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# Assessing change in national forest monitoring capacities of 99 tropical countries ☆

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ABSTRACT

Monitoring of forest cover and forest functions provides information necessary to support policies and decisions to conserve, protect and sustainably manage forests. Especially in the tropics where forests are declining at a rapid rate, national forest monitoring systems capable of reliably estimating forest cover, forest cover change and carbon stock change are of vital importance. As a large number of tropical countries had limited capacity in the past to implement such a system, capacity building efforts are now ongoing to strengthen the technical and political skillsets necessary to implement national forest monitoring at institutional levels. This paper assesses the current status and recent changes in national forest monitoring and reporting capacities in 99 tropical countries, using the Food and Agriculture Organization of the United Nations (FAO) Forest Resources Assessment (FRA) 2015 data, complemented with FRA 2010 and FRA 2005 data. Three indicators "Forest area change monitoring and remote sensing capacities", "Forest inventory capacities" and "Carbon pool reporting capacities" were used to assess the countries' capacities for the years 2005, 2010 and 2015 and the change in capacities between 2005–2010 and 2010–2015. Forest area change monitoring and remote sensing capacities improved considerably between 2005 and 2015. The total tropical forest area that is monitored with good to very good forest area change monitoring and remote sensing capacities increased from 69% in 2005 to 83% in 2015. This corresponds to 1435 million ha in 2005 and 1699 million ha in 2015. This effect is related to more free and open remote sensing data and availability of techniques to improve forest area change monitoring. The total tropical forest area that is monitored with good to very good forest inventory capacities increased from 38% in 2005 to 66% in 2015. This corresponds to 785 million ha in 2005 and 1350 million ha in 2015. Carbon pool reporting capacities did not show as much improvement and the majority of countries still report at Tier 1 level. This indicates the need for greater emphasis on producing accurate emission factors at Tier 2 or Tier 3 level and improved greenhouse gases reporting. It is further shown that there was a positive adjustment in the net change in forest area where countries with lower capacities in the past had the tendency to overestimate the area of forest loss. The results emphasized the effectiveness of capacity building programmes (such as those by FAO and REDD+ readiness) but also the need for continued capacity development efforts. It is important for countries to maintain their forest monitoring system and update their inventories on a regular basis. This will further improve accuracy and reliability of data and information on forest resources and will provide countries with the necessary input to refine policies and decisions and to further improve forest management.



## 1. Introduction

About one third of the earth's land surface is covered by forests which store about 45% of the world's terrestrial carbon in wood, leaves, roots and soil. Almost half of this area consists

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of tropical forests, which, on average, can store 50% more carbon in the trees than other types of forests (Houghton, 2005; Bonan, 2008). In addition to playing a critical role in regulating the world's climate, forests provide a variety of functions for people and the planet, including ecological, economic, social and aesthetic functions (Miura et al., 2015). Moreover, forests contribute largely to livelihood security and provide fuelwood and charcoal, which are major energy sources in developing countries (FAO, 2014a).

Humans are continuously changing the land use to get access to the planet's resources through clearance of forests for agricultural activities and urban expansion. Land use and land cover change have a climate forcing effect and play a major role in changing the world's climate (Pielke, 2005; Hosonuma et al., 2012). Deforestation is a global threat, not only because it causes habitat fragmentation and loss of biodiversity, but it also degrades environmental conditions and has an impact on global greenhouse gas emissions (GHG) by releasing $CO_2$ to the atmosphere. This causes changes in the global carbon cycle and alters the surface energy and water balance. As a consequence, the release of carbon affects climatic patterns and causes changes in environmental conditions and ecosystems (Cramer et al., 2004; Foley et al., 2005). Avoiding deforestation could reduce GHG emissions significantly. Forest management, including reducing and preventing deforestation is an important climate mitigation strategy and helps to secure the different forest functions (Bonan, 2008; Salvini et al., 2014). Numerous studies used global remote sensing data to highlight the fact that during the last decades forests in the tropics have been rapidly declining (DeFries et al., 2002; Achard et al., 2004; Hansen et al., 2010, 2013; FAO and JRC, 2012). FRA 2015 data show that the annual rate of net forest loss in the tropics has decreased compared to the 1990s (9.5 M hectare per year) and 2000s (7.2 M hectare per year). Recent estimates indicate a decline of 5.5 M hectare of forests per year between 2010 and 2015 in the tropics (Keenan et al., 2015).

Monitoring forests over time allows countries to observe changes. Regular and accurate monitoring of forest cover, forest cover change and drivers of change provides the necessary information to support policies and management practices to protect, conserve and sustainably manage forests and to ensure the different functions of forests (Mayaux et al., 2005; Achard et al., 2007; MacDicken, 2015). Consistent information on forest resources is needed for developing these policies and monitoring should be done at a national scale to properly assist localized land management decisions. At the global level, the importance of monitoring forest cover change and forest functions is reflected in environmental conventions such as the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity.

Main focus of forest observation systems is on monitoring forest area and changes in forest area and on monitoring forest carbon stocks and changes. Earth observation has a key role in monitoring tropical forests. It should be noted that different studies use different definitions of forests and earth observation may provide varying estimates of "forest area" depending on the definition and method that is used. For example, the FRA (FAO, 2015) uses a forest land use definition. The JRC/FAO Remote Sensing Survey (FAO and JRC, 2012) uses a forest cover definition, while Hansen et al. (2013) measures tree cover change. This results in varying estimates of forest extent for a similar area. A detailed explanation on this matter can be found in Keenan et al. (2015).

Several papers discuss the technical requirements for implementing national forest monitoring systems in the context of REDD+ (Mayaux et al., 2005; Achard et al., 2007; DeFries et al., 2007; Herold and Johns, 2007; De Sy et al., 2012). Earth observing satellite data analyses, together with field-based national forest inventories provide data on forest cover and forest cover change at national scale. At least a time series of Landsat-type remote sensing data with 30 m spatial resolution should be used for national deforestation monitoring. An example of operational national and regional remote sensing monitoring is Brazil's PRODES system for monitoring deforestation in the Brazilian Legal Amazon region. This system uses Landsat, DMC and CBERS satellite data at 20–30 m resolution (GOFC-GOLD, 2014). National forest inventories provide data that are needed to estimate the carbon content of different forest types. India has a long history of national forest inventories. The new national forest inventory, established in 2001, generates national level estimates of growing stock at similar time intervals as the biennial forest cover assessment which is based on 23.5 m resolution IRS P6 satellite imagery. Using a sampling design, estimates of growing stock are developed for 14 physiographic zones based on physiographic features including climate, soil and vegetation. Every two years different districts are inventoried (GOFC-GOLD, 2014).

Remote sensing technologies are continuously in development and new available satellite and airborne sensors, analysis and methods are emerging at a constant pace (De Sy et al., 2012). Evolving technologies include the use of LIght Detection And Ranging (LIDAR) and Synthetic Aperture Radar (SAR) observations for forest characterization and biomass estimation. These techniques can help to overcome the challenge of cloud cover in the tropics. Unmanned Aerial Vehicles (drones) can be used for local scale validation studies. New techniques for acquiring, processing and managing vast amounts of satellite remote sensing data include cloud-based databases and data processing platforms which offer space for large datasets and computational resources for processing (GOFC-GOLD, 2014). An example of new and forthcoming initiatives includes the Copernicus program with a constellation of earth observation satellites (Sentinels) and in-situ sensors for monitoring the earth.

Capacities of tropical Non-Annex I countries to monitor forests and forest cover change were limited in the past. However, through capacity building efforts capacities are strengthening at technical, political and institutional levels (Herold and Skutsch, 2011; Romijn et al., 2012). A few Non-Annex I countries like Mexico and India have well developed national forest monitoring systems. Other countries are in the process of developing capacities and are at various stages of development; they need considerable capacity improvements before they are able to produce accurate estimates of forest area, forest area change and carbon stock change (Tulyasuwan et al., 2012).

