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Suitability of Global Forest Change data to report forest cover estimates at national level in Gabon

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ABSTRACT

For purposes of greenhouse gas emissions (GHG) accounting, estimation of deforestation area in tropical countries often relies on satellite remote sensing in the absence of National Forest Inventories (NFI). Gabon has recently launched a National Climate Action Plan with the intent of establishing a National Forest Monitoring System that meets the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines for the Agriculture, Forestry and Other Land Use (AFOLU) sector. The assessment of areas of forest cover and forest cover change is essential to estimate activity data, defined as areas of various categories of land use change by the IPCC guidelines.
An appropriately designed probability sample can be used to estimate forest cover and net change and their associated uncertainties and express them in the form of confidence intervals at selected probability thresholds as required in the IPCC 2006 guidelines and for reporting to the United Nations Framework Convention on Climate Change (UNFCCC). However, wall-to-wall mapping is often required to provide a comprehensive assessment of forest resources and as input to land use plans for management purposes, but wall-to-wall approaches are more expensive than a sample based approach based on visual interpretation and require specialized equipment and staff. The recent release of the University of Maryland (UMD) Global Forest Change (GFC) map products could be an alternative for tropical countries wishing to develop their own wall-to-wall forest map products but without the resources to do so. Therefore, the aim of this study is to assess the feasibility of replacing national wall-to-wall forest maps with forest maps obtained from the UMD GFC initiative.
A model assisted regression (MAR) estimator was applied using the combination of reference data obtained from a probability sample and forest cover and forest cover change maps either (i) produced nationally or (ii) obtained from the UMD GFC data. The resulting activity data are potentially more accurate than the SRS estimate and provide an assessment of the precision of the estimate which is not available from map accuracy indices alone. Results obtained for 2000 and 2010 for both the national and UMD GFC datasets confirm the high level of forest cover in Gabon, more than 23.5 million ha representing approximately 88.5% of the country.
Although the UMD GFC dataset provides a reliable means of producing area statistics at national level combined with appropriate sample reference data, thus offering an alternative to nationally produced datasets (i) the classification errors associated with the Global dataset have non-negligible effects on both the estimate and the precision which supports the more general statement that map data should not be used alone to produce area estimates, and (ii) the maps obtained from the UMD GFC dataset require specific calibration of the tree cover percentage representing a non-negligible effort requiring specialized staff and equipment. Guidelines on how to use and further improve UMD GFC maps for national reporting are suggested. However, this additional effort would still most likely be less than the production of national based maps.

1. Introduction

1.1. Background

Deforestation, particularly in tropical countries, is widely acknowledged to account for as much as 20% of global greenhouse gas (GHG) emissions (Achard et al., 2007; Gullison et al., 2007). In addition, any reduction in deforestation is estimated to have an immediate positive impact on reducing global GHG emissions. This has been recognized through various initiatives of which REDD+ is the most widely studied. More recently, the concept of zero deforestation was introduced and proposed as part of the recent UN New York Declaration on Forests (UN, 2014) which emphasizes the key role of tropical forests for the future of mankind.

The Congo Basin is the second largest forest area in the world after the Amazon (Wilkie & Laporte, 2001). Congo Basin countries are currently developing measurement, reporting, and verification (MRV)

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systems as part of the UNFCCC, particularly if they wish to benefit from REDD+. Gabon does not currently intend to participate in REDD+, but has recently launched a National Climate Action Plan with the intent of establishing a National Forest Monitoring System that meets the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines for the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006). The assessment of forest cover and forest cover change area is essential to estimate activity data as defined in the IPCC guidelines. In this context, activity data refer to the area change data for a particular land use category expressed in unit area and are combined with the emission factor which is the amount of GHG emission per unit area for that category. The product of activity data and emission factor provides the total GHG emission for a given area (IPCC, 2006). Estimation of activity data for the forest sector in tropical countries often relies to a large degree on satellite remote sensing in the absence of national forest inventories (NFI).

A probability sample combined with a suitable methodology to collect reference observations can be used to estimate forest cover and net change area and their associated uncertainties in the form of confidence intervals at selected probability thresholds as required by the IPCC, 2006 guidelines and for reporting to the United Nations Framework Convention on Climate Change (UNFCCC). However, wall-to-wall mapping is often required to provide a comprehensive assessment of forest resources and spatially explicit characterization of drivers of deforestation and as input to land use management plans.

Sannier, McRoberts, Fichet, and Makaga (2014) demonstrated that the combination of a sample-based approach and wall-to-wall mapping can substantially improve the precision of activity data estimates. This approach was further described in the Methods and Guidance Document (MGD) produced by the Global Forest Observatory Initiative (GFOI, 2013). The MGD document, as well as the GOFC-GOLD Source Book (GOFC-GOLD, 2014) and the REDD-Plus Cookbook (Hirata, Takao, Sato, & Toriyama, 2012), provide detailed scientific and technical background and guidance on how to implement wall-to-wall national forest monitoring systems using satellite imagery. However, construction of national wall-to-wall forest cover maps by national agencies is associated with extra costs, specialized equipment and staff that are often not available. The recent release of the University of Maryland (UMD) Global Forest Change (GFC) map products at 30-m × 30-m resolution (Hansen et al., 2013) could provide an alternative to national mapping efforts for tropical countries. Other global datasets could also be investigated including the Global Land Cover dataset (Jun, Ban, & Li, 2014), a global land cover map at 30 m × 30-m resolution for 10 main land cover types and for two reference years, 2000 and 2010. The maps were constructed using the Landsat and HJ-1 satellite archives complemented by auxiliary data from a wide range of sources. Another candidate is the new global (2007–2010) forest/Non forest map based on ALOS PALSAR sensor data (Shimada et al., 2014) which provides annual maps between 2007 and 2010 that depict forest cover in four density classes ranging from 10 to 100%. Both datasets provide maps at different reference time periods, 2007 to 2010 for ALOS PALSAR and 2000 and 2010 for the Global Land Cover dataset. However, the ALOS PALSAR map dates are not compatible with dates of reference data for Gabon. In addition, the forest class definition for the Global Land Cover dataset is not directly compatible with the forest definition used for Gabon, because the former includes sparse woodlands with crown cover from 10 to 30% in addition to forest with a minimum percentage cover of 30%. Tsendbazar et al. (2014) reviewed other global land cover datasets, all of which are available at much coarser resolutions (from 300 m to 1 km) and are based mostly on medium to coarse resolution satellite data not compatible with the minimum forest area to be mapped in Gabon. Therefore, given the Gabonese definition of forest (Section 2.1), the UMD GFC product was determined to be the most suitable among the alternatives for assessing forest cover in Gabon.

Global land cover data sets are typically not validated at national or local scales, but at best only at continental or even global scales (Tsendbazar et al., 2014) even though products based on similar methodologies but produced specifically for those regions or countries were assessed over the area covered (Potapov et al., 2015). Therefore, a suitable assessment of the quality of the UMD GFC dataset must be carefully undertaken to determine if it can be used for characterizing forest cover and forest cover change at the national level. However, map accuracy as assessed using confusion or error matrices does not provide a direct means for estimating areas and their associated uncertainties (McRoberts, 2011) and map accuracy is only one parameter relevant for assessing the suitability of the map for improving area and area change estimates. Model-assisted regression (MAR) estimators provide a method for combining reference and map information to produce area estimates and to increase the precision of the estimates. Sannier et al. (2014) used this approach for a representative study area representing 38% of the total area of Gabon. The same methodological approach is proposed for this study. The differences are that the study area now includes the entire area of Gabon and estimates obtained using the UMD GFC dataset are compared to estimates obtained using national maps as a means of assessing the suitability of the UMD GFC data for providing national estimates of activity data.

1.2. Aims and objectives

The aim of this study is to assess the feasibility of replacing national wall-to-wall forest map products with maps obtained from the UMD GFC initiative. More specifically, the objectives of this study are fivefold: (i) to assess whether the UMD GFC dataset can be processed to match the selected national forest definition for Gabon, (ii) to determine the degree to which estimates of forest cover and forest cover change and their associated uncertainties are enhanced using the UMD GFC dataset relative to using reference data alone, (iii) to quantify the loss, if any, of accuracy and precision resulting from using UMD GFC maps rather than a nationally produced map, (iv) to quantify, if necessary, the level of additional effort in terms of increased sample size and/or post-processing of the UMD GFC data that would be required to obtain comparable estimates with respect to accuracy and precision to estimates based on a nationally produced map and (v) to develop guidelines on how to use global products for national reporting.

