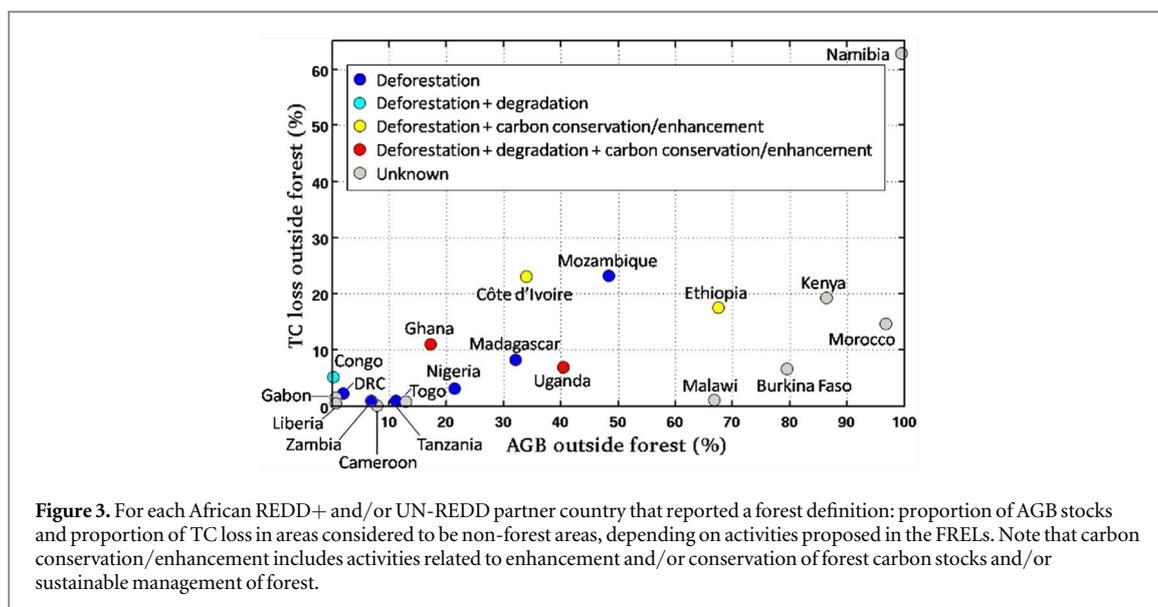
1.6% of TC loss occur in areas with TC $<30\%$, and 0.3% of AGB and 0.05% of TC loss in areas with TC $<10\%$. The use of the TC map (Hansen *et al* 2013), which addresses only trees greater than 5 m, does not appear to be a problem even though three out of seven countries employ a minimum H less than 5 m.

Group G_2 comprises six countries (Ghana, Malawi, Nigeria, Tanzania, Togo and Zambia). These countries selected TC values (15% for Ghana and 10% for the others) under which the proportions of national AGB stocks remain below approximately 20% and the proportions of national TC loss below 11%. With TC values larger than 15%, more than 20% of national AGB stocks and TC loss would be in non-forest areas.

Group G_3 comprises nine countries (Benin, Côte d'Ivoire, Guinea, Guinea-Bissau, Madagascar, Mozambique, South Sudan, Uganda and Zimbabwe). These countries have in common the fact that the proportions of national AGB stocks below the TC selected as the NFD are all above 20% but may be below 20% with lower TC values. Côte d'Ivoire, for example, exhibits AGB stocks of 33.9% in non-forest areas for the selected TC of 30%, but only 2.1% of AGB would be stocked in non-forest areas if a TC of 10% were selected. This result can be explained by

the fact that the proportion of savannah is $>75\%$ for all the countries belonging to group G_3 . In these countries, a considerable proportion of national AGB stocks are located in areas with TC values below 30%. In addition, more than 40% of national TC loss occur in areas with TC $<30\%$ in Benin, Zimbabwe, South Sudan and Guinea-Bissau. In Côte d'Ivoire and Mozambique, 23% of national TC loss occur in non-forest areas. Lowering TC values associated with these countries, where a large part of AGB is stocked in non-forest areas subject to disturbances, is crucial when using the TC map from Hansen *et al* (2013) in the context of REDD+.

