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Monitoring deforestation and forest degradation in the context of REDD+

Lessons from Tanzania

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Key Points

- To qualify for future REDD+ financial incentives, both for deforestation and forest degradation reductions, countries need to assess historical forest-cover changes and establish forest reference emission levels, i.e. CO_2 emissions resulting from changes in forest cover. The establishment of a national forest definition is essential to monitor changes in forest areas and a prerequisite to develop a consistent system to monitor forest reference emission levels.
- The establishment of such a monitoring system requires choices on many variables (e.g. mapping unit, forest thresholds, remote sensing techniques). The choices made will have technical, political and economic implications that are difficult to predict and that will have impacts on, among others, the type of forests monitored, the methods and data required to provide accurate and reliable information, and possibly, the people deriving their livelihoods from forest land.
- The minimum mapping unit selected by countries has to be adapted to the spatial resolution of the remote sensing data employed, and selected as a balance between the ease of visual interpretation (processing and quality control) and the feasibility of the work load. The forest definition has to be adapted to every country and each ecoregion; otherwise, forest maps will not reflect the natural conditions and will derive misleading deforestation and degradation area estimates.
- Current attempts at mapping forest cover and forest-cover changes globally are seen by countries as potential baseline data for assessing and monitoring forest-cover changes on their national territory. However, there are important differences in the reported forest cover and forest-cover change estimates depending on sources.
- The Tanzania case study shows that i) global data sets on forest cover and forest-cover change misrepresent several land-cover classes; they need to be carefully assessed for accuracy and integrated with locally relevant data before being used for national statistics or baseline forest change scenarios, and ii) the commonly used "30 metres (m)" Landsat data are unsuitable for mapping areas with fragmented and degraded forests, as in many areas with forest cover of 20%-90% is difficult to accurately quantify; we suggest that 5-m resolution data (e.g. from the RapidEye sensor) demonstrates a viable potential for current and future land-cover estimates.
- Carbon stock estimates for degradation monitoring remain difficult to retrieve directly with optical remote sensing data, while field surveys at the national level are very expensive and time consuming. Estimation of carbon stock at national levels could be feasible using a combination of high resolution optical satellite and limited field data. For this, satellite data need to be affordable for countries and field data collected with remote sensing imagery in mind; this would facilitate the correlation of forest biophysical variables and remote sensing parameters. However, more work is needed in developing adequate and reliable methods with needs adapted according to the ecoregion.
- The reflectance and textural properties of high resolution imagery can be correlated to forest biophysical variables that are related to biomass; therefore, biomass prediction models can be developed from remote sensing parameters. Country forest biomass maps can be obtained by extrapolating adequate models, which have to be adapted according to the ecoregion.
- In order to exploit field data for monitoring forest degradation, the field survey has to be specifically designed for linking with satellite images. This is needed to avoid geolocation problems and sampling bias. Moreover, the field survey has to include a balanced data set from all the ecoregions in the country, as information collected in one vegetation type cannot be exploited in others.
- In this Infobrief, we outline the rules and choices to be addressed by participatory countries in REDD+ activities, and show some technical problems they can face, and some options they can adopt.

Monitoring deforestation and forest degradation for REDD+

The activities proposed in 2011 under the Reduced Emissions from Deforestation and forest Degradation (REDD+) framework brought new requirements for monitoring deforestation and forest degradation at national levels (UNFCCC 2011). Deforestation is defined as a direct human-induced decrease in tree- crown cover below 10%-30% of forest areas with a minimum size of 0.05-1 hectare (ha) (UNFCCC 2001), and degradation as a loss of carbon stock with a decrease in the tree-crown cover not below 10%-30% (IPCC 2003). Within the ranges provided by these general definitions, each country has to specify its own thresholds for the minimum size, tree-crown cover and tree height of a "forest", to be used for national accounting of greenhouse gas (GHG) emissions (UNFCCC 2007). Moreover, to qualify for future REDD+ financial incentives, countries need to assess historical forest-cover changes and establish forest reference emission levels (FREL). The establishment of a national definition of "forest" is essential to monitor changes in forest area and a prerequisite to develop a consistent FREL monitoring system.

For methodological guidance to the countries, the UNFCCC stated that REDD+ should be implemented by establishing monitoring systems that "use an appropriate combination of remote sensing and ground-based forest carbon inventory approaches, with a focus on estimating forest area changes, forest carbon stocks and anthropogenic forest-related greenhouse gas emissions by sources and removals by sink" (UNFCCC 2009). While monitoring deforestation implies assessing forest carbon stock changes from one land-cover class to another (e.g. from forest to agriculture), monitoring degradation also implies monitoring transitions within the same class (i.e. forest remaining forest, but with lower carbon content). Again, countries can define their own methods (e.g. remote sensing techniques, field sampling or carbon estimates) according to their policy goals, available data and means, and particular land cover characteristics and dynamics.