2. 3. Data

2.1. 3.1. Study area

Gabon is a tropical, equatorial country located in the Congo-Ogoué basin region of Central Africa with a total area, including land and water, of 267,667 km^2 (Central Intelligence Agency (CIA), 2012). A small population and substantial oil and mineral resources contribute to making Gabon one of the wealthiest countries in Africa. One favorable consequence is that equatorial forest cover in Gabon is among the greatest in the world, and most of it has been preserved.

Gabon has yet to adopt a national definition of forest. However, the UNFCCC (2006) defines forest as "a minimum area of land of 0.05–1.0 hectare (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 at maturity in situ." For this study, the largest values in the ranges were selected for defining forest land: minimum area of 1 ha, tree crown cover of at least 30%, and minimum potential height at maturity of 5 m. In addition, to these quantitative criteria, the forest in Gabon refers to natural forest formations excluding commercial industrial plantations such as rubber or oil palm but potentially including agroforestry systems and urban tree vegetation if they meet the quantitative thresholds described above. However, all of these land use types are known to be very limited in extent.

2.2. Reference data

A reference data set for the entirety of Gabon was constructed using a probability sample and acquired based on the visual interpretation of available imagery and auxiliary data as described by Fichet, Sannier, Makaga, and Seyler (2014) and Sannier et al. (2014). A 1% sampling fraction was adopted because it was expected to produce a coefficient of variation for forest cover area estimates of less than 5%. To achieve this level, Gabon was tessellated into 20-km × 20-km grid cells and a 2-km × 2-km primary sampling unit (PSU) was randomly selected from within each of the 665 cells (Fig. 1). This combination of systematic and random approaches ensures that the entire study area is covered and avoids the drawback of a pure systematic approach. In addition, the lack of a priori stratification ensures that the sampling scheme is stable over time which facilitates estimation of area change over multiple time periods.

Construction of error matrices using all pixels contained within PSUs would have led to the inclusion of a large number of non-independent, spatially contiguous observations. Therefore, 50 secondary sampling units (SSUs) in the form of individual pixels were randomly selected within each PSU. SSUs were used only for accuracy assessment and in a few cases to guide the visual interpretation of PSUs but were not included in the area estimation analyses.

All PSUs were visually interpreted using all available imagery and auxiliary data by a team of photo-interpreters working independently from the production team, thus fulfilling the requirement that reference data produce "higher quality determination of land cover" (Stehman, 2009). Visual interpretation of earth observation data at a sufficient spatial resolution with respect to the classification scheme was acknowledged as a suitable source of reference data by Czaplewski (2003). The reference data can include errors, but their occurrence is likely to be less than the frequency of errors in the maps. Fichet, Sannier, Makaga, et al. (2014) demonstrated that errors in the reference data could be assumed to be very few because there is a very sharp spectral difference between forest, which is mostly evergreen in Gabon, and non-forest.

The interpretation of forest boundaries in transition zones is potentially more difficult, but is limited to few cases in Gabon. This is because forest cover in Gabon almost always exceeds 30%. In addition, once an area is cleared, forest regrowth is particularly fast when no further human intervention such as bush fire occurs. This is due to the very favorable climatic and ecological conditions in Gabon with high rainfall spread out during most of the year and good seed dispersal thanks to the high diversity of fauna (Doucet, 2003). The rare cases where transition zones occur are located in areas of very limited extent: (i) where subsistence agriculture takes place, (ii) some swamp forests and (iii) mangrove. In these cases, the use of VHR imagery on which individual tree canopy is visible, available to us or from Google Earth and Bing Maps, were used to calibrate the interpretation. In cases where the boundary between forest and non-forest is difficult to identify, SSUs were used to guide the interpretation following a similar approach described by Fichet, Sannier, Mermoz, Pennec, and Le Toan (2014) to map the boundary between dry forest and grassland in Central African Republic. Each SSU is classified as forest or non-forest following the selected definition of forest. The classification of an SSU as forest or non-forest depends on four parameters: (i) minimum area (1 ha), (ii) tree height (>5 m), (iii) percentage tree cover (>30%) and (iv) land use. Each SSU can be considered to represent the center of a 1 ha plot to match the minimum area requirement. Tree height was estimated on available VHR imagery by measuring projected shadows (Shettigara & Sumerling, 1998) or by inferring a height greater than 5 m from tree crown diameter. Forest cover could be directly characterized visually when tree cover was considerably greater than 30%. In cases when percentage tree cover was closer to 30%, a systematic grid of points centered on the SSU and covering a 1 ha area could be overlaid to guide the interpretation by recording whether each point intersected with a tree canopy thus determining if forest cover for the SSU was less than or greater than the 30% threshold. A 5 × 5 grid was sufficient to determine the threshold, but the number of points could be increased if the actual percentage tree cover would need to be recorded as described by Fichet, Sannier, Mermoz, et al. (2014). Finally, land use, primarily

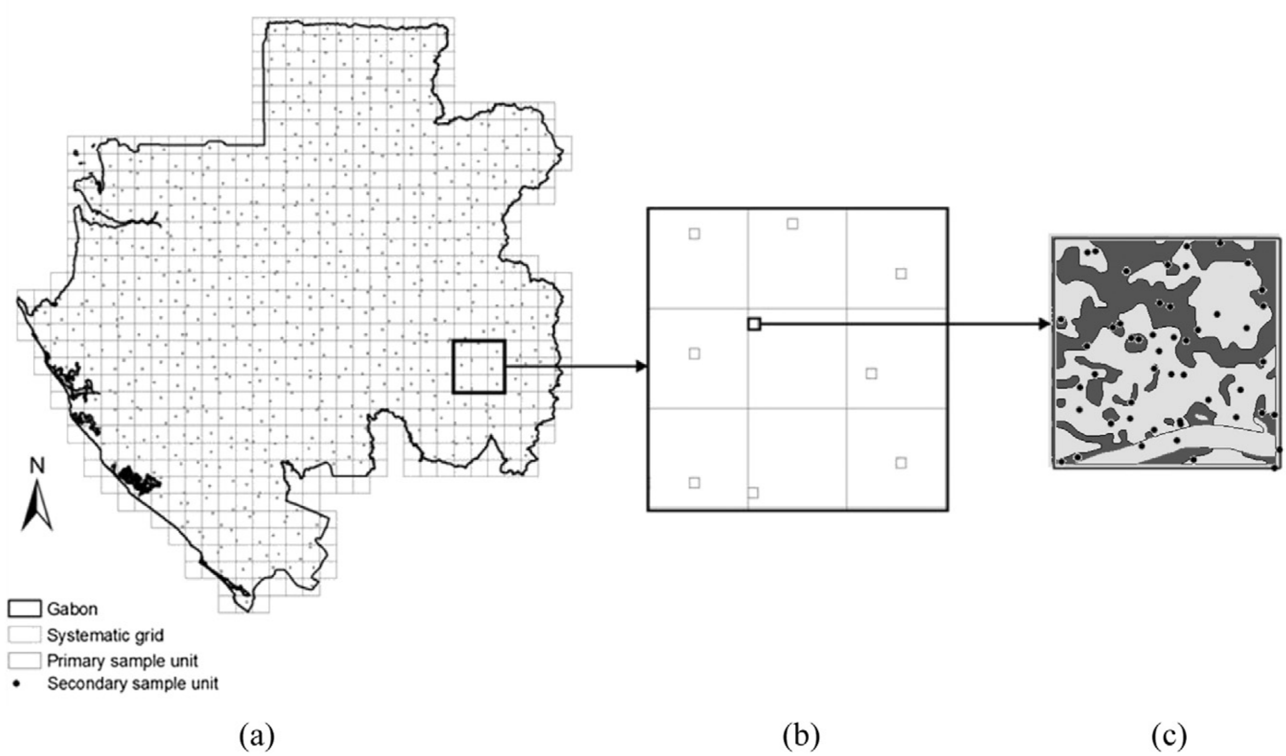

Fig. 1. Identification of Primary Sample Units (PSU) over (a) Gabon and (b) a smaller area and (c) example of Secondary Sample Units (SSUs) overlaid on top of the interpretation of a PSU.

the presence of tree plantations, could be identified by the alignment of trees and presence of infrastructure. The characterization of SSUs could then be used to guide the interpretation of forest boundaries on the PSU.

2.3. National forest cover maps

National forest cover and cover change maps for Gabon were constructed using a combination of semi-supervised classification and manual enhancements to ensure the greatest possible accuracy and expand on the work described by Fichet, Sannier, Makaga, et al. (2014) and Sannier et al. (2014). The initial forest cover map was produced for the year 2000, and forest change maps were constructed using the initial forest cover map as a stratification layer. The forest and non-forest strata were re-classified using the 1990 and 2010 imagery. This reclassification ensures that artifacts due to slight differences in the geometry of the same objects for each period that could lead to false change assessments were not introduced. The forest cover maps for the remaining two periods were constructed using the existing forest cover map and the corresponding forest cover change map.