Lastly, group G_4 comprises eight countries (Burkina Faso, Chad, Ethiopia, Kenya, Morocco, Namibia, Sudan and Tunisia). These countries are distinguishable in that the proportions of national AGB stocks are all above 20% and would remain above 20% regardless of TC selection. Burkina Faso, Chad, Sudan and Namibia would show a large part of their national TC loss in areas with TC $>10\%$ and TC $<30\%$. However, less than 20% of national TC loss occur in non-forest areas in Burkina Faso, Ethiopia, Kenya, and Morocco. In group G_4 , four countries selected minimum H values lower than 5 m, and three other countries do not have an official NFD.



Values of 0% from the TC map, which addresses trees greater than 5 m in height, are likely to be assigned to trees between 2 and 5 m, although significant amounts of AGB would be stocked in these trees. An example of such tree misdetection by the TC map (Hansen *et al* 2013) can be observed in Sudan (see figure S1). The Sudanian savannah is characterized by the mix of grasses and trees. The presence of tree pockets is clear in very high resolution images from Google Earth, and the AGB stored in these trees is indicated in yellow in figure S1. These trees represent nearly all of the carbon stocks of Sudan. However, values of 0% from the TC map are assigned to most of these areas. This example illustrates the strong limitations, in some countries, of using the TC map directly for REDD+ MRV. The use of the TC map for these countries requires supplementary national mapping to correct for areas that were erroneously excluded. The direct use of AGB maps would be relevant as well.

Figure 3 shows for each country that reported a NFD, proportions of AGB stocks and TC loss in areas considered to be non-forest areas (refer to $biomass < TC$ and $TC\ loss < TC$ in table 1). Dark blue dots represent countries that proposed, in their FREL, activities related to deforestation, light blue dots activities related to deforestation and degradation, yellow dots activities related to conservation of forest carbon stocks and/or sustainable management of forests and/or enhancement of forest carbon stocks, and red dots represent countries that did not reported any REDD+ activities yet. We stress the fact that three out of the seven countries that proposed activities related to deforestation/degradation only (blue dots in figure 3) have more than 20% of their national carbon stock located in non-forest areas (Nigeria 21%, Madagascar 32% and Mozambique 48%). In addition, Mozambique has 23% of national TC loss in non-forest areas. Such proportions of carbon stocks and TC loss outside forest in countries that proposed activities related to reducing deforestation only, may prevent from

meeting the REDD+ objectives. Among countries that did not report any REDD+ activities yet (grey dots in figure 3), Morocco, Kenya and Namibia exhibit in non-forest areas AGB stocks of 96.8%, 86.4% and 99.5% respectively, and TC loss of 14.6%, 19.3% and 62.9% respectively. These results can be used as guidance for countries like Namibia that might select activities related to deforestation/degradation only, despite large proportions of AGB stocks and TC loss outside forest.

3. Discussion

This paper proved that the estimates of forest cover and forest cover change, and thus the carbon emissions that are MRV in the frame of REDD+, depend drastically on the definition of a forest. This study also provides for each African REDD+ and/or UN-REDD country a quantitative assessment of the proportions of both carbon stocks and tree cover loss in forest and non-forest areas depending on their NFD selection. These new results can be used as guidance for adjusting NFDs in order to improve the REDD+ MRV efficiency, and for choosing relevant NFDs for countries that did not select any forest definition yet.

The results confirmed that in Africa, the fact that large amounts of carbon and tree cover loss may be found in non-forest areas is likely to happen in savannah countries. This finding is in line with Bastin *et al* (2017) who showed that global forest extent in dryland biomes has been strongly under-estimated. Zomer *et al* (2016) as well showed that 43% of all agricultural land globally had at least 10% TC and that this has increased by 2% over the previous 10 years. This represents a large amount of carbon, under-estimated until now and likely stocked in non-forest areas.

However, generalization should be avoided, and each country has to be analyzed separately. Sexton *et al* (2016)

indicates that Côte d'Ivoire, the Democratic Republic of Congo, Nigeria, Tanzania, Zambia, Cameroon, the Central African Republic, Ethiopia, Madagascar and South Sudan may experience changes in forest carbon assets valued at US\$10 billion depending on the UNFCCC NFD (using two TC values of 10% and 30% and tropical estimates of biomass from Saatchi *et al* (2011) at a fixed social value of US\$23/tC). Our asset estimates are comparable but lower for the Democratic Republic of Congo and the Central African Republic (US\$7 billion and US\$5.7 billion, respectively, using same social value). These values are substantial, although the differences in AGB stocks are only 1.7% and 9.6% relative to national AGB stocks depending on NFD. Tanzania, Cameroon and Zambia have already selected a TC of 10% for their NFDs, leading to AGB stocks in non-forest areas of 11.2%, 7.9% and 6.9% respectively and TC loss $\leq 1\%$ only, and are therefore not subject to debate.