The aim of this paper is to assess the capacity status and the changes in national forest monitoring and reporting capacities in 99 tropical Non-Annex I countries for the years 2005, 2010 and 2015, using the FAO FRA data. The specific objectives are to explain the change in forest monitoring and reporting capacities and to investigate the effectiveness of capacity building initiatives for improving national forest monitoring systems. Additional objectives are to assess the effect of increased capacities on the area of tropical forest that is monitored with accurate and reliable data and methods, and to assess the effect of increased capacities on reported FRA numbers of net change in forest area for similar time periods.

## 2. Materials and methods

### 2.1. Data

This study focuses on 99 tropical Non-Annex I countries. These include countries that are located in the sub-tropical or tropical domain, as defined in the FRA 2015 datasets (FAO, 2015) and

China, which in the Southern part is covered by tropical forests. The main data sources used for this study were the FAO FRA country reports and global tables for 2005, 2010 and 2015. Table 1 specifies which sections from the country reports were used. National data on forest extent and forest monitoring capacities were extracted from the report sections on area of forest and other wooded land; growing stock; and carbon stock (including Tiers as specified by FRA). Data for each individual country were compiled in a database which allowed to make global maps and systematic global comparisons.

Additional sources of information were used to explain the status of current country capacities and to investigate what drives the recent change in capacities. This information was found in (online) reports and articles concerning capacity building initiatives related to tropical forest monitoring from bilateral initiatives (e.g. USAID, AUSAID, Norway, Japan), multilateral initiatives (UN-REDD, World Bank FCPF, FAO NFMA), international initiatives (COMIFAC) and by digging deeper into the individual country reports.

### 2.2. Methodology

The countries' national forest monitoring and reporting capacities and the change in capacities were assessed by examining three different indicators. For each of the 99 tropical Non-Annex I countries data were compiled for the three indicators "Forest area change monitoring and remote sensing capacities", "Forest inventory capacities" and "Carbon pool reporting capacities". These are similar to the indicators used in the study about assessment of national forest monitoring capacities of Non-Annex I countries in the context of REDD+ by Romijn et al. (2012). The first indicator reflects the capacities of a country to monitor forest area and forest area changes and its ability to produce forest cover and forest cover change maps using time series of remote sensing data. The second and third indicators reflect the capacities to perform a carbon stock assessment. The focus of the second indicator is on performing a national forest inventory for collecting data on forest species and biomass, while the third indicator focuses on reporting on biomass and carbon stocks and changes in the five different carbon pools of forest: aboveground biomass (AGB), belowground biomass (BGB), soil organic matter (carbon in mineral and organic soils, including peat), dead wood and litter, using different Tiers for estimating emission factors as set out in IPCC guidelines (IPCC, 2003, 2006, 2014). Tier 1 uses the default emission factors provided by IPCC for carbon stock change estimation. Tier 2 employs country-specific data for the most important land uses and activities, making use of forest volume or biomass values from existing forest inventories and/or ecological studies. Tier 3 is most demanding and uses repeated measurements of trees from plots and/or calibrated process models, tailored to address national circumstances. For each indicator a score was calculated based on the characteristics of the country, see Table 1. Because qualitative data sources were used for this analysis, the indicator outcomes were determined on an ordinal scale. This enables to make systematic global comparisons and to observe relative differences between the 99 countries. There are a few points of consideration in assigning ordinal values to the indicators. For example, forest area change monitoring and remote sensing capacities were deemed as good or very good when one or multiple forest cover maps were produced by the country itself on a regular basis. This however, did not take into account the quality of the maps, as there were no accuracy estimates available for all of these maps within our analysis. Nevertheless, it does reflect the progress that a country has made in performing forest area change assessments independently. The same applies for the other two indicators. The analysis did not take into account the accuracy of the forest biomass and carbon estimates in the forest inventories, but assignment of values to indicators was based on the information that was available from the country reports.

In addition, the change in capacities for each of the indicators was calculated as follows:

$$\text{Change 2005–2010} = \text{Indicator score 2010} - \text{Indicator score 2005}$$
$$\text{Change 2010–2015} = \text{Indicator score 2015} - \text{Indicator score 2010}$$

**Table 1**
Indicators used to assess a countries' national forest monitoring capacities, the data sources that were used to gather information for each indicator, and the scoring system.

| Indicator | FAO FRA data source | Indicator score | Value | Characteristics |
|---|---|---|---|---|
| Forest area change monitoring and remote sensing capacities | Section 1.2.1 in the country reports of 2005, 2010 and 2015 | 0 | Low | No forest cover map |
| | | 1 | Limited | One forest cover map (external) |
| | | 2 | Intermediate | Multiple forest cover maps (external) |
| | | 3 | Good | One or more forest cover map(s) (in-country), most recent produced before 2000 for 2005 assessment; before 2005 for 2010 assessment; before 2010 for 2015 assessment |
| | | 4 | Very good | Multiple forest cover maps (in-country), most recent produced after 2000 for 2005 assessment; after 2005 for 2010 assessment; after 2010 for 2015 assessment |
| Forest inventory capacities | Section 5.2.1 in the country report of 2005; Section 6.2.1 in the country report of 2010; Section 3.2.1 in the country report of 2015 | 0 | Low | No forest inventory |
| | | 1 | Limited | One forest inventory (external) |
| | | 2 | Intermediate | Multiple forest inventories (external); or in-country, but no full cover for all forests |
| | | 3 | Good | One or more forest inventories (in-country), most recent before 2000 for 2005 assessment; before 2005 for 2010 assessment; before 2010 for 2015 assessment |
| | | 4 | Very good | Multiple forest inventories (in-country), most recent produced after 2000 for 2005 assessment; after 2005 for 2010 assessment; after 2010 for 2015 assessment |
| Carbon pool reporting capacities | Section 7 in the country report of 2005; Section 8 in the country report of 2010; Section 3.4 in the country report of 2015, including Tier system of FRA | 0 | Low | No reported carbon stocks |
| | | 1 | Limited | Above ground biomass (AGB) reported (using Tier 1) |
| | | 2 | Intermediate | Minimum AGB and soil reported (using Tier 1) |
| | | 3 | Good | AGB reported (using Tier 2 or Tier 3) |
| | | 4 | Very good | More than one pool reported (using Tier 2 or Tier 3) |

Global maps and tables were created with GIS and spreadsheet software, showing the capacities of the three indicators "Forest area change monitoring and remote sensing capacities", "Forest inventory capacities" and "Carbon pool reporting capacities" for the years 2005, 2010 and 2015, as well as the change in capacities for the periods 2005–2010 and 2010–2015. Capacities were expressed in relation to the percentage of total tropical forest area of the 99 countries that is monitored with this level of capacities. Information from several capacity building programmes was gathered in order to observe the effect of these programmes on improvements of capacities. Reported FRA numbers of net change in forest area (data from 2005, 2010 and 2015) for a similar period (i.e. 2000–2005 or 2005–2010) were compared for countries with increased capacities to see the actual effect of capacity improvements on reported numbers.