The main sources of imagery was Landsat (see Table 1). The best coverage was obtained for 2000 with 98% of the country covered by cloud free images within one year of year 2000 and full coverage was obtained within two years. In 2010, 98% of the country was covered within two years and full coverage was obtained within three years. For 1990, there were no data available in the USGS Landsat archive after 1990, and only 92% of the country was covered within two years. To obtain full coverage, it was necessary to use data as far back as 1984, but this was for only a very small area.

Due to the continuous presence of cloud cover in Gabon, very few cloud free images were available. Therefore, a compositing procedure was applied to individual classifications of selected image scenes. Image scenes were selected starting with the image closest to the reference year filling the cloud covered gaps gradually with other image data scenes. Each selected image was classified using an unsupervised classification procedure with an interactive grouping of spectral classes in F/NF thematic classes. The classification outputs were composited based on the image selection rule. A minimum mapping unit of 1 ha was applied to ensure compliance with the forest definition and classification artifacts were removed by visual assessment. An initial F/NF map was produced for 2000 and the same procedure was applied to 1990 and 2010 selected image scenes, but using the 2000 F/NF map to provide context for identifying forest cover change.

The source of imagery for the national map is expected to be essentially the same than for the UMD GFC data even though for the national data carefully selected single image observation was used for any given area and reporting year, whereas multiple observations are likely to have been used for the UMD GFC data. The main differences between the two approaches are threefold:

- Different pre-processing applied with simple cloud masking and processing of individual image scenes for the national map and more advanced image radiometric correction and mosaicking for the UMD GFC data
- Different classification procedures with classification of individual image scenes with partial coverage due to cloud cover and aggregation of classification results to obtain complete spatial coverage for the national map as opposed to classification of global image mosaics for the UMD GFC product
- Greater reliance on manual processing for the national map to correct artifacts mainly due to the atmospheric disturbance.
- The national map is provided in vector format.

Table 1
Spatial and temporal coverage of satellite imagery used for the national map production.

Epoch		Area Covered (%)		
		+/−0 year	+/−1 year	+/−2 years
Landsat 4 & 5 TM	1990	35	66	92
Landsat 7 ETM+	2000	84	98	100
Landsat 7 ETM+ SLC-off and some limited Terra ASTER	2010	59	95	98

2.4. UMD Global Forest Change maps

As described by Hansen et al. (2013), the UMD GFC dataset includes a 30-m × 30-m percent tree cover map for year 2000 in which trees are defined as vegetation taller than 5 m. Yearly forest loss maps from 2001 to 2012 are also included. Forest loss is a binary layer (1: loss, 0: no loss) and is understood as complete or comprehensive removal of forest cover and is defined as “a stand-replacement disturbance, or a change from a forest to non-forest state”. Forest gain is only available for the whole 2000–2012 period and is understood as complete or comprehensive recovery of forest cover and is defined as “the inverse of loss, or a non-forest to forest change entirely within the study period.” The percent tree cover map for 2000 and the individual forest loss and gain maps from 2001 to 2012 were downloaded from the Google Earth Engine dedicated web site and clipped to Gabon's boundaries.

3. Methods

3.1. Processing of UMD GFC map data

The UMD GFC data do not directly comply with the forest definition used for this study (Section 2.1). However, the definition of tree as vegetation taller than 5 m matches the criterion used for forest height for Gabon's definition of forest. As a result, a threshold of 30% which corresponds to the maximum tree cover criterion of the UNFCCC forest definition (UNFCCC, 2006) can easily be applied to the percent tree cover dataset. Finally, a minimum mapping unit (MMU) threshold can also be applied to the data.

To determine the level of post-processing necessary to produce the most accurate characterization of forest cover and forest cover change, the following processes where applied to the data (Fig. 2):

1) Application of the 30% tree cover percentage threshold to the 2000 UMD GFC tree cover percentage map data 2000 resulting in a UMD GFC F/NF map for 2000 with no MMU applied
2) Application of 1 ha MMU filter on F/NF classes: groups of pixels representing less than 1 ha are removed resulting in a UMD GFC F/NF map for 2000 with a 1 ha MMU applied in compliance with the selected forest definition for Gabon
3) Integration of « Forest Gains» within the NF class defined in 1) and 2), which will then be classified as forest in the circa 2010 F/NF map
4) Integration of « Forest Losses » within the F class defined in 1) and 2), which will then be classified as non-forest in the resulting circa 2010 F/NF map
5) The circa 2010 F/NF map results from the combination of the 2000 F/NF map from which the forest gain and losses are added following the procedure described in 3) and 4).
6) A 1 ha MMU filter is applied to both the F and NF class resulting from 2) and 5) following the same procedure than for 2).

Initial visual inspection of the maps produced using the processes described above and comparisons of the UMD GFC with the national maps showed a substantially greater forest cover area compared with that of the national map (Fig. 3). The difference was likely related to overestimation of the percent cover in the original UMD GFC dataset for Gabon. Therefore, an alternative percent tree cover threshold was applied. An evaluation of several thresholds from 0 to 80% was made by observing visually the results over several known F/NF transition

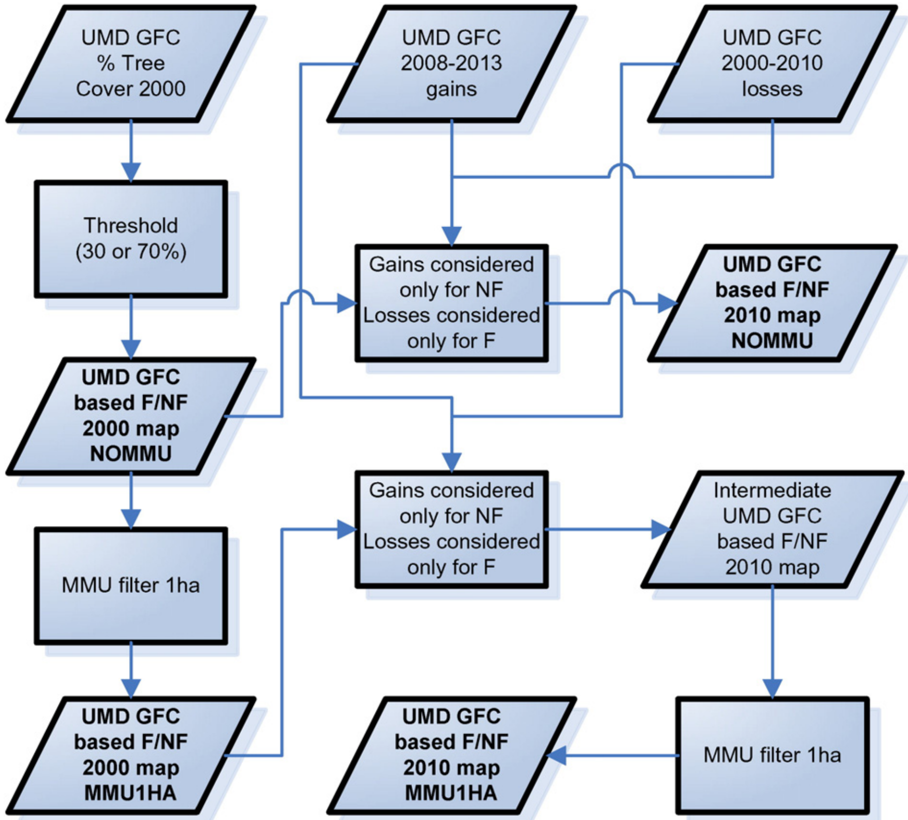

Fig. 2. Description of the processes applied for the production of the UMD Global Forest Change based 2000 and 2010 F/NF maps for Gabon.

zones (Lopé national Park, Bateke plateau and Libreville region). After multiple trials, a threshold of 70% percent tree cover was selected as the best compromise and two additional sets of maps were produced:

1) A set of maps with forest identified with a percent tree cover greater than 70% and without applying any MMU. The change map and 2010 forest cover map were produced following the same procedure than as described for the 30% threshold.
2) A set of maps with forest identified with a percent tree cover greater than 70% and a 1 ha MMU for the 2000 forest cover map. The change map and 2010 forest cover map were produced following the same procedure as described for the 30% threshold.

3.2. Accuracy assessment

Error matrices were constructed for both the national and UMD GFC maps using paired observations extracted from the forest cover map and the pixel-level reference data (SSUs) as described in Section 2.2.