Our study shows that selecting minimum TC of at least 40% or higher and minimum H of at least 5 m would be relevant in some dense forest countries belonging to G_1 . In fact, degradation would be more accounted for in those countries particularly affected by selective logging in closed canopy forests, but less than approximately 20% of their national AGB stocks and TC loss would be located in non-forest areas (and even less than 10% for the Democratic Republic of Congo, Congo, Gabon, Liberia and Equatorial Guinea). In Cameroon, Congo, the Democratic Republic of Congo, Equatorial Guinea, Gabon and Liberia, TC of 60% may be even selected. This would be particularly relevant for Congo that declared, in his FREL, activities related to forest degradation. In the Democratic Republic of Congo, TC of 60% instead of 30% would lead to the reduction of 12.7% of the national carbon stocks in the forest area. And given that (1) most of tree cover loss (81.3%) in the Democratic Republic of Congo occurs in areas with $TC \geq 60\%$, (2) TC of 60% would allow more disturbances to qualify as deforestation rather than degradation, and (3) the Democratic Republic of Congo proposed in its FREL, activities related to deforestation and not degradation, the Democratic Republic of Congo increases its theoretical potential for REDD+ performance related to reducing deforestation.

However, the G_2 , G_3 and G_4 countries, which include savannahs that are largely prone to disturbances, would all have more than approximately 40% of their AGB stocks in non-forest areas when selecting minimum TC of at least 40% or higher. This effect would be worsened with a minimum H of 5 m. In Mozambique for example, TC of 60% instead of 30% would lead to the reduction of 47.5% of the national carbon stocks in the forest area and put most of the countries woody carbon stocks outside forests. Given that (1) most of tree cover loss (90%) in Mozambique occurs in areas with $TC \leq 60\%$, and (2) Mozambique proposed in its FREL, REDD+ activities

related to deforestation only, Mozambique's performance is very sensitive to the choice of the forest definition, where lowering the minimum TC threshold means less deforestation and more degradation (not chosen as REDD+ activity), or where increasing the minimum TC threshold resulting in many changes in AGB do not qualify as deforestation and thus are not part of the REDD+ activities performance currently proposed (deforestation only). In addition, great areas of savannah in countries such as Ethiopia and Madagascar are located in biodiversity hotspots (Conservation International 2018). Although biodiversity is not related to REDD+, such areas that are rich in biodiversity and are already under strong anthropogenic pressure should be protected to avoid further dramatic losses of biodiversity for the sake of carbon conservation, and should therefore be accounted for as forests.

In summary, selecting a higher TC would enable the reporting of carbon losses from forest degradation in closed forests, such as from selective logging, whereas a lower TC would enable the reporting of a large proportion of carbon loss from forest degradation in countries dominated by savannah while missing a small proportion of national AGB stocks. It is also important to note that if the forest definition is chosen to be rather narrow (i.e. in case of a high minimum TC threshold), then the changes in AGB outside forests will have to be accounted in non-forest land use categories for the greenhouse gas inventory, and the estimation of emission factors will have to consider the rather higher non-forest woody carbon stocks, something that is currently not commonly done.

Although this study highlights the relative relevance of using the global TC map from Hansen *et al* (2013) (except in countries belonging to group G_4), AGB should be directly used for REDD+ MRV in the near future, as stated in previous studies (Mitchard *et al* 2013, Goetz *et al* 2015). Global biomass maps are increasingly available and will certainly be improved (in terms of both quality and resolution) with recent advancements in remote sensing technology. The P-band BIOMASS (Le Toan *et al* 2011) and L-band NISAR (Alvarez-Salazar *et al* 2014) SAR satellites and the GEDI Lidar (Dubayah *et al* 2014) are scheduled for launch in the near future. Remote sensors can also detect and monitor minor changes in forest canopy cover using, for example, the Sentinel satellites that were launched from April 2014, which makes it possible to monitor forest degradation caused by illegal and unplanned logging operations.

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