## 3. Results and discussion

### *3.1. Forest area change monitoring and remote sensing capacities*

Forest area change monitoring and remote sensing capacities improved significantly between 2005 and 2015. Fig. 1 shows the forest area change monitoring and remote sensing capacities in all 99 tropical Non-Annex I countries for the assessment years 2005, 2010 and 2015. Fig. 2 shows the changes in capacities for the periods 2005–2010 and 2010–2015. In 2015, 54 countries had good to very good capacities to monitor changes in forest area using remote sensing data, which means they were able to produce their own forest change maps. Overall, capacities in Latin American and South-East Asian countries are now very well developed. In Africa, capacities improved over time, with a few countries (DRC

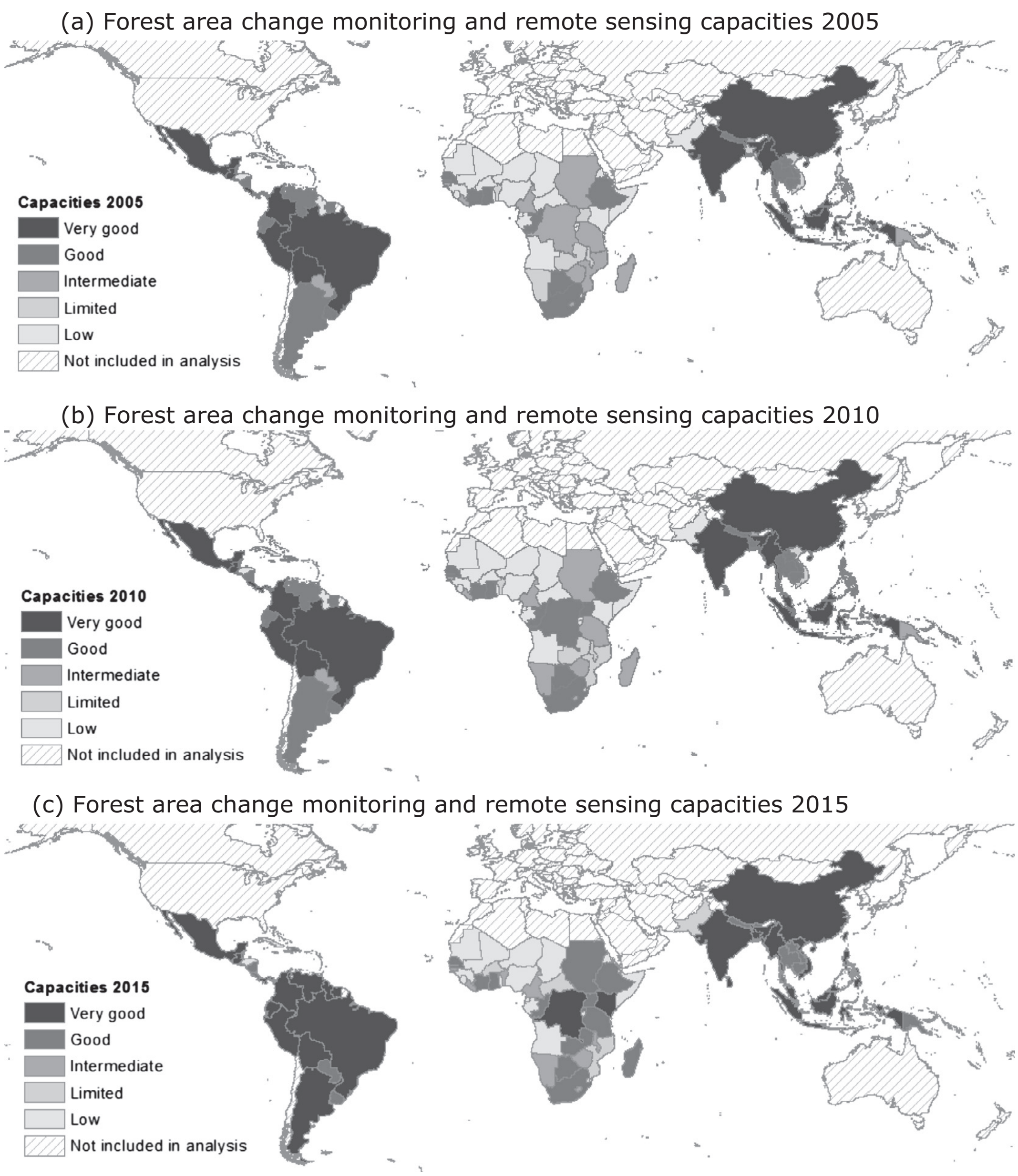


**Fig. 1.** Forest area change monitoring and remote sensing capacities in 2005 (a), 2010 (b) and 2015 (c). The outcomes, ranging from "low" to "very good", reflect the indicator score for each of the 99 tropical Non-Annex I countries, based on analysis of FAO FRA country reports.

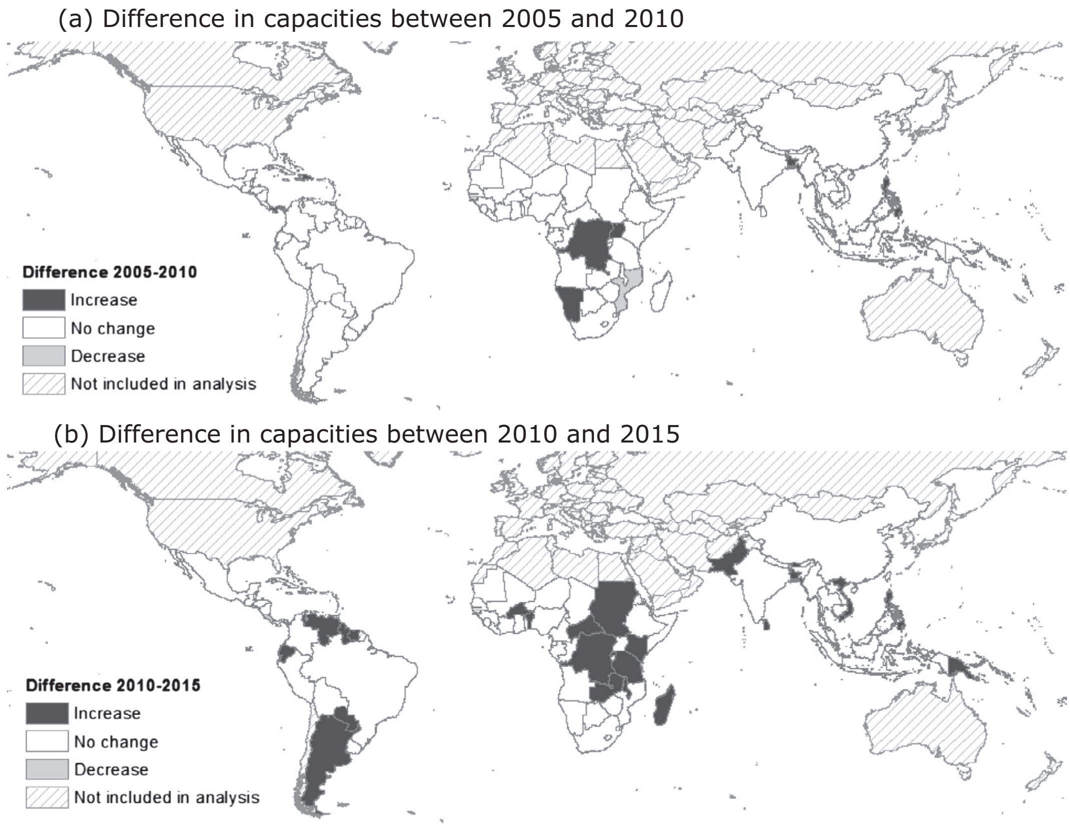


**Fig. 2.** Change in forest area change monitoring and remote sensing capacities between the years 2005–2010 (a) and 2010–2015 (b).

and Kenya) now having very good capacities to monitor changes in forest area using remote sensing. Between 2005 and 2010 capacities improved slightly, with most changes taking place in Central African countries. Between 2010 and 2015 considerable capacity improvements took place, mainly in Central African countries and Latin American countries. In many African countries the maps are now made by the country itself instead of by external researchers and the countries in Latin America are now able to produce maps to assess forest area change on a more regular basis. Between 2005 and 2015 the number of countries with low monitoring capacities reduced from 35 to 24 countries, while the number of countries with good and very good capacities grew from 25 to 31 and from 12 to 23 respectively (see Table 2). In 2015, one quarter of the countries still had low capacities. Especially in Africa, there is a large number of countries with low (17 countries), limited (6 countries) or intermediate (8 countries) capacities and considerable improvements are needed. Appendix A contains the indicator values of forest area change monitoring and remote sensing capacities for all 99 tropical Non-Annex I countries.