In the framework proposed by the UNFCCC, forest is an area of land with at least 0.05-0.5 ha and a minimum tree-crown cover of 10%-30%, with trees that have reached, or could reach, a minimum height of 2-5 m at maturity in the same location (OECD and IEA 2007). Inside these limits, the national forest definition selected by countries will have its own technical and political consequences; for instance, the definition will affect the forest baseline area and change estimates. However, it is not easy for both practitioners and policy makers to determine *a priori* the exact future repercussions of the chosen forest definition; these will depend on the proportions of different forest types and changes, as well as on the spatial and temporal scales at which they take place. At least three major concepts need clarification as they may foster better understanding of the potential future impacts of chosen definitions: the *minimum mapping unit*, the *minimum canopy cover* and the *minimum tree height*.

1. The minimum mapping unit (MMU) is the smallest land unit that is mapped. The adopted MMU will affect the most suitable type of satellite data to use, and therefore the type and amount of work required for monitoring a country. For example, a larger MMU facilitates visual interpretation by expert analysts, but also means that one land unit will most likely contain mixed land-cover types (e.g. forests in different states of degradation). Therefore, clear protocols on land-cover legends will be needed to deal with such mixed types. In contrast, a smaller MMU implies more work involved in quality control because the number of land units to check will be larger; however, digital image processing will be more reliable by avoiding mixed classes (i.e. improved spectral purity).
2. The minimum canopy cover is the minimum area of a land unit that has to be covered by trees' canopies to be classified as forest. The selected minimum canopy cover will influence the classification of the land units (i.e. forest or non-forest) and therefore affect estimates of changes occurring in the carbon pools. For example, setting the canopy cover threshold at 30% will place degraded forests with a canopy cover between 10%-30% into the non-forest land use type, and therefore would not be included in any reporting system. The opposite will be true with a lower threshold (i.e. 10%), allowing those degraded forests to be included as forest in the baseline and change estimates.
3. The chosen minimum height of trees would similarly impact the land-cover transitions on which carbon pools changes are estimated. For example, if the minimum height is set at 2 m, an area that shifts from a situation with trees higher than 5 m to one with trees between 2-5 m would be classed as degradation. Instead, if the minimum height is set at 5 m, the same change would be classed as deforestation. Similarly, a minimum height set at 2 m would result in deforestation if trees of 2-5 m were to become lower than 2 m, while the same change would be classed as "no-change" if the minimum height were set at 5 m. This will have important consequences for forest management, as areas such as regenerating forest or logged-over forest will fall under different legislation depending on the land category.

In addition to the technical matters that indeed will play a role in setting the parameter's levels, eminently political choices will have to be made. In the best-case scenarios, such choices will have to be discussed and agreed upon in broad national consultations. For example, let us assume that a country with large areas of already degraded forest (e.g. low canopy cover and few tall trees) decides to adopt low thresholds in its definition of forest. It could decide this for technical reasons: the baseline area of forest (on which present emissions and future changes will be reported) will be larger than with higher thresholds. But it could make the same decision for more political reasons: some degraded areas (for instance, those from where rural communities generally derive their livelihoods) could be included in the forest class to encourage community participation in the REDD+ process and foster community engagement in nation-wide environmental processes. Certainly, financial reasons can steer these political decisions from one definition to another; for example, emission levels could give potential financial credits, if levels are reduced.

While the number of REDD-related country-led initiatives is increasing, a few global attempts at measuring forest cover and change (e.g. in the form of global maps) have also been made in recent years. Although such efforts are generally too crude for small national-scale definitions and measurements, some countries have seen them as an opportunity for assessing historical land-cover changes and establishing reference emissions levels. However, such maps – and the data and information derived from them – must be handled with extreme caution when used for REDD+ purposes. To highlight the difficulties that may arise in using available maps at face value, and to alert practitioners and policy makers to the care needed when devising national policies based on such maps, we compared forest areas and forest-area changes for Tanzania from three publicly available global maps and datasets.