3.3. Forest cover area and forest cover change estimation

The analyses of forest cover area were based on the two sets of estimators described in Sannier et al. (2014). A model-assisted regression (MAR) estimator was used with the combination of reference and map data. The resulting area estimate is more accurate than either the SRS estimate from the sample data or the area estimate obtained from the forest cover map alone. In addition, probability sampling facilitates statistically valid estimation of the precision of the area estimate value which is not available from the map alone.

3.3.1. Simple random sampling estimators

The simple random sampling (SRS) estimators were used with the PSU-level reference data from the sample, S_I, to estimate population means for the four response variables: (1) *proportion forest* for which $z_i = y_i^{ref,t}$ is the reference observation for $i \, \varepsilon \, S_I$ for the t^{th} reference year, (2) *net proportion deforestation* for which $z_i = y_i^{ref,t_2} - y_i^{ref,t_1}$ is the reference observation for $i \, \varepsilon \, S_I$ for the interval t_1 to t_2, (3) *gross proportion deforestation* for which z_i is the reference observation for $i \, \varepsilon \, S_I$ for the interval t_1 to t_2:

$$z_i = \begin{cases} y_i^{ref,t_2} - y_i^{ref,t_1} & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} < 0 \\ 0 & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} \geq 0 \end{cases},$$

and (4) *gross proportion forest regeneration* for which z_i is the reference observation for $i \, \varepsilon \, S_I$ for the interval t_1 to t_2:

$$z_i = \begin{cases} y_i^{ref,t_2} - y_i^{ref,t_1} & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} > 0 \\ 0 & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} \leq 0 \end{cases}$$

The SRS estimators take the forms,

$$\mu = \frac{1}{m} \sum_{i \, \varepsilon \, S_I} z_i$$

and

$$\mathrm{Var}(\mu) = \frac{1}{m(m-1)} \sum_{i \, \varepsilon \, S_I} (z_i - \mu)^2,$$

where $m = 665$ denotes the number of PSUs. In this manner, proportion forest is estimated for each reference year, and net proportion deforestation is estimated for each time interval.

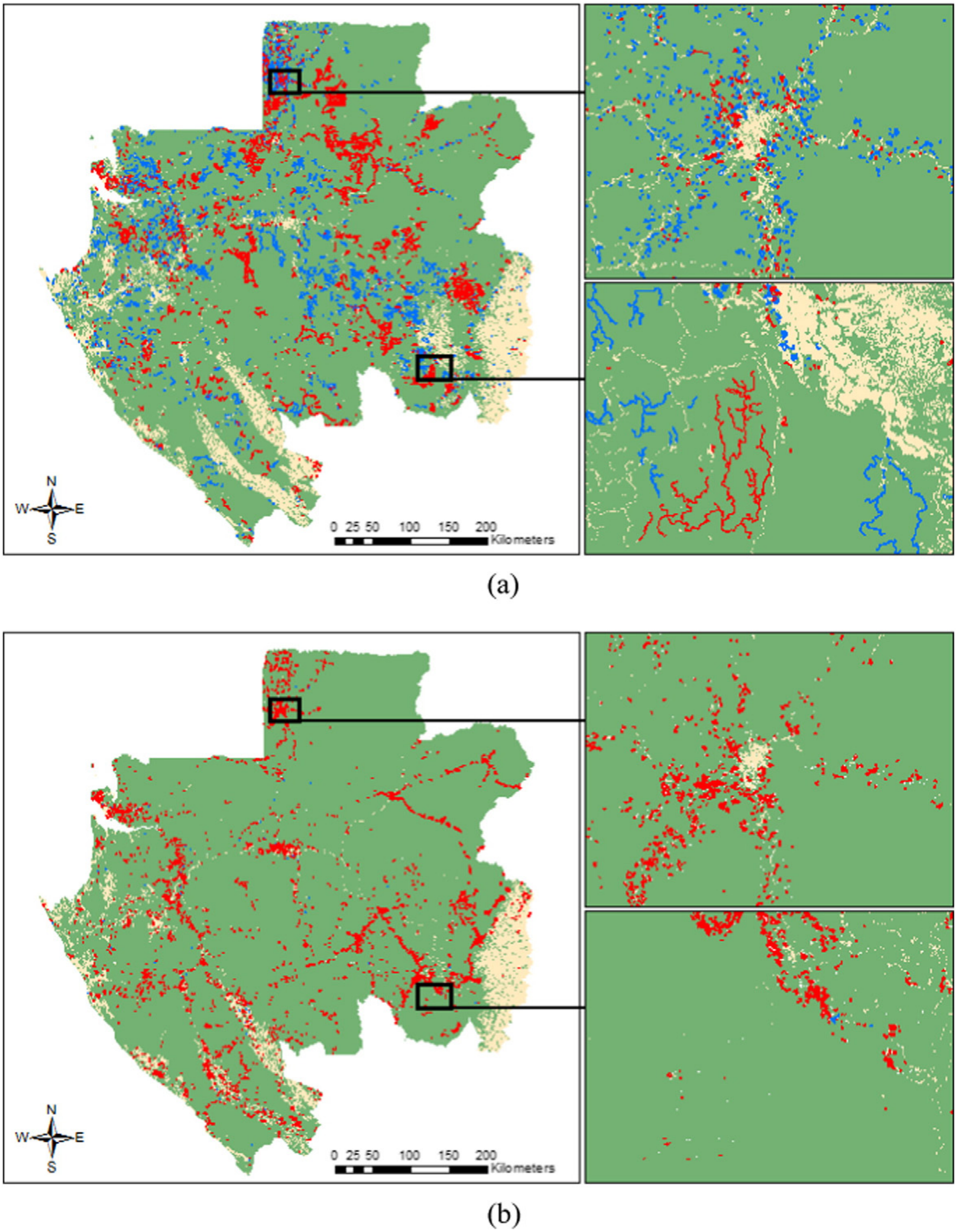

Fig. 3. Forest cover change maps for the 2000–2010 period for (a) the national dataset and (b) the UMD Global Forest Change based dataset using a 30% tree cover and 1 ha minimum mapping unit. Forest is in green, non-forest in yellow, deforested areas are in red and regenerated areas are in blue.

3.3.2. Model-assisted regression (MAR) estimators

The MAR estimators were used with the combination of the PSU-level reference and map data for which $S_I = \{i: i = 1,\ldots, n\}$ indexes the selected PSUs, to estimate population means for the four response variables: (1) *proportion forest* for which $z_i = y_i^{ref,t}$ is the reference observation for i ε S_I for the t^{th} year and $z_i^{map,t}$ is the corresponding map prediction, (2) *net proportion deforestation* for which $z_i = y_i^{ref,t_2} - y_i^{ref,t_1}$ is the reference observation for i ε S_I for the interval t_1 to t_2. (3) *gross proportion deforestation* for which z_i is the reference observation for i ε S_I for the interval t_1 to t_2:

$$z_i = \begin{cases} y_i^{ref,t_2} - y_i^{ref,t_1} & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} < 0 \\ 0 & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} \geq 0 \end{cases},$$

and z_i is the corresponding map prediction:

$$z_i = \begin{cases} y_i^{map,t_2} - y_i^{map,t_1} & \text{if} \quad y_i^{map,t_2} - y_i^{map,t_1} < 0 \\ 0 & \text{if} \quad y_i^{map,t_2} - y_i^{map,t_1} \geq 0 \end{cases},$$

and (4) *gross proportion forest regeneration* for which z_i is the reference observation for $i \varepsilon S_I$ for the interval t_1 to t_2:

$$z_i = \begin{cases} y_i^{ref,t_2} - y_i^{ref,t_1} & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} > 0 \\ 0 & \text{if} \quad y_i^{ref,t_2} - y_i^{ref,t_1} \leq 0 \end{cases},$$

and z_i is the corresponding map prediction:

$$z_i = \begin{cases} y_i^{map,t_2} - y_i^{map,t_1} & \text{if} \quad y_i^{map,t_2} - y_i^{map,t_1} > 0 \\ 0 & \text{if} \quad y_i^{map,t_2} - y_i^{map,t_1} \leq 0 \end{cases}$$

An initial estimator of the population mean is,

$$\hat{\mu}_{initial} = \frac{1}{M}\sum_{i=1}^{M}\hat{z}_i,$$

where M = 66,500 is the total number of PSUs in the population. However, this estimator may be biased as the result of systematic classification error. An estimator of the bias is,

$$\hat{\text{Bias}}(\hat{\mu}_{initial}) = \frac{1}{m}\sum_{i \varepsilon S_I}(\hat{z}_i - z_i),$$

where m = 665 is the number of PSUs selected in the first-stage sample. The MAR estimator (Särndal, Swensson, & Wretman, 1992, Section 6.5) is defined as the difference between the initial estimator and the bias estimator and is expressed as,

$$\mu_{MAR} = \mu_{initial} - \text{Bias}(\mu_{initial})$$

$$= \frac{1}{M}\sum_{i=1}^{M}\hat{z}_i - \frac{1}{m}\sum_{i \varepsilon S_I}(\hat{z}_i - z_i).$$

An estimator of the variance of μ^{MAR} is

$$\text{Var}(\mu_{MAR}) = \frac{1}{m(m-1)}\sum_{i \varepsilon S_I}(\varepsilon_i - \bar{\varepsilon})^2,$$

where $\varepsilon_i = \hat{z}_i - z_i$ and $\bar{\varepsilon} = \frac{1}{m}\sum_{i \varepsilon S_I}\varepsilon_i$. In this manner, proportion forest cover is estimated for each reference year, net proportion deforestation, gross proportion deforestation and gross forest regeneration are estimated for each time interval.