**Table 2**
Change in forest area change monitoring and remote sensing capacities between 2005, 2010 and 2015. The numbers in the table refer to the number of countries which fall into each category for a certain year.

| Forest area change monitoring and RS capacities | 2005 | 2010 | 2015 |
|---|---|---|---|
| Low | 35 | 31 | 24 |
| Limited | 12 | 11 | 11 |
| Intermediate | 15 | 14 | 10 |
| Good | 25 | 30 | 31 |
| Very good | 12 | 13 | 23 |

### *3.2. Forest inventory capacities*

Forest inventory capacities in 2005, 2010 and 2015 and changes in capacities between 2005–2010 and 2010–2015 are presented in Figs. 3 and 4. Indicator values for all 99 tropical Non-Annex I countries can be found in Appendix A. In 2015, 40 countries had good to very good capacities which means they performed national forest inventories on a regular basis. In South East Asian countries capacities were well developed, where 13 out of 17 countries had good or very good capacities in 2015. In Latin America and Africa, capacities were less well developed and considerable capacity improvements are needed before countries will be able to perform regular national forest inventories. Nevertheless, in these two continents capacities have improved over time. Between 2005 and 2010 capacities improved especially in Africa. In many cases this was a change from limited to intermediate capacities, which means that they produced more forest inventories, but these were still done by external researchers. From 2010 to 2015 increases in capacities can be seen in Latin American countries, Central African countries and in Indonesia. Some of these countries had a medium or large increase in capacities (i.e. Colombia, Ecuador, Zambia, Tanzania) and now have good forest inventory capacities which means their inventories are done in-country instead of by external researchers. In a few cases, a decrease in capacities can be seen. This can be due to altering national circumstances or unstable conditions due to the political situation in a country. The number of countries with low or limited capacities decreased from 63 in 2005 to 40 in 2015 (see Table 3). The number of countries with intermediate capacities increased from 7 in 2005 to 19 in 2015 and the number of countries with good capacities increased from 23 in 2005 to 31 in 2015. The number of countries with very good capacities increased only slightly, from 6 countries in 2005, to 8 countries in 2010 to 9 countries in 2015.

### 3.3. Carbon pool reporting capacities

Fig. 5 shows the carbon pool reporting capacities for the years 2005, 2010 and 2015. Fig. 6 shows the capacity changes between the years 2005–2010 and 2010–2015. Indicator values for all 99 tropical Non-Annex I countries can be found in Appendix A.

Overall, carbon pool reporting capacities improved over time. However, most improvements imply changes from low, to limited and intermediate capacities. This means countries started to report on more carbon pools but still used Tier 1 emission factors.

In many African countries, modest improvements took place between 2005 and 2010. This was a change from only reporting AGB carbon stocks, to reporting AGB and soil carbon stocks, but still using Tier 1 methods. Similar modest improvements took place in a few Latin American and South East Asian countries between 2005 and 2010. From 2010 to 2015 more improvements took place. In 2015, 14 countries had very good carbon pool reporting capacities. The largest group of countries had low to intermediate capacities, as can be seen from Table 4. Half of the countries (50) were "stranded" with intermediate capacities. They were able to report on various carbon pools, at least on AGB and soil, but were not able to use Tier 2 or Tier 3 methods for biomass conversion. A large number of countries (17), still had low capacities and were not able to report on carbon in the five different pools. This mainly concerns countries and small island states in the Caribbean and Pacific. Also, a large number of countries (17) had limited carbon pool reporting capacities and were only able to report AGB at Tier 1 level. An example of a country that steadily improved over time is Mexico. The country had low capacities in 2005, increased to intermediate capacities in 2010 and to very good capacities in 2015. In 2005, no carbon stocks were reported. In 2010 AGB, BGB and soil carbon stocks were reported at Tier 1 and in 2015, AGB, BGB and dead wood carbon stocks were reported at Tier 3.

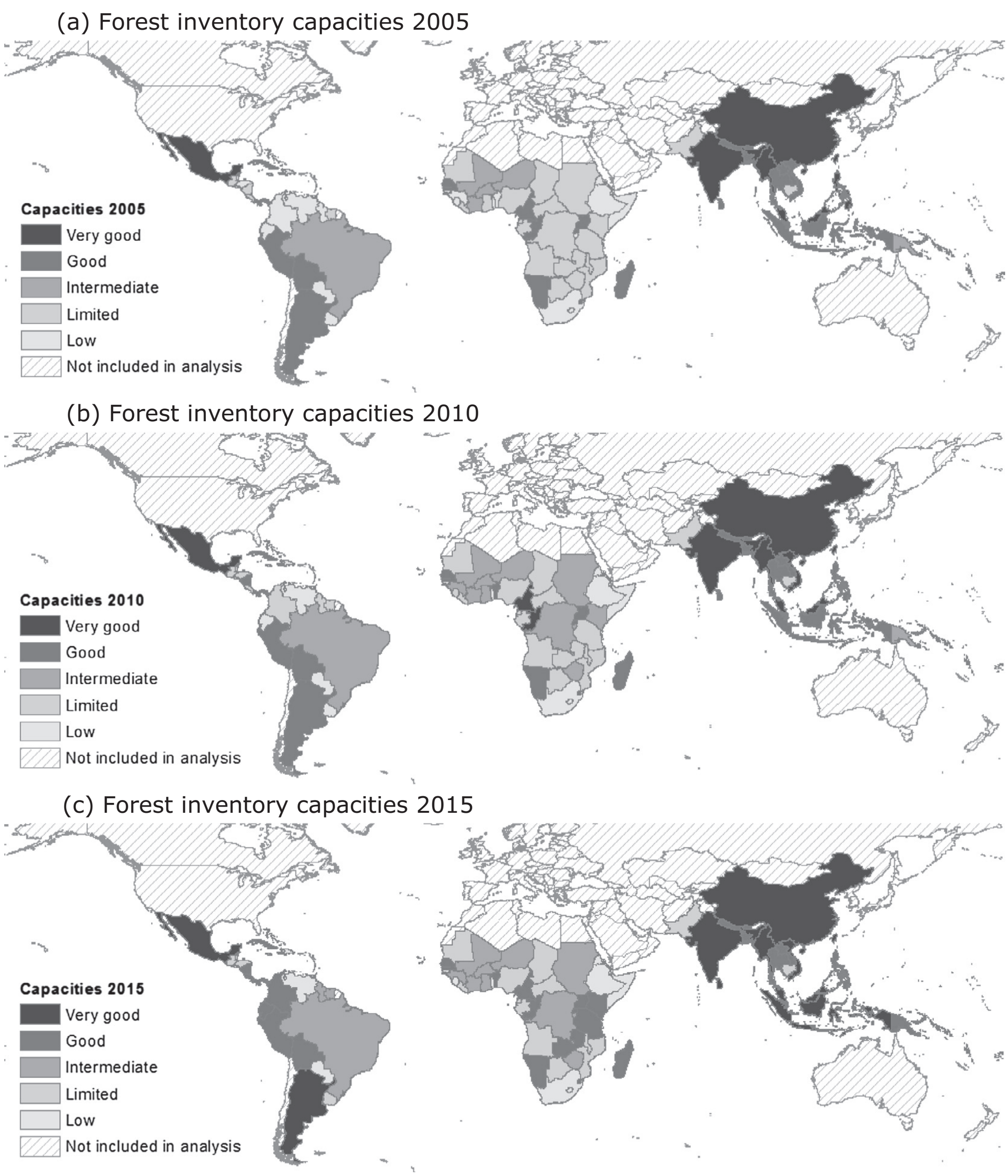


**Fig. 3.** Forest inventory capacities in 2005 (a), 2010 (b) and 2015 (c). The outcomes, ranging from "low" to "very good", reflect the indicator score for each of the 99 tropical Non-Annex I countries, based on analysis of FAO FRA country reports.