The Tanzania case study

Monitoring deforestation

Deforestation has been successfully monitored at regional and national levels using moderate spatial resolution satellite data, predominantly from the 30-m spatial resolution Landsat sensor. The Joint Research Centre (JRC) of the European Commission has assessed forest-cover change in the tropics over 1990-2000, 2000-2005 and 2005-2010 using Landsat images, supporting the FAO Forest Resource Assessment (FRA) remote sensing survey (FAO et al. 2009). The sampling units are classified at a minimum mapping unit of 5 ha (50,000 square metres or about 12 acres). While the data are targeted at continental estimates, they can also be used for large countries such as Tanzania (about 94.7 million ha), as a guide to overall forest area and forest-change trends. More recently, the University of Maryland and Google have produced global forest-change maps — the High-Resolution Global Maps of 21st-century Forest

Cover Change (henceforth Global Forest Maps or GFM) — based on a synthesis of the Landsat archive for 2000 to 2012, where each pixel cell is given a tree cover percentage (Hansen et al. 2013). Data are also provided on a yearly basis for "forest losses".

In this case study, we compared the GFMs with data from the JRC and with the published FAO FRA country statistics derived from the Tanzania Forest Service. We compared both the forest baseline area for the year 2000 and the forest-cover change between 2000 and 2010 for Tanzania. We did not compare among identical classes because the datasets have different legends and mapping units (albeit trees are defined as higher than 5 m in all three). However, the differences in magnitude in reported values are so big that they call for further enquiry. Indeed, not only are the baseline forest areas very different, but also the JRC and the FAO FRA estimates (FAO 2010) result in annual forest losses that are more than double the values reported by the GFMs with the 10% canopy cover threshold (i.e. about 400,000 ha/year vs. a maximum of 160,000 ha/year) and a stunning 25-fold difference with the 75% threshold (Table 1).

For assessing historical land-cover changes and establishing reference emissions levels for REDD+ purposes, the wall-to-wall GFMs can be seen as the best choice for countries: the FAO FRA country statistics are not spatially specific and the JRC sampling scheme is not targeted for a specific country. For instance, the Democratic Republic of the Congo has recently used the GFMs in official documents prepared

Table 1. Tanzania's forest area in the year 2000 and forest area loss between 2000 and 2010

Source and category	Forest area in 2000 (km²)
Global Forest Maps	
Tree Cover (>75%)	12,320
Tree Cover (>40%)	97,028
Tree Cover (>10%)	646,643
JRC	
Tree Cover (>75%)	210,184
Tree Cover + Tree Cover Mosaic (>40%)	383,655
FAO FRA	
Tree Cover (>10%)	374,620
Source and category	**Forest area loss 2000-10 (km²)**
Global Maps	
Tree Cover (>75%)	977
Tree Cover (>40%)	7853
Tree Cover (>10%)	15,572
JRC	
Tree Cover (>75%)	25,231
Tree Cover + Tree Cover Mosaic (>40%)	37,991
FAO FRA	
Tree Cover (>10%)	40,340

for the Forest Carbon Partnership Facility Carbon Fund (FCPF 2014). To examine the consistency of the GFM, we compared it with very high spatial resolution (VHR) images[1] for four sites (7x7 km) in the main ecoregions of Tanzania. The sample sites are close to Kisarawe (tropical rainforest), Ikwiriri (tropical moist deciduous forest), Mtera (tropical dry forest) and Mgongila (tropical shrubland) (Figure 1). We chose them because field data were available from previous fieldwork carried out by the JRC in 2012, 2013 and 2014. The field survey comprised of a targeted sampling aimed to characterize the main forest types and conditions along with the collection of biomass-related variables such as height and diameter at breast height (Hojas Gascón and Eva 2014). The VHR data were classified into tree, shrub and non-woody classes in land units of 0.5 ha. Tree height was estimated from the image texture information calibrated with the field data. The classifications were overlaid with the GFMs and the tree percentage for the year 2010 was compared by a cross tabulation (Figure 2).

Results indicate important differences between the two data sets. In the dry ecoregions, the GFMs underestimate tree cover. The maximum tree cover percentage recorded on the Landsat data used by the GFMs was 30%, while in the VHR data, supported by the JRC and NAFORMA field survey, tree cover percentages go up to 100%. On the other hand, in the humid and semi-humid ecoregions, the GFMs tend to overestimate forest cover (especially in the humid ecoregion). Areas classified as shrub (tree height lower than 5 m) from fieldwork and through examination of the VHR data were classified as tree cover in the GFMs. Also, significant areas where tree-cover loss had occurred in both regions went undetected in the GFMs.

For example, in the humid forest area of Kisarawe, the GFMs failed to detect an area of about 100 ha that was deforested in 2008 (Area A, Figure 3). At the same time, shrub cover was classified as 50%-60% of tree cover (Area C, Figure 3).

Conversely, in the dry forest area of Mtera, the GFMs map the full tree cover on the hills as only 15%-20% of tree cover (Figure 4). Tree height measured on the hills in the field survey was 8-10 m.