4. Results and discussion

4.1. Forest cover map accuracy assessment results

Fig. 3 illustrates the forest cover change maps for 2000–2010 for the national and one of the UMD GFC maps considering the tree cover and minimum area threshold of the forest definition used for Gabon. The estimates of net deforestation were extremely small, even though these were emphasized for visualization purposes. The most noticeable difference between the two maps is much less regeneration for the UMD GFC map. This may be due to the fact that the regeneration signal is more difficult to detect than the loss of tree cover and also more logging roads are picked up in the national map which represents the greatest proportion of regeneration areas when roads are abandoned. As previously noted, error matrices were constructed using only the pixels selected as SSUs. The results are detailed in Table 2 for the national and UMD GFC forest cover maps for 2000 with very similar results obtained for

Table 2
Error matrices for the 2000 national and UMD Global Forest Change (GFC) based forest cover using a 30% tree cover and 1 ha minimum mapping unit maps for SSUs (n = 33,250).

		Reference			User's accuracy
		Forest	Non-forest	Total	
National	Forest	28,984	338	29,322	0.9885
Classification	Non-forest	312	3616	3928	0.9206
Total		29,296	3954	33,250	
Producer's accuracy		0.9894	0.9145	Overall accuracy	0.9805
GFC 30% 1 ha MMU	Forest	29,222	1298	30,520	0.9575
Classification	Non-forest	74	2656	2730	0.9729
Total		29,296	3954	33,250	
Producer's accuracy		0.9975	0.6717	Overall accuracy	0.9587
GFC 70% 1 ha MMU	Forest	28,802	536	29,366	0.9801
Classification	Non-forest	494	3418	2912	0.8800
Total		29,296	3954	33,250	
Producer's accuracy		0.9861	0.8644	Overall accuracy	0.9690

2010 because of the small magnitude of change. Overall accuracies for all maps are comparable and range from 96% for the UMD GFC map with 30% threshold and 1 ha MMU to 97% for the UMD GFC with 70% threshold and 1 ha MMU, which is an excellent result for a global map product assessed at national level and very close to the 98% obtained for the national map. In addition, producers' and users' accuracies were close to 90% with the exception of the producers' accuracy for the UMD GFC 30% threshold map for the non-forest class which was less than 70%. The latter result indicates underestimation for the non-forest class and a substantial imbalance in the error distributions, meaning that omission errors did not compensate for commission errors. One consequence was that the bias estimate for the UMD GFC 30% threshold map-based estimate was greater than the estimate for the national map or UMD GFC 70% threshold map for which there was considerably less imbalance.

These results were confirmed at PSU-level as shown in Fig. 4. Error matrices shown in Table 2 were based on SSU (sampled pixel) with each SSU labeled as forest or non-forest. PSUs represent 2 × 2 km areas and were independently visually interpreted with a detailed delineation of forest and non-forest area. As a result, forest proportion can be extracted for each PSU to compare map with reference observations at PSU level. The main advantage of performing the analysis at PSU rather than SSU level is that geo-location errors or small differences between map and reference data should then be minimized. For the national and UMD GFC forest/non-forest maps for 2000 shown in Fig. 3, the estimates of forest proportion based on the reference data were similar to the estimates for the PSUs with the exception of a few PSUs for which the differences were large; even so, systematic errors were not evident. A simple linear regression model fit to the reference observations as the dependent variable and the corresponding map predictions as the independent variable (Fig. 4a) produced $R^2 = 0.98$, and estimates of the intercept and slope were close to 0 and 1, respectively, thus confirming the results obtained from the error matrices. In contrast, there is far more scatter for the UMD GFC maps processed with a 30% threshold for which there is a clear overestimation of forest proportion for a substantial number of PSUs as illustrated in Fig. 4b. Although the intercept and slope for the simple linear regression model were still close to 0 and 1, respectively, $R^2 = 0.76$ which is considerably less than for the national map. However, the results for the UMD GFC map processed with a 70% threshold are much closer to the national map with $R^2 = 0.94$, thus illustrating that the UMD GFC map tends to overestimate percentage tree cover, at least for Gabon.

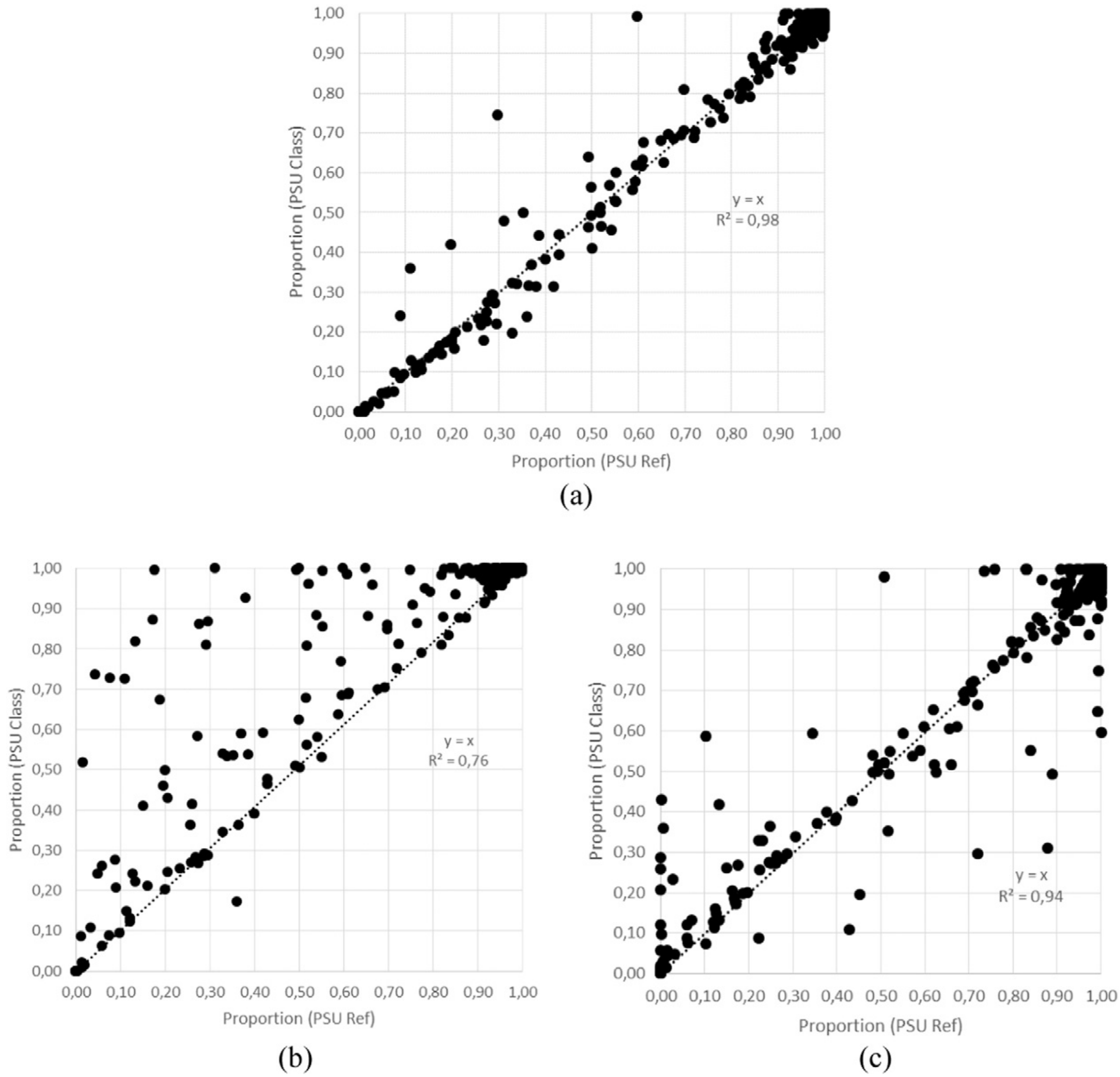

Fig. 4. Comparison of map class and reference observation forest proportion at the PSU level for the (a) 2000 National Forest Cover Map, (b) the 2000 UMD Global Forest Change based map using a 30% tree cover and 1 ha minimum mapping unit and (c) the 2000 UMD Global Forest Change map using a 70% tree cover and 1 ha minimum mapping unit.