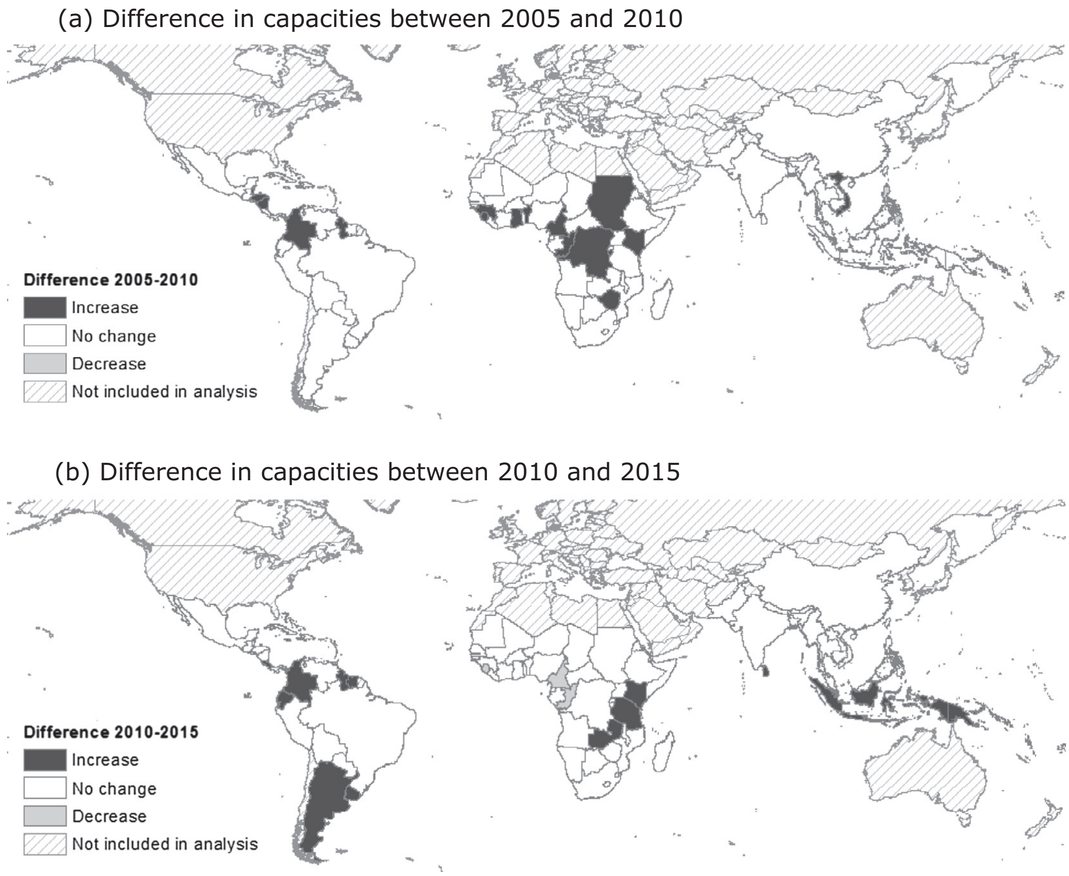


**Fig. 4.** Change in forest inventory capacities between the years 2005–2010 (a) and 2010–2015 (b).

**Table 3**
Change in forest inventory capacities between 2005, 2010 and 2015. The numbers in the table refer to the number of countries which fall into each category for a certain year.

| Forest inventory capacities | 2005 | 2010 | 2015 |
|---|---|---|---|
| Low | 31 | 22 | 21 |
| Limited | 32 | 29 | 19 |
| Intermediate | 7 | 17 | 19 |
| Good | 23 | 23 | 31 |
| Very good | 6 | 8 | 9 |

Overall, progress has been made, but reporting is still very rudimentary. Many countries (84) were reporting at Tier 1 level in 2015. Several studies showed that Tier 1 does not adequately represent national circumstances and may have uncertainties of up to ±70% from the mean (Meridian institute, 2009). At least for significant pools such as AGB and BGB, reporting should be done at higher Tiers which use allometric equations or models that are specific for the biomes and tree species in the country and have lower uncertainties (Wertz-Kanounnikoff et al., 2008; Baker et al., 2010; GOFC-GOLD, 2014).

### *3.4. How can the change in forest monitoring and reporting capacities be explained?*

#### *3.4.1. A few country cases*

The "very large" improvement in forest area change monitoring and remote sensing capacities in Kenya can be explained by recent acquisition and analysis of detailed satellite imagery. In 2013, Kenya, through support from the Government of Japan, completed a wall-to-wall mapping and analysis of its forests and land cover for three epochs: 1990, 2000 and 2010; using ALOS AVNIR and Landsat images. This allowed the country to map forest and land cover changes for the periods 1990–2000, 2000–2010 and 1990–2010. The analysis was conducted by a team comprising of representatives from the Kenya Forest Service, Department of Resource Survey and Remote Sensing with the technical back-stopping of PASCO consulting company (Pasco Consultants, 2013).

Indonesia is currently revisiting its national land cover change assessment and is extending the analysis which started in 1990, to 2013 (Indonesian Ministry of Forestry, 2013). The land cover information was based on visual interpretation of mosaic Landsat TM/ETM/LDCM data generated by the Ministry of Forestry of Indonesia (Romijn et al., 2013). The country now has more than two decades of deforestation and forest cover change estimates, and subsequently is capable of analyzing drivers of deforestation and forest degradation over these periods. This explains why Indonesia was classified among countries with very good capacity for monitoring forest area change and remote sensing competence. The slight increase in forest inventory capacities from 2010 to 2015 was mainly due to improvements of national forest inventory (NFI) sampling design. The sampling density increased to more than 3000 inventory plots across the entire nation. In the near future, Indonesia is ready to report forest reference emissions levels (FRELs) not only for the AGB pool but also for other carbon pools (Krisnawati et al., 2014). Indonesia's first national FREL submission, incorporating the refined NFI product, was planned during the UNFCCC Conference of Parties (COP) in Lima, in December 2014.

In some cases, a decrease in capacities occurred between the FRA reporting years. Reasons may vary, but some reoccurring motives were found in this study.

Both Cameroon and Congo showed a decline in forest inventory capacities between 2010 and 2015. The decrease was from "very good" in 2010 to "good" in 2015. The 2010 FRA country reports showed that both countries performed regular national forest inventories, with the most recent inventory less than five years before. However, in the 2015 report no new inventories were mentioned, so it was classified as "good". This indicates the risk that countries face when they are not maintaining their forest monitoring system and update their inventories regularly. Once a country has good capacities, it needs to keep investing in the national forest monitoring programme in order to maintain its capacities.

Another obvious decline concerned the decrease in carbon pool reporting capacities from "intermediate" to "limited" in Cape Verde (2010–2015) and Panama (2005–2010). In the first year, in Cape Verde, carbon was reported for AGB, BGB, litter and soil. In Panama carbon was reported for all pools. However, in the second year, carbon was reported for fewer pools in each country, and the soil pool was omitted from all the analyses. The reason for this is unclear, but again this example shows that maintaining capacities is very important to ensure consistent updates for the five year reporting cycle.