These errors of omission and commission arise due to the resolution of the Landsat data used to produce the GFMs and to the calibration method employed with respect to the seasonality and the diversity of ecoregions in Tanzania. For example, images acquired during the dry season over dry areas can be misclassified in low tree-cover classes as background soil will have a strong influence on the reflectance response; images with disturbed forests over the humid domain can be misclassified as high tree-cover as they can regenerate freely and appear in pristine conditions; also in the dry forest, minimum tree height should be lower (e.g. 3 m) as primary forest is shorter than in the humid ecoregion. All in all, results corroborate previous assessments of the possible misinterpretations present in the GFMs (e.g. Tropek et al. 2014). More importantly, and as also recommended by the GFMs' authors, results indicate that forest maps produced with a global aim must be integrated with more locally relevant and appropriate data sets (Hansen et al. 2014). This is especially true when countries plan to use the resulting information — in the national REDD+ debates or elsewhere — to devise strategies that could have serious impacts on the livelihoods of their citizens and beyond.

1 From the WorldView-2, Geoeye and IKONOS-2 satellites acquired in the year 2010.

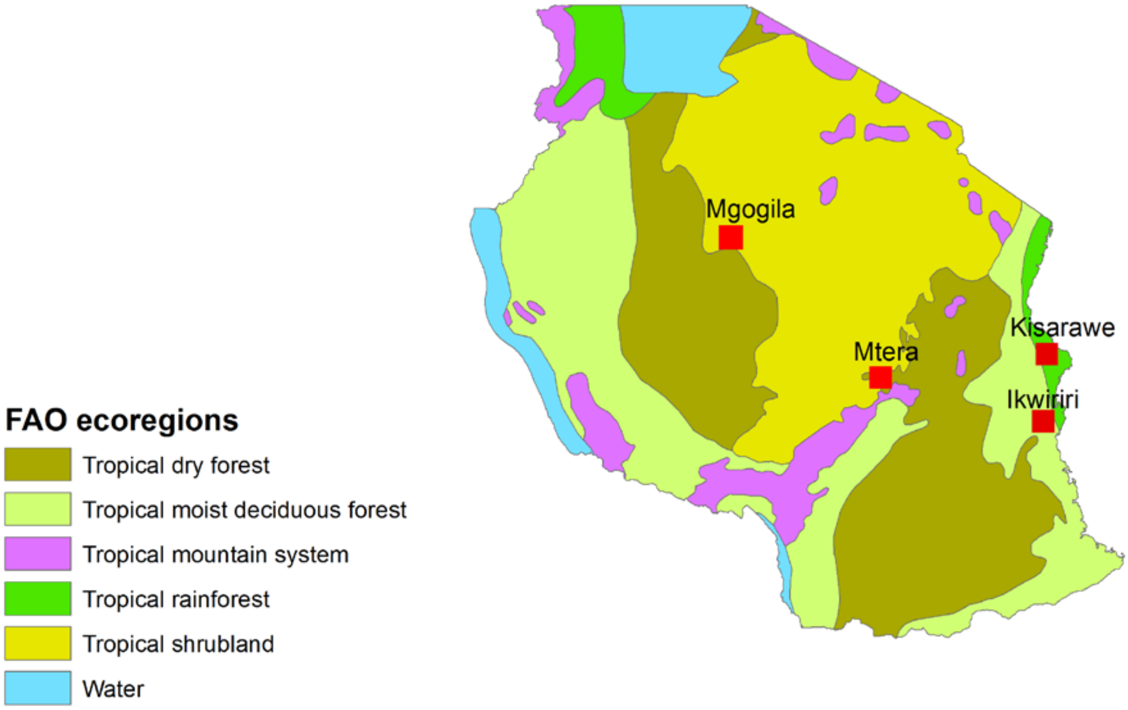

Figure 1. Location of the sample sites for the comparison study of the Global Forest Maps with very high spatial resolution data in Tanzania