The high overall accuracies obtain for all three maps reinforce the notion that overall accuracy can be misleading particularly for the evaluation of binary classification map results such as F/NF and that other accuracy metrics should be used such as the proportion of omission and commission errors or producer and user accuracies as suggested by many others (Story & Congalton, 1986; Stehman, 1997).

4.2. Forest cover area estimates

When applying the tree cover and minimum area threshold of the forest definition to the UMD GFC dataset, the forest cover estimates for the national and GFC maps were within 0.5% of each other with forest proportion estimates of approximately 88.5% representing a total area of slightly more than 23.5 million ha. However, the 953,000 ha adjustment for estimated bias for the UMD GFC dataset is much greater than the 12,000 ha adjustment for the national dataset as illustrated in Table 3 for 2000. In addition, the width of the 95% MAR confidence interval for the national dataset is 70,000 ha which represents less than 0.3% of the forest cover estimate and a reduction in variance by a factor of 58 relative to the width for the SRS estimators. This means that if the sample data were used alone, the reference sample size would have to be increased by a factor of 58 to obtain the same precision achieved when using the map as auxiliary information. The variance of the forest cover estimate for the UMD GFC map is also reduced compared to that of the SRS estimate, but only by a factor of 6. Thus, the reference sample would have to be increased by a factor of nearly 10 for the UMD GFC dataset to obtain the same precision as that of the national map. Similar results were obtained for 2010.

A possible explanation for these large differences could be related to the forest definition applied which is based purely on land cover for the UMD GFC data as shown by Tropek et al. (2014) and takes into account some elements of land use for the national map (oil pam and rubber commercial plantations are not considered as forest). However, the area of commercial plantations in Gabon represents less than 0.1% of the total area of the country according to our estimates. Therefore, the inclusion of land use in the forest definition is most likely not the cause of the large difference between the national and UMD GFC based maps; rather, the difference is more likely to be due to different map construction processes: a scene by scene semi-automated interactive approach for the national map versus a fully automated approach based on a global image mosaic for the UMD GFC map based product.

Table 3
Simple Random Sample (SRS) and Model Assisted Regression (MAR) Estimates of 2000 forest cover and 2000–2010 forest cover net change, forest cover gross deforestation and forest cover gross regeneration proportion and area for national and UMD Global Forest Change based maps from PSUs.

		Forest cover area estimates					Net change estimates				
Study area	(ha)	26,766,700									
SRS estimate	(ha)	23,589,452					24,343				
	(%)	88.13					0.09				
SRS estimate at 95% confidence interval	(ha)	±534,395					±26,573				
	(%)	±2.00					±0.10				
		National	GFC TCD30% MMU 1 ha	GFC TCD30% No MMU	GFC TCD70% MMU 1 ha	GFC TCD70% No MMU	National	GFC TCD30% MMU 1 ha	GFC TCD30% No MMU	GFC TCD70% MMU 1 ha	GFC TCD70% No MMU
Map area statistics	(ha)	23,663,416	24,717,461	24,726,364	23,774,699	23,677,428	4142	92,444	176,117	84,476	138,869
	(%)	88.41	92.45	92.38	88.82	88.46	0.02	0.35	0.66	0.32	0.52
Bias	(ha)	11,393	978,763	964,694	15,331	−78,471	−15,950	71,166	143,429	45,851	126,205
MAR estimate	(ha)	23,651,643	23,768,378	23,761,669	23,759,368	23,755,899	20,092	21,277	32,688	38,625	12,664
	(%)	88.36	88.80	88.77	88.76	88.75	0.08	0.08	0.12	0.14	0.05
MAR estimate at 95% confidence interval	(ha)	±70,332	±216,512	±213,461	±136,830	±137,385	±25,072	±35,356	±40,119	±53,875	±40,451
	(%)	±0.26	±0.80	±0.80	±0.51	±0.51	±0.09	±0.13	±0.15	±0.20	±0.15

		Gross deforestation estimates					Gross forest regeneration estimates				
Study area	(ha)	26,766,700									
SRS estimate	(ha)	74,099					49,756				
	(%)	0.28					0.19				
SRS estimate at 95% confidence interval	(ha)	±21,057					±14,835				
	(%)	±0.08					±0.06				
		National	GFC TCD30% MMU 1 ha	GFC TCD30% No MMU	GFC TCD70% MMU 1 ha	GFC TCD70% No MMU	National	GFC TCD30% MMU 1 ha	GFC TCD30% No MMU	GFC TCD70% MMU 1 ha	GFC TCD70% No MMU
Map area statistics	(ha)	51,211	96,335	184,359	93,754	157,780	47,069	3891	8242	9277	18,911
	(%)	0.19	0.36	0.69	0.35	0.59	0.18	0.01	0.03	0.03	0.07
Bias	(ha)	−27,848	22,002	97,538	19,483	80,844	−11,898	−49,165	−45,891	−26,368	−45,362
MAR estimate	(ha)	79,059	74,333	86,821	74,270	76,936	58,967	53,056	54,133	35,645	64,273
	(%)	0.30	0.28	0.32	0.28	0.29	0.22	0.20	0.20	0.13	0.24
MAR estimate at 95% confidence interval	(ha)	±17,690	±29,701	±34,474	±29,215	±34,360	±15,937	±14,840	±14,953	±43,338	±15,050
	(%)	±0.06	±0.11	±0.13	±0.11	±0.12	±0.06	±0.06	±0.06	±0.16	±0.06

The effect of the MMU was assessed by producing a UMD GFC dataset for which no MMU threshold was applied. Very similar results were obtained. This result is likely attributable to forest patches in Gabon that tend to be larger than the 1 ha MMU and compensation for added smaller forest patches by added smaller non-forest clearings when no MMU is applied.

The very large adjustments for estimated bias for the UMD GFC datasets were caused by over-estimation of forest area which, in turn, was caused by overestimation of percent tree cover. The underlying cause was apparently that the 30% tree cover threshold actually represented a smaller percentage of tree cover in Gabon. As a result, a 70% threshold was applied that was deemed to better correspond to reality. The results obtained for the map with the 70% threshold and the 1 ha MMU threshold were most similar to those for the national dataset (Table 3), with the adjustment for estimated bias of 15,000 ha for the map with the 70% threshold. This was much smaller than the adjustment for the map with the 30% threshold. The reduction in variance by a factor of 15 relative to the variance for the SRS estimate represents an improvement of 2.5 with that of the estimate based on the 30% threshold and no MMU, but the national estimate still provides an additional variance reduction by a factor of almost 4. Finally, the effect of the 1 ha MMU is more noticeable with the 70% percentage tree cover threshold than with the 30% threshold probably because of a more fragmented forest induced by the stricter forest definition resulting from applying the greater percent tree cover threshold.

However, when considering the resulting forest/non-forest map based on the 70% threshold, much of the forest area in the eastern part of the country on the Batéké plateau is classified as non-forest. However, the 70% threshold was still considered the best compromise nationally because this only affects a very small portion of Gabon forest area. The reason for this becomes apparent when looking at unprocessed UMD GFC data as shown in Fig. 5. In Fig. 5a, the area in the eastern part of the country appears different than the rest of the country and coincides with Landsat scene boundaries (Fig. 5b). There could be several reasons for this linked to image scene radiometric calibration or the presence of different forest biomes and land cover which would require further investigations. However, this may suggest that to improve further the forest/non-forest map created from the UMD GFC data, percentage tree cover adjustment should be applied not only at national, but also at a more local level. Fig. 6 compares reference data with the national forest cover map and the UMD GFC maps with the 30%, 70% and 50% thresholds and the 1 ha MMU for 2 reference sites located within Landsat scene WRS2 183/061. The top site is located in the eastern part of the area whereas the bottom one is located in the western part of the area. The national map results (Fig. 6b) are very close to the reference data (Fig. 6a), but appear more generalized than the UMD GFC based forest maps illustrating the difference in processing with the national map vector based and the UMD GFC pixel based. The UMD GFC results for the 30 and 70% threshold were sometimes very close to the reference data, but can also be very far (Fig. 6c & d). The best compromise appears to be obtained with a 50% threshold (Fig. 6e). This means that Landsat scene boundaries (or other relevant data such as forest biomes) could be used to apply different thresholds for different parts of the country ensuring the best correspondence between the percentage tree cover and the reference data. However, additional reference data would need to be acquired or existing data should be split between calibration (to determine the optimal percentage tree cover) and validation (to produce area estimates) to ensure that the observations used in the area estimation are independent from the map production process.