#### 3.4.2. Capacity building initiatives for improving national forest monitoring capacities

Table 5 gives an indication of the effectiveness of the different international capacity building initiatives related to forest monitoring. It shows which initiatives are present in the countries where improvements have taken place for performing forest area change assessments and national forest inventories, but also which initiatives are present in the countries without improvements. Please note that the total number of countries does not add up to 99 because a few countries already had very good capacities in 2005, 2010 and 2015 for both assessing change in forest area and for performing a forest inventory. Therefore, China, India,

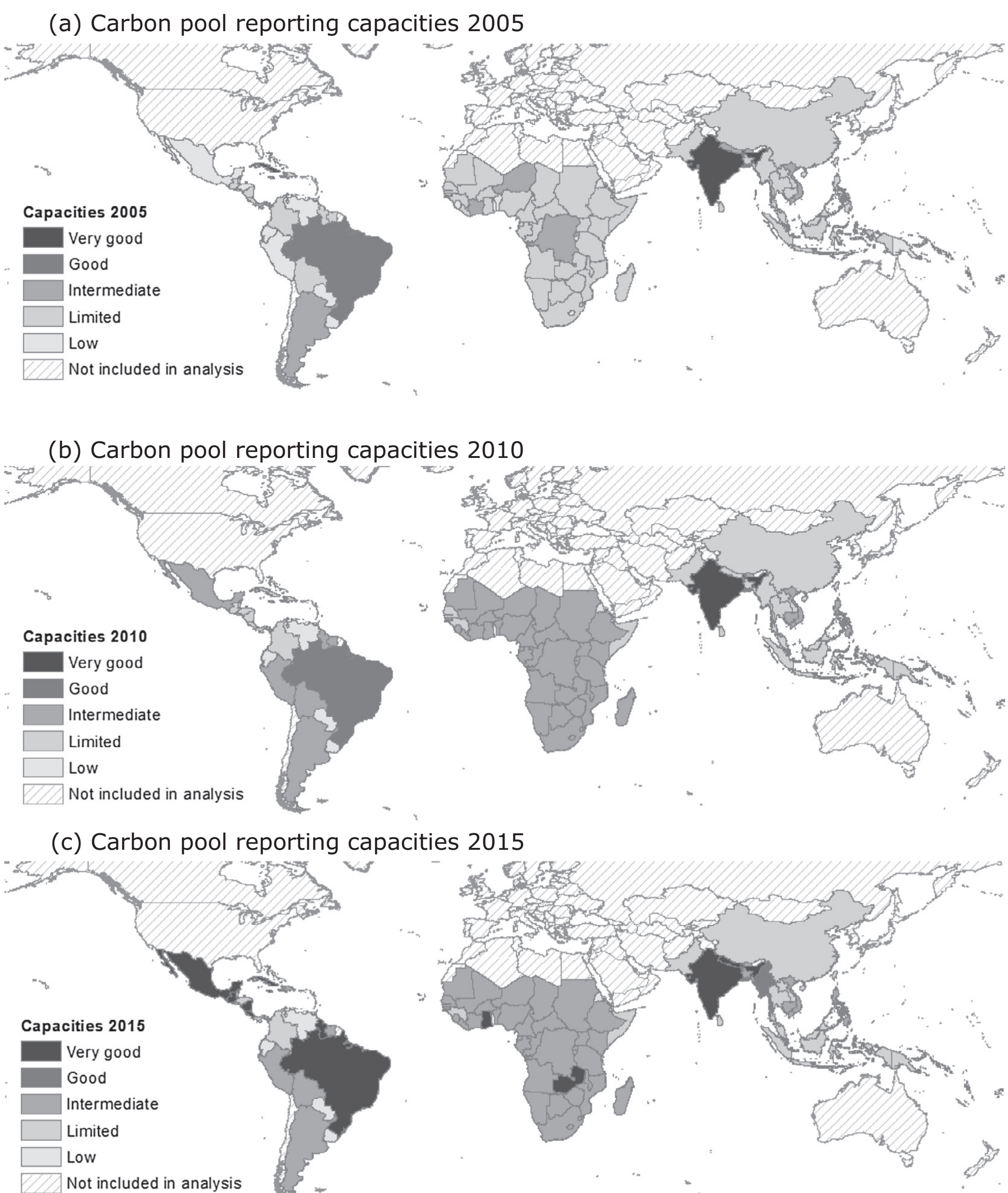


**Fig. 5.** Carbon pool reporting capacities in 2005 (a), 2010 (b) and 2015 (c). The outcomes, ranging from "low" to "very good", reflect the indicator score for each of the 99 tropical Non-Annex I countries, based on analysis of FAO FRA country reports.

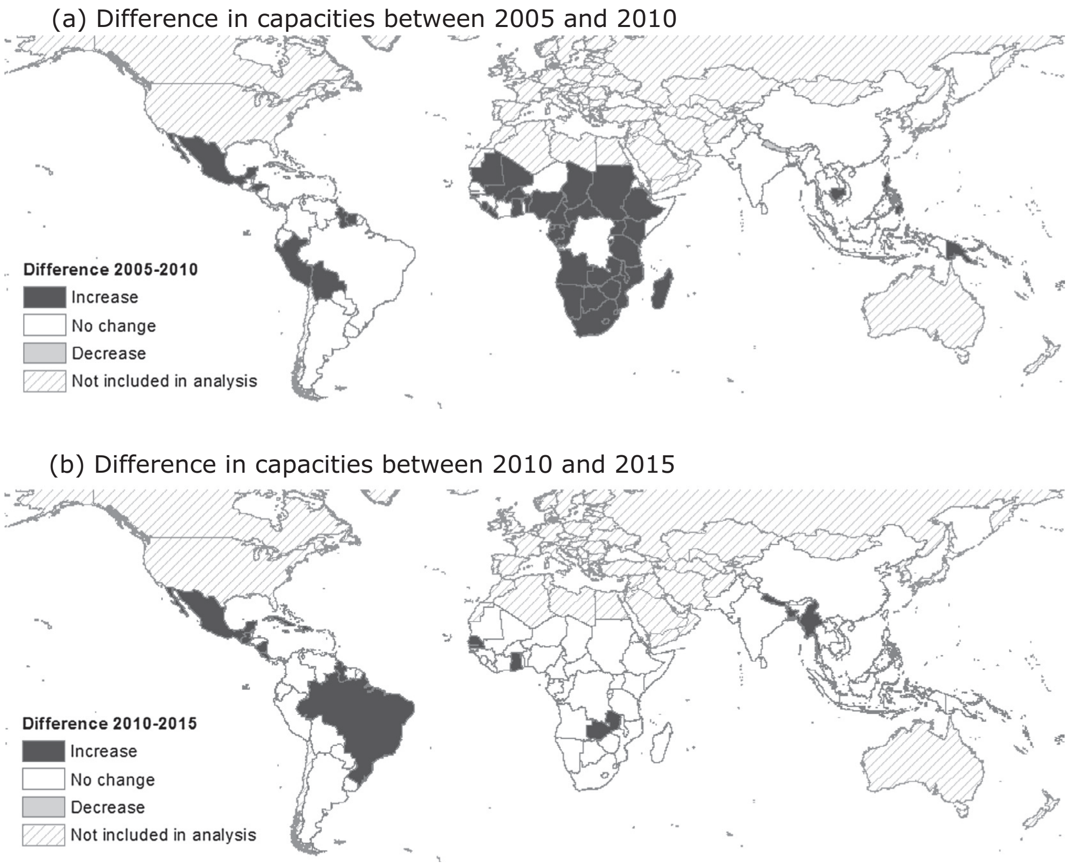


**Fig. 6.** Change in carbon pool reporting capacities between the years 2005–2010 (a) and 2010–2015 (b).

**Table 4**
Change in carbon pool reporting capacities between 2005, 2010 and 2015. The numbers in the table refer to the number of countries which fall into each category for a certain year.

| Carbon pool reporting capacities | 2005 | 2010 | 2015 |
|---|---|---|---|
| Low | 28 | 17 | 17 |
| Limited | 56 | 26 | 17 |
| Intermediate | 12 | 54 | 50 |
| Good | 1 | 1 | 1 |
| Very good | 2 | 1 | 14 |

Malaysia, Mexico and Myanmar were not included in this table. Malaysia, Mexico and Myanmar are UN-REDD partner countries and Mexico is also a WB FCPF REDD+ country participant.