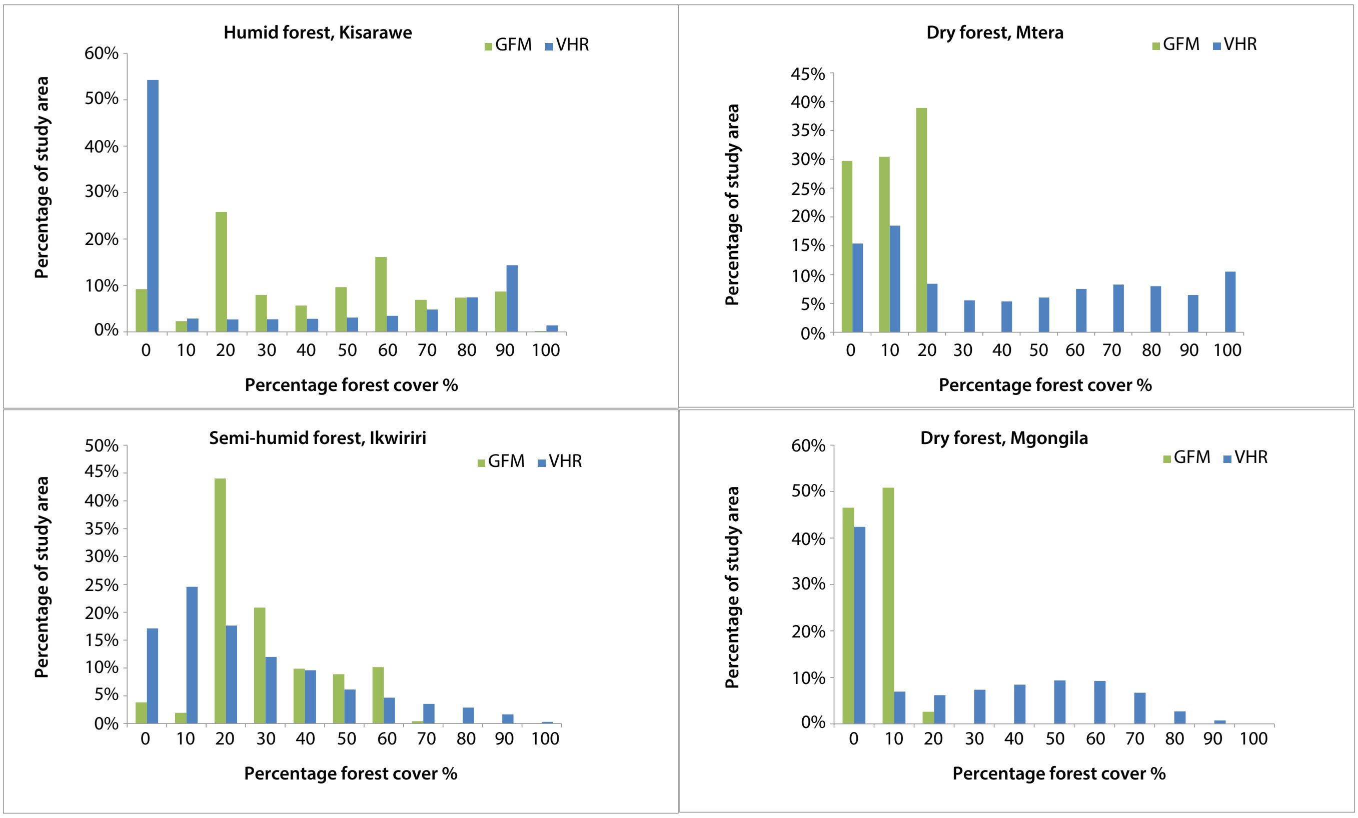

Figure 2. The distribution of forest cover percentage in the four study areas as mapped by VHR data (blue) and the Global Forest Maps (green)

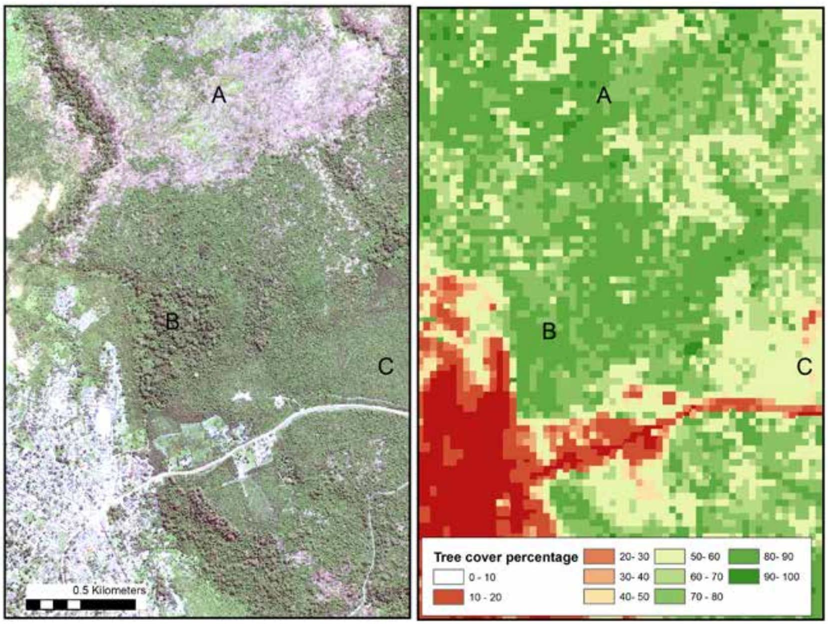

Figure 3. WorldView2 image subset (true color composite) of 2010 of The Pugu Hills forest reserve around Kisarawe (left) and tree cover percentage from the Global Forest Map for the same area and date (right).