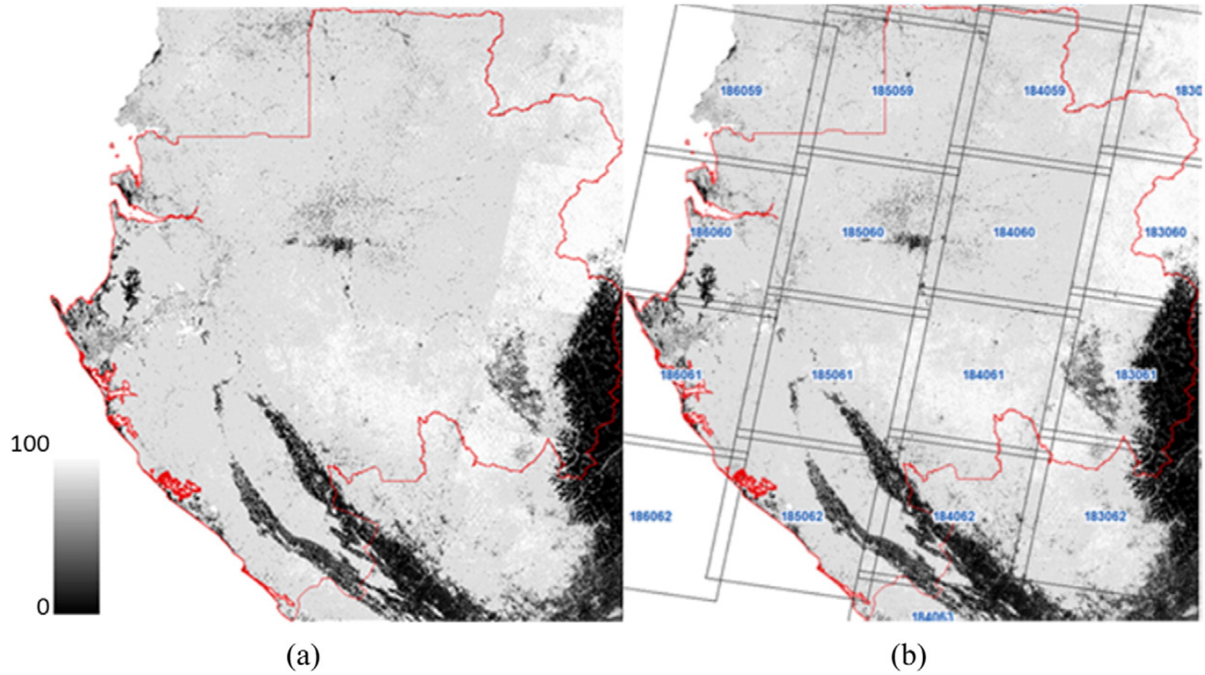

Fig. 5. UMD Global Forest Change tree cover percentage dataset for 2000 over Gabon without (a) and with (b) Landsat WRS2 scenes boundaries. The example shown in Fig. 5 is contained with the Landsat 183/061 Path/Row.

4.3. Forest cover change area estimates

Although the UMD GFC map with the 70% threshold and the 1 ha MMU produced forest cover area estimates that were most similar to the estimates obtained from the national forest cover map, the results were not as clear for net forest cover change (Table 3). For the four GFC maps, the smallest adjustment for estimated bias was 46,000 ha for the map with the 70% threshold and the 1 ha MMU, although the adjustment was still much greater than the 16,000 ha adjustment for the national map. In addition, the GFC map with the 70% threshold and the 1 ha MMU produced the widest confidence interval.

The UMD GFC map with the 30% threshold and the 1 ha MMU produced the confidence interval with the smallest width from among the four UMD GFC maps, but the 71,000 ha adjustment for estimated bias was greater than for the map with the 70% threshold. In addition, confidence interval widths for the four UMD GFC maps using the MAR estimators were all greater than the width for SRS estimate. For the national map, the increase in precision obtained using the MAR estimator rather than SRS estimator was small, likely because the level of change itself is very small overall and because of many small patches as opposed to few large patches (Fig. 3). In addition, none of the change estimates were significantly different from 0 at the 95% confidence level. Other studies in the Congo basin region such as from Ernst et al. (2013) have shown that there is a negative relationship between the magnitude of change and the level of uncertainty. More substantial improvements are available from results for the Gabonese national map

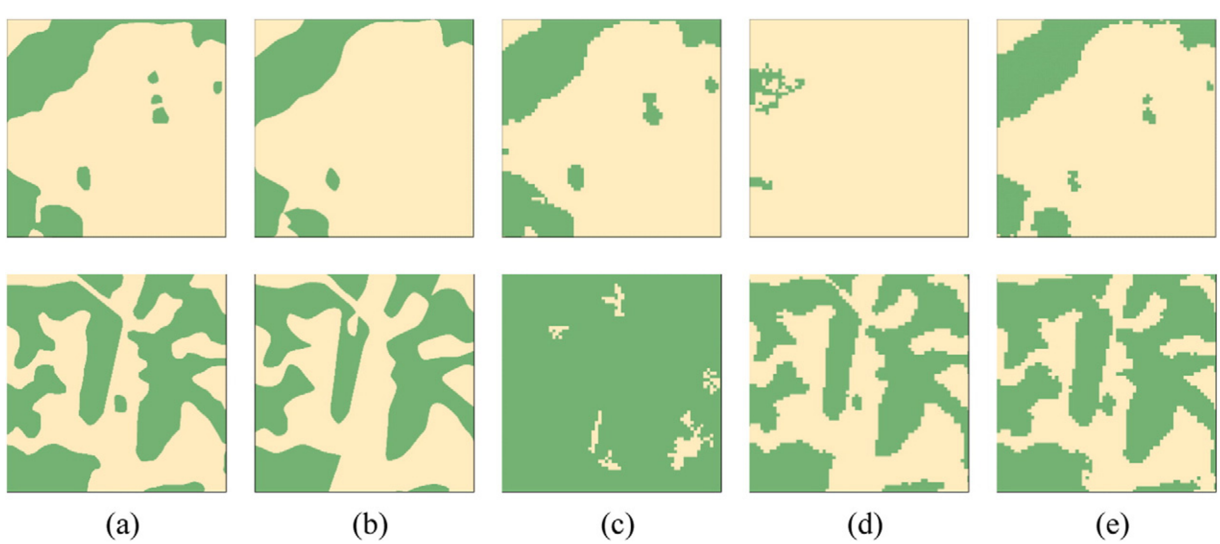

Fig. 6. Comparison of (a) the reference data (b) the national forest cover map (both are in vector format), the Global Forest Cover based forest cover map with, (c) a 30% tree cover threshold, (d) a 70% tree cover threshold and (e) a 50% threshold over two sample units (2×2 km for each sample unit) contained within the WRS2 183/061 Landsat Path/Row in Eastern Gabon for the Eastern (top) and western (bottom) part of the area with forest appearing in green color.

produced for the 1990–2000 period not presented here, but for which a greater magnitude of change was detected (Desclée et al., 2014). Considerable effort can be spent in improving the maps produced to reduce the width of confidence intervals, but the benefits should be carefully considered against the considerable additional costs that would be incurred. Under certain circumstances (e.g. very small and scattered patterns of change), there could be a threshold for magnitude of changes less than which wall-to-wall forest change maps would only provide marginal improvement compared with a pure SRS approach and resulting change estimates would not be significantly different from 0 such as in this case.

Differences between the national and the UMD GFC change estimates could be attributed to net changes resulting from the combination of substantially greater gross deforestation and regeneration as can be seen mainly in Fig. 3. The national map apparently detected considerably more forest regeneration than the UMD GFC map, a result confirmed by the gross deforestation and regeneration estimates shown in Table 2.