Targeted forest monitoring programmes like the FAO NFMA project (Saket et al., 2010) seem to be most effective: 86% of the participating countries improved their national forest monitoring capacities. For countries where the FAO NFMA project is still ongoing, already 67% of the countries showed improvements and more results can be expected at a later stage. 55% of the countries supported by FAO capacity building for REDD+ NFMS (FAO, 2014b, accessed online) showed improvements. The UN-REDD national programme (UN-REDD, 2014, accessed online) is also very effective; 79% of the participating countries showed capacity improvements. On the contrary, UN-REDD partner countries did not show this obvious success. However, these countries are new within the UN-REDD programme and may request to receive funding for a national programme in the future. World Bank (WB) FCPF REDD+ programme (WB FCPF, 2014, accessed online) is supporting 49 countries in building up their capacities; 61% of the country participants and 80% of the country candidates showed progress in their monitoring capacities. These countries receive support

**Table 5**
International initiatives to support capacity development with respect to national forest monitoring in tropical Non-Annex I countries. For each initiative the number and percentage of countries that showed improvements and the number and percentage of countries that did not show improvements are indicated in the table.

| | Countries with improvements | | Countries without improvements | |
|---|---|---|---|---|
| | Number | Percentage (%) | Number | Percentage (%) |
| Total number of countries | 51 | 54 | 43 | 46 |
| UN-REDD national programmes | 15 | 79 | 4 | 21 |
| UN-REDD partner countries | 16 | 57 | 12 | 43 |
| FAO NFMA project completed | 6 | 86 | 1 | 14 |
| FAO NFMA project ongoing | 8 | 67 | 4 | 33 |
| FAO Capacity Building for REDD+ NFMS | 6 | 55 | 5 | 45 |
| Support from FAO only mentioned in country reports[a] | 8 | – | – | – |
| WB FCPF REDD+ country participant | 27 | 61 | 17 | 39 |
| WB FCPF REDD+ country candidates | 4 | 80 | 1 | 20 |
| Other support mentioned in country reports (e.g. bilateral/COMIFAC)[a] | 10 | – | – | – |
| Total number of initiatives | 100 | 69 | 44 | 31 |

[a] For these two categories, the column "countries without improvements" remains blank, as the information was taken from the FRA reports for countries that showed an improvement in capacities.

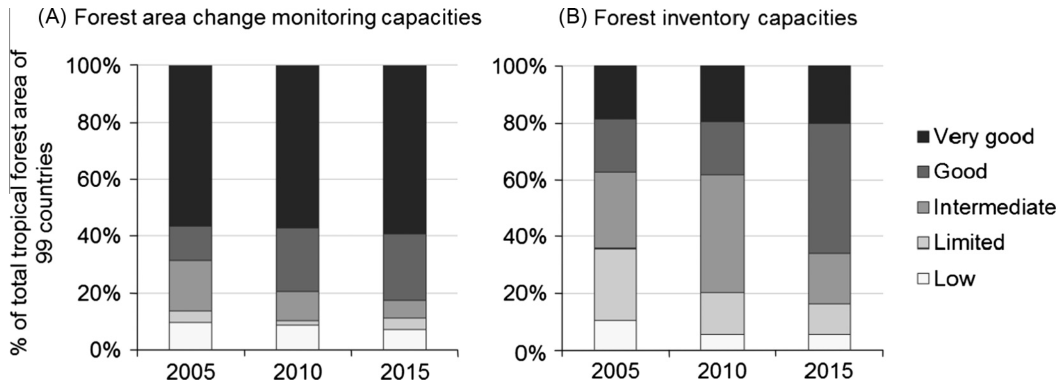


**Fig. 7.** Percentage of total tropical forest area of the 99 countries that is monitored with "low", "limited", "intermediate", "good" or "very good" forest area change monitoring and remote sensing capacities (A) and forest inventory capacities (B) in the assessment years 2005, 2010 and 2015.

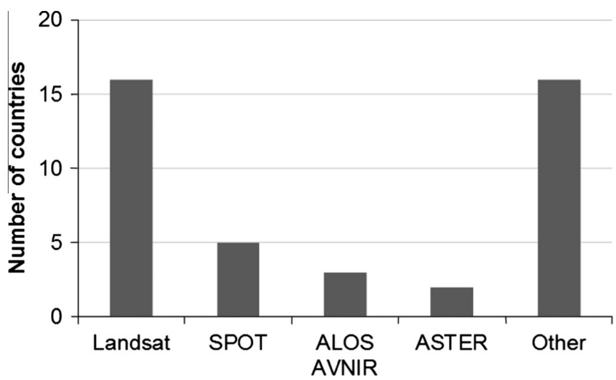


**Fig. 8.** Type of satellite data mentioned in the country reports for countries that showed an improvement in forest area change monitoring capacities between 2005–2010 and/or 2010–2015.

through the readiness funds or carbon funds and setting up a monitoring system is only part of the support. The information about UN-REDD and WB FCPF participating countries was derived in October 2014, which is consistent with the timing of their reporting to the FAO FRA exercise. The status of the countries may change over time. Other targeted support, mentioned in the country reports, which included FAO and bilateral support (e.g. from Norway in Guyana) or international support from COMIFAC in the DRC and Congo was very effective.

Other type of efforts from FAO included 19 regional workshops, held between 2009 and 2011, which brought together more than 200 experts from over 100 countries to improve forest mapping results. This was part of the FRA 2010 Remote Sensing Survey where forest area and changes in forest land use were analysed and mapped (FAO and JRC, 2012). However, these are not included in Table 5 as it was not possible to perform a country-by-country comparison.

It has to be noted that countries may get support in different ways, for example for preparing an R-PIN, or for setting up a national forest monitoring system. Not all of these may be equally effective for improving their national forest monitoring capacities.

### 3.5. What is the effect of increased forest monitoring capacities?

#### 3.5.1. Total area of tropical forests that is monitored with good to very good capacities

Fig. 7 shows the progress of Non-Annex I countries in monitoring the world's tropical forests. Forest area change monitoring and remote sensing capacities (panel A) and forest inventory capacities (panel B) are expressed in relation to the percentage of total tropical forest area of the 99 countries that is monitored with the different levels of capacity. Overall, it can be concluded that a larger percentage of tropical forest area is now better monitored than in the past. For forest area change monitoring capacity, the total tropical forest area that is monitored with good to very good capacity increased over the years from 69% in 2005, to 80% in 2010 to 83% in 2015. This corresponds to 1435 million ha in 2005, 1649 million ha in 2010 and 1699 million ha in 2015. This means that the absolute tropical forest area that is monitored with good to very good forest area change monitoring capacities increased as well over the years. The 83% of forest area in 2015 is located in the 54 countries which have good to very good forest area change monitoring capacities. They are able to produce their own forest change maps on a regular basis. The remaining forest area (17%; 355 million ha) is located in 45 countries which need to improve their capacities in the coming years to be able to accurately map and follow forest area and area changes over time. For forest inventory capacity, the total tropical forest area that is monitored with good to very good capacities increased from 38% in 2005, to 39% in 2010 to 66% in 2015. This corresponds to 785 million ha in 2005, 799 million ha in 2010 and 1350 million ha in 2015. So the absolute tropical forest area that is monitored with good to very good forest inventory capacities also increased. In 2015, 40 countries with good to very good capacities regularly perform national forest inventories, without input from external researchers. For the remaining 59 countries, that together encompass 34% (705 million ha) of the total area of tropical forest, capacities still need to improve in order to establish a good system for performing regular national forest inventories.