Area A, deforested in 2008, is assessed as over 70% of tree cover. Area B is correctly assigned as over 80% of tree cover (field survey at this point found the average tree height to be 20 m). Area C is wrongly classed as 50%-60% of tree cover (field survey measured full canopy of shrubs with an average height of 3.6 m).

Monitoring degradation

Monitoring degradation was introduced in the RED mechanism (now called REDD+) at the Bali COP 13 (UNFCCC 2008) as a response to reports in some high-level publications (e.g. Asner 2005). Such research showed that large areas of forest, notably in the Amazon, were severely degraded mainly due to selective logging. Nevertheless, these areas had still been classified as "forest" (logged areas between 1999 and 2002 were equivalent to 60% to 123% of previously reported deforestation area). Therefore, carbon losses in these areas were not reflected in the deforestation statistics compiled by national forest monitoring programs. Clearly, monitoring of forest degradation is more challenging than monitoring deforestation, especially when considering regional and national levels. Indeed, the recent Brazilian FREL submission does not cover this issue, as it was believed that data were lacking to estimate it (Government of Brazil 2014).

Many national forest monitoring systems rely on the Landsat (30-m) resolution sensor; monitoring of degradation can be problematic at this resolution. For the Kisarawe site in Tanzania, we examined the performance of Landsat and RapidEye (5-m) in mapping fragmented forests using a MMU of 0.5 ha. VHR data were employed as a reference of the "true" forest area. Results indicate that, in fragmented landscapes, Landsat fails to detect forest in areas with the 20%-90% forest-cover range (red area, Figure 4 right), and has high variance in areas with forest cover higher than 90% (blue area, Figure 5 right), while RapidEye data provide a far better estimate (Figure 5, left). This indicates the spatial resolution of the Landsat sensor is too crude for monitoring forest degradation in the context of REDD+.

The differences in results of forest-cover estimates that arise from the selection of different MMU are difficult to predict. They may also vary from site to site depending on the proportions of changes and the scales at which they take place (Eva et al. 2015). In this test, at an MMU of 0.5 ha (approximately the middle of range values proposed for REDD+), 30-m spatial resolution satellite data have been shown to be too crude for mapping forest cover. We noted that 5-m spatial resolution gives considerable improvements, despite a relatively low accuracy. The selection of a lower MMU could result in more accurate results, but also in too many land units to analyze and validate.

Monitoring forest degradation, however, consists not only of measuring forest-cover changes, but also of carbon stock changes. Ideally, these have to be measured in the field; with optical satellite data, even of high spatial resolution, it is difficult to determine vegetation biomass. New techniques and sensors are becoming more available, notably active radar and lidar sensors that promise to give direct measurements of vegetation biomass. Currently, pilot studies and products are available (Saatchi et al. 2011; Baccini et al. 2012). However, they remain at the prototype level and exhibit some major inconsistencies both in biomass level and spatial distribution (Langner et al. 2014).

Forest carbon stock estimations

The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly affected by deforestation and degradation in forest areas. In tropical rainforest, the total aboveground biomass of a tree can be estimated with high accuracy from field inventory data of tree height and basal area (essentially the cross section of a tree at a fixed height of 1.3 m) (Henry et al. 2011). Belowground carbon stock can be estimated as a proportion (often 20%) of the aboveground stock (Santantonio et al. 1977).

Field surveys to estimate carbon stocks at the national level are very expensive and time consuming due to the amount of data required. The use of earth observation data could be more cost effective in mapping carbon stocks: forest biophysical variables can correlate with remote sensing parameters extracted from VHR (approximately 1 m)