For gross deforestation, the best UMD GFC map in terms of adjustment for estimated bias and confidence interval width was the map with the 30% threshold and the 1 ha MMU map followed closely by the map with the 70% threshold and the1 ha MMU. However, the confidence intervals for both maps were wider than for the SRS estimate. In addition, the national map produced a slight increase in precision relative to the SRS estimate with a reduction in variance by a factor of 1.4. Overall, gross deforestation estimates were significantly different from 0.

Although the national forest map tended to underestimate deforestation whereas the UMD GFC maps tended to overestimate deforestation, a different outcome was found for forest regeneration which was underestimated by all maps, but far less by the national map (Fig. 3). In addition, the national map had the smallest adjustment for estimated bias at 12,000 ha compared to 26,000 ha for the UMD GFC map with the 70% threshold and the 1 ha MMU map which had the smallest adjustment for the four UMD GFC maps. However, the confidence interval widths were all very similar with the exception of the map with the 70% threshold and the 1 ha map for which the width was three times greater than for the other maps and which produced the only estimate that was not significantly different from 0. Of importance, none of the MAR estimates for the UMD GFC maps provide substantial improvement in precision relative to the SRS estimate.

4.4. Guidelines for processing global datasets to report forest cover estimates at national level

Currently, none of the available guidelines from UNFCCC or even more specifically from the REDD documentation (Hirata et al., 2012, GFOI or GOFC-GOLD) indicate a minimum standard for precision. The general statement is only that estimates should “neither over- nor under-estimates so far as can be judged, and in which uncertainties are reduced as far as is practicable” (IPCC, 2006). A starting point would be that use of the map should improve the precision of the estimates relative to the precision obtained using a simple random sampling approach that does not use the map as auxiliary information. A suitable minimum threshold for this improvement should be based in part on the additional cost incurred by processing the map as opposed to simply the cost of increasing the sample size to reach the same level of precision. As mentioned earlier, there are additional benefits to using the map other than simply improving on a pure SRS approach. In addition, the decision regarding use of a global-based map versus a fully national-based map should also focus on comparing costs and precision obtained versus the additional payment for the country that would be generated from a performance-based system, if additional precision was obtained. Finally, even though improvement in the forest cover map may not appear necessary, the results of Table 3 suggest that when the forest cover map is improved a positive impact accrues in that estimation bias that results from misclassification in the forest cover change maps is reduced, even though this is not so obvious for improving the precision (confidence intervals) of the estimates. This result should be confirmed elsewhere for countries with greater magnitude of change such as DRC (Potapov et al., 2012).

From the results and discussions from this study, it was shown that the UMD GFC data cannot be used directly by just applying a percentage tree cover and minimum area threshold corresponding to the selected national forest definition if the uncertainty of the estimates are to be minimized. However, additional steps can be applied to approach the level of precision obtained for the national map.

The first step identified was to adjust the percentage tree cover threshold to be applied at national level in order to minimize the bias resulting from forest/Non-forest map misclassification. However, the nature of the reference data acquired for this study did not permit an automatic adjustment. This is because the data were collected initially in combination with the national map directly in the form of a forest/non forest sample based map dataset (see Fig. 6) which is quite different to the tree cover percentage of the UMD GFC data. An additional reason is also that to apply the MAR method, the reference data should be independent from the map data which would no longer be the case if the reference data were used directly to determine the threshold. Nevertheless, it was shown that forest/non forest sample data can still be used to identify a suitable percent tree cover threshold based on the interactive approach that was applied for this study. Therefore, should similar reference data be available or collected at national level elsewhere, the following steps should be implemented to use the UMD GFC data for national level forest cover reporting:

1. A starting point is to apply the threshold corresponding to the national forest definition to the UMD GFC data. Pixel values greater than the threshold are classified as forest and those lower than the threshold are classified as non-forest
2. A minimum area threshold can then be applied to match the minimum forest area of the national forest definition
3. Land use elements of the national forest definition can be integrated based on external data sources if required
4. The resulting forest/non forest map can be compared to a probability sample reference data similar to the one used for this study
5. Forest cover proportion for individual PSUs can be compared to determine if the map produced under or over estimation forest cover. In the case of over estimation, the threshold selected would need to be increased, in case of under estimation, the threshold would need to be lowered.
6. Steps 1–5 can be repeated with a succession of thresholds (e.g. start with 30%, then 50% and 70% as in this case) until there is no substantial bias detected based on visual estimation of scatterplots (e.g. as in Fig. 4) or based on the difference between omission and commission error which should be close to 0 (see Table 2).
7. The forest/non-forest map corresponding to the selected threshold can then be used for producing area estimates based on the MAR approach.

A more automated approach to determine a suitable threshold of tree cover percentage could be achieved if additional reference data were collected in a suitable form following an approach similar to the one described at the end of Section 2.2. A probability sample could be designed in which PSU size would correspond to the minimum forest area and SSU would correspond to a grid of points. The number of points could be adjusted to match the level of heterogeneity in the landscape and the presence and absence of tree canopy would be recorded for each SSU based on the visual assessment of VHR imagery. The number of SSUs intersecting with tree canopy for each PSU can then be used to determine percentage tree cover at PSU level. This data can then be compared directly with UMD GFC data to determine a suitable threshold corresponding to the national forest definition. Such an approach should be sufficiently generic to be applied across a wide variety of landscape and was already applied in Central African Republic by Fichet, Sannier, Mermoz, et al. (2014).

In addition, the results and analysis of this study suggest that further improvements may be achieved if some more localized adjustment is applied (see Figs. 5 & 6). Data collected following the procedure described above could be used to provide the means for more spatially detailed adjustment of the percentage tree cover. Such a dataset could be used to determine optimal thresholds both at national and local level in combination with relevant additional spatial data sources on forest biomes or Landsat scene boundaries and would then contribute to further improvement of the resulting UMD GFC based forest/non-forest map thus reducing the uncertainty of the forest cover estimates. In addition, it could also be applied to other global datasets which provide estimates of percentage tree cover classes such as the one described by Shimada et al. (2014). The sampling approach used for this study would still be required to provide an independent assessment of the resulting forest/non-forest map product.

5. Conclusions

The results obtained from this study demonstrate that in the case of Gabon the UMD GFC data can be processed to match the land cover component of the selected national forest definition.

The MAR method as described by Sannier et al. (2014) was applied to the combination of reference data available and the UMD GFC based forest maps to determine the degree to which estimates of forest cover and forest cover change and their associated uncertainties are enhanced using the UMD GFC dataset relative to using the reference data alone. There is a substantial improvement for forest cover area estimates although a more detailed assessment of the costs versus the benefits of using the maps would need to be undertaken including taking into account the additional income that would be generated by the increased precision through a performance based payment system. With regards to forest cover change, there was no substantial improvement to using the UMD GFC based maps, but very few changes were observed in Gabon during this period and most of the net forest change estimates are not statistically different from 0. Therefore, a similar exercise should be conducted in an area where more substantial changes occur.

The same approach was applied to the national map. Although the estimates of the area of forest cover for the national map were substantially more precise than the UMD GFC based, the loss of precision for the UMD GFC based change estimates were quantified and less substantial than for the forest cover area estimates. Again an assessment of the relative benefits of increasing the level of accuracy and precision would need to be made considering the flowing elements:

- costs and resources required by a national mapping exercise
- processing costs of UMD GFC data
- extra costs for collecting and interpretation of additional samples
- additional income generated by the increased precision from a performance based payment scheme

Although the UMD GFC dataset provides a reliable means of producing area statistics at national level combined with appropriate sample reference data, thus offering an alternative to nationally produced datasets (i) the classification errors associated with the Global dataset have non-negligible effects on both the estimate and the precision supporting the more general statement that map data should not be used alone to produce area estimates, and (ii) the maps obtained from the UMD GFC dataset require specific calibration of the tree cover percentage representing a non-negligible effort requiring specialized staff and equipment. Guidelines on how to use and further improve global maps for national reporting are suggested. However, this additional effort would still be most likely less than the production of national based maps.

Forest cover area estimates obtained for 2000 confirm the high level of forest cover in Gabon with approximately 88.5% of the country covered by forest which covers an area of more than 23.5 million hectares for both national and global datasets. Forest cover change results indicated that the net deforestation in Gabon was not significantly different from 0 from 2000 to 2010. Gross deforestation estimates were all significantly different from 0 and all but one estimates of forest regeneration were also significantly different from 0 suggesting that the loss of forest cover in Gabon is counter balanced by regeneration.

It should also be noted that despite some very substantial differences between the maps produced in terms of forest area and forest area change, the adjustment for estimated bias with the MAR estimator considerably reduces the differences between the maps for the area and area change estimates compared with the maps alone. Thus accurate estimates can still be produced based on the combination of reference data and maps with varying levels of accuracy.

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