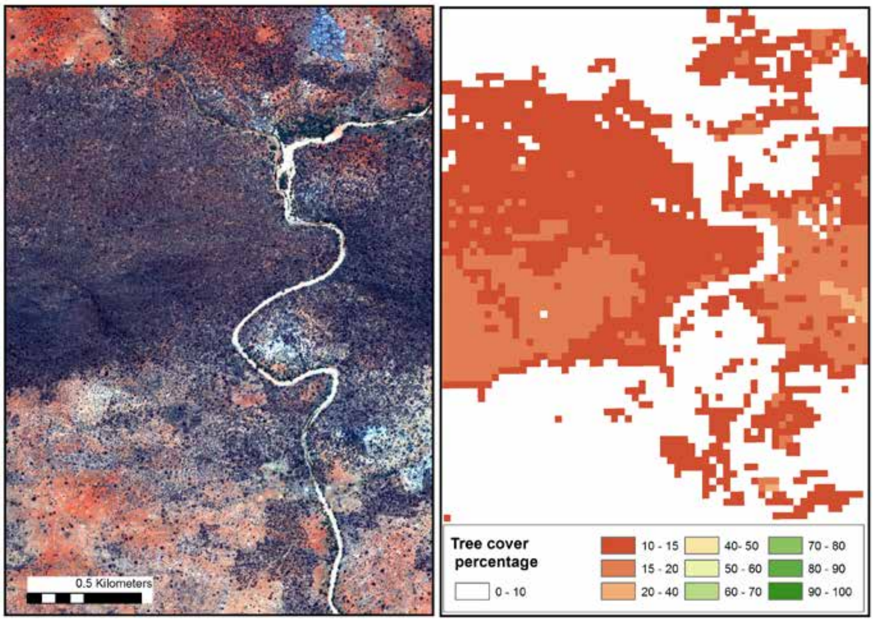

Figure 4. Worldview-2 image subset (true color composite) of 2010 of the study area at Mtera (left) and the corresponding Global Forest Map for the same year (right)

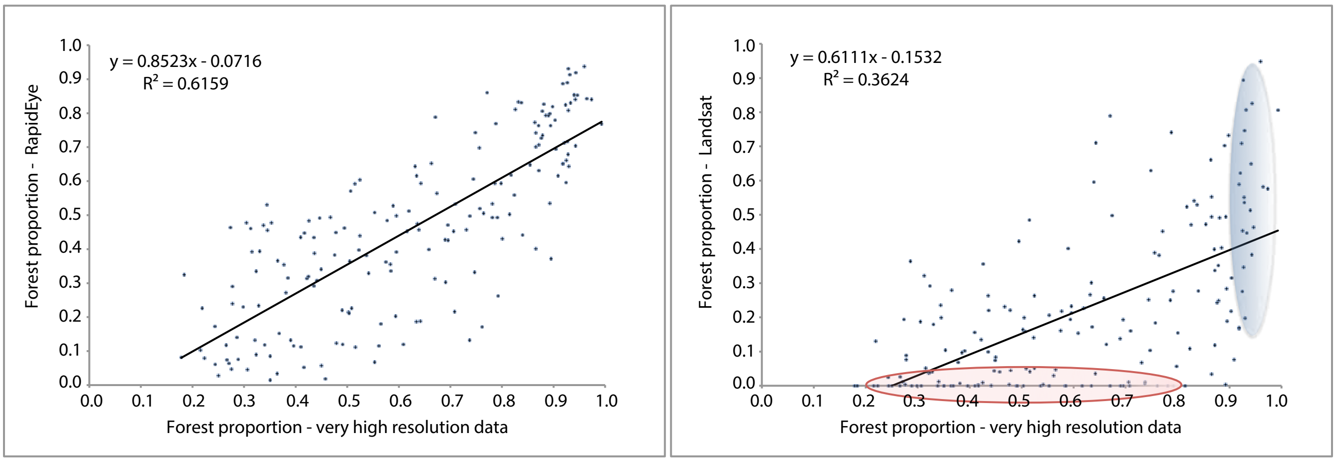

Figure 5. Forest proportion estimates

data (Hojas Gascón and Eva 2014). However, more work is needed to develop adequate and reliable methods based on affordable satellite data, as VHR data are relatively expensive and cannot yet be considered for a countrywide survey.

For this purpose, the Tanzania case study offers a good testing ground, as the Ministry of Natural Resources of Tanzania (MNRT) and UN-REDD, technically supported by FAO-Finland (UN-REDD 2012), recently carried out the National Forest Monitoring and Assessment program (NAFORMA). The NAFORMA field survey resulted in 32,660 plots across the country (Tomppo et al. 2010) measured between 2010 and 2013. Among others, data on tree biophysical information (e.g. DBH and tree height) were collected for biomass calculations (NAFORMA 2010).

Given the availability of a national field dataset, we investigated the possibility of using more widely available 5-m resolution satellite data with the *in situ* measurements, so as to propose a more cost-effective method for mapping carbon stocks. We obtained RapidEye data, covering 14% of the country or a total of 76 squares of 40x40 kilometer (km) equally distributed across the country. Through collaboration with the Tanzania Forest Service and the Food and Agriculture Organization (FAO), access was granted to the field data corresponding to those 76 sites (670 plots). We examined the relationship between forest variables as measured in the field (basal area [BA] and mean tree height); and a set of remote sensing parameters extracted from the RapidEye data related to reflectance and texture properties (listed in Box 1). We calculated these on the 20-m radius areas of the plot and developed a series of prediction models of biomass-related variables. These models can then be extrapolated to obtain forest biomass maps.

Preliminary results show that correlations gave better results dividing the data by ecoregions, probably due to the differences in the spatial distribution of trees and in the structure of canopy layers. Therefore, different linear regression models were calculated for each ecoregion. The models for the humid ecoregion gave better results (R^2=0.73 for BA and R^2=0.52 for height), followed by the dry forest (R^2=0.38 for BA and R^2=0.44 for height) and the tropical shrub (R^2=0.35 for both BA and height). The models for the moist deciduous forest gave the worst

Box 1. Remote sensing parameters used to calculate prediction models of forest biomass-related variables

1. Channel reflectance: Mean and standard deviation of blue, green, red, red edge and near infrared channels.
2. Texture measures after Haralick (1973): Grey level co-occurrence, with different formulations (standard deviation, correlation, contrast, angular second moment, entropy, dissimilarity) and at different angles of analysis (All directions, 0, 45, 90 and 135 degrees).
3. Vegetation indices: NDVI = normalized difference vegetation index, EVI = enhanced vegetation index, SAVI = soil adjusted vegetation index.

results (R^2=0.20 for BA and R^2=0.11 for height). This can be due to the fact that plot basal area and mean tree height were calculated using general allometric equations grouping all species together, which can work worse in more diverse ecoregions. Each model was composed by different parameters, but all of them contained a combination of channel reflectance information, texture measures (usually both of homogeneity and variation) and a vegetation index (for instance, NDVI for the humid, SAVI for the dry and EVI for the moist deciduous ecoregion).

Since the national field survey had not been designed with remote sensing analysis in mind, the data collected were difficult to use in combination with the satellite images. Accurate co-location of the field plots with the high spatial resolution imagery was problematic, weakening correlations between forest parameters derived from the field data (basal area, height) and the remote sensing parameters extracted from the images. Other factors such as site heterogeneity, seasonality and burned areas add further complications. In general, results indicate that estimates of carbon stock at national levels could be feasible using a combination of earth observation data and field data. However, the national field survey needs to be designed for use in combination with satellite images, and more robust models need to be developed.

Nevertheless, our results indicate that, in the humid domain, biomass measurements from field survey can be directly linked to remote sensing parameters; a different approach may be needed in the other domains, as these areas exhibit far higher variances in cover, stand height and condition (wet, dry or burnt). A more robust approach for these areas, for example, would generate broad land-cover classes from the satellite data, and associate biomass levels to them from the relevant field data.

The way forward

The Tanzania case study indicates that international “best practices” and improved support to national parties are needed to ensure that consistent, repeatable and transparent methods are used in mapping forest areas and monitoring deforestation at national to regional levels.

Clearly, it is in the interests of each country to assess the different options that exist under REDD+ definitions and the implementation of a measurement, reporting and verification system. These different options and subsequent action plans may have major financial implications, determine the work involved and ultimately have consequences on forest preservation.

Yet the lack of consistency in forest area and deforestation estimates coming from reputable sources remains a major concern. Such inconsistencies can undermine confidence in national emissions reference levels and even lead to countries adopting the product that simply gives them the best financial rewards under a REDD+ funding system. In the context of REDD+, a critical mass of scientists, in conjunction with potential funding agencies, needs to insist on setting standards for data sets on forest cover and forest- cover change. Such products need to be carefully assessed for accuracy by both researchers and governments before exploitation for national statistics or baseline forest-change scenarios.

In particular, we believe the following next steps are worth considering:

1. More access to satellite data of high spatial resolution are needed in order to use remote sensing techniques for monitoring deforestation and forest degradation for REDD+ requirements. In this line, the forthcoming Sentinel-2 program from ESA and EU should provide 10-m spatial resolution satellite data every five days with an open data access policy.
2. Remote sensing methods to monitor deforestation and forest degradation need to be adapted to every country and to every biome. Special attention has to be paid on the selection of the forest definition, as it will have big implications on the results of deforested and forest degraded area estimates.
3. Improved links between national forest services and remote sensing scientists are needed to ensure that field data can be employed in conjunction with satellite data to monitor deforestation and forest degradation for REDD+ in a cost-effective way and with better guidelines.
4. Better support to forest services is required to exploit field data already collected and to improve its capacities to process and analyze remote sensing data. Given the major effort by some national forest services in collecting a national data set on biomass, it is important they capitalize on this in a variety of ways.

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