Fig. 8 shows that from the 31 countries with improved forest area change monitoring and remote sensing capacities between 2005–2010 or 2010–2015, 16 countries reported the use of Landsat satellite data. Far fewer countries reported the use of other type of data like SPOT, ALOS AVNIR and ASTER. This demonstrates the usefulness of high resolution Landsat data which are available free of charge for historical periods for more than two decades. Open data policies enable countries to have access to historical time series of satellite data and contribute to better monitor their forest resources (Wulder et al., 2012; Giri et al., 2013). Even though there is free data access, in some regions most notably in Africa, challenges remain with regards to internet connectivity to the US Landsat archive and download speed (Roy et al., 2010).

#### 3.5.2. Effect of increased capacities on FRA reporting numbers

Fig. 9 shows the effect of increased capacities on the reported numbers of annual net change in forest area in the FRA reporting of 2005, 2010 and 2015. In each of the FRA reporting years (05/10/15) a number for annual net change in forest area is

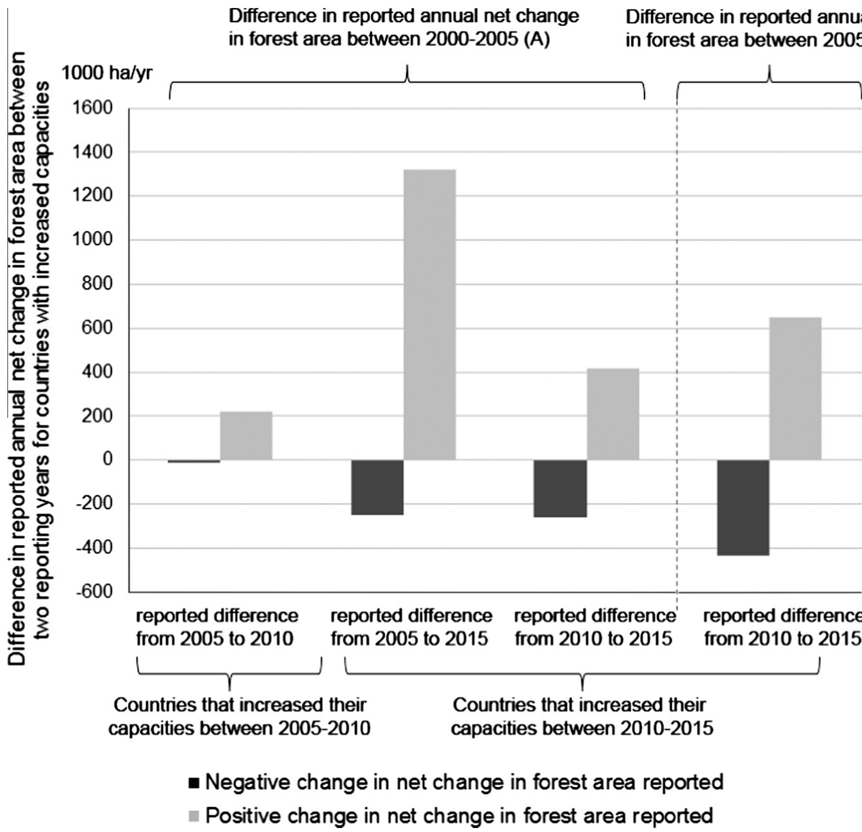


**Fig. 9.** Difference in reported numbers of annual net change in forest area for the periods 2000–2005 (A) and 2005–2010 (B) in 1000 ha/yr between two different reporting years (2005 and 2010; 2005 and 2015; 2010 and 2015). The difference is indicated for countries that showed an increase in forest area change monitoring and remote sensing capacities between 2005–2010 and 2010–2015.

reported for the same time period (for example 2000–2005). The figure depicts the change that happened in reported numbers of net change in forest area for a similar time period between two different reporting years. It only includes the countries with capacity improvements. The dark gray bars in the figure sum up the total negative change between two reporting years for all countries included. The light gray bars in the figure sum up the total positive change between two reporting years for all countries included.

For example when looking at the net change in forest area between 2005 and 2010 (two columns at the right side of the figure), there is a difference in reported numbers of net change for this period in the FRA 2010 and FRA 2015 reporting. All countries that had negative change in net change in forest area between those two reporting years together had a difference of −433.000 ha/yr and all the countries that had a positive change in net change in forest area between those two reporting years together had a difference of +651.000 ha/yr.

The figure clearly shows that reported numbers tend to be more positive (increasing forest area) when capacities increase. This indicates a trend that countries with lower capacities in the past had the tendency to overestimate the net area of forest loss. The reason for this trend is not very clear but it points at an important issue that national estimations based on low quality data and expert judgements do not balance in their effects of over- or underestimating the forest area change but can result in biases in forest loss estimations in large area assessments. This effect is most pronounced for the previous estimates from FRA 2005 where the investments in better data and national capacities resulted in lower forest loss numbers in FRA 2010 and FRA 2015 which are based on more robust data.

## 4. Conclusions

Major improvements can be seen in forest area change monitoring capacities and in forest inventory capacities. The total tropical forest area that is monitored with good to very good forest area change monitoring and remote sensing capacities increased from 69% (1435 million ha) in 2005 to 83% (1699 million ha) in 2015. Fifty-four of the 99 countries now have good to very good forest area change monitoring and remote sensing capacities. Free and open source high resolution satellite data such as Landsat remain an important data source for assessing historical forest cover change and have been an asset to allow countries to take the steps for improving their national forest monitoring. The total tropical forest area that is monitored with good to very good forest inventory capacities increased from 38% (785 million ha) in 2005 to 66% (1350 million ha) in 2015. This concerns 40 countries with good to very good capacities. Continued capacity building investments are needed to ensure that the remaining countries will be able to accurately monitor the tropical forest area with sufficient level of capacity. Carbon pool reporting capacities did not increase as dramatically and at this moment fifteen countries have good to very good capacities and are able to report on one or more carbon pools using Tier 2 or Tier 3 methods. The majority of the countries report at Tier 1, which may contain large uncertainties up to 70%. Priority now needs to go to improving carbon pool reporting. More country-specific data of carbon stocks are needed to be able to report at Tier 2 or Tier 3 in order to represent the specific biomes and tree species and to have lower uncertainties. In most countries, the data for reporting on carbon in different pools are present from forest inventories, however more capacity building and training is needed so countries can actually perform the reporting. Some countries showed a decrease in capacities within a five-year cycle. It is important for countries to keep the level of acquired capacities by maintaining their forest monitoring system and updating their maps inventories on a regular basis.

Increased capacities had an effect on the annual net change rate in forest area that was reported in the FRA. Overall, there was a positive change in the net change in forest area that was reported between two reporting years for a similar time period. This means that countries with lower capacities in the past had the tendency to overestimate the net area of forest loss and that use of low quality data and expert judgements resulted in biases in forest loss estimations in large area assessments.

The results demonstrate that capacity building programmes have proven to be successful. Countries which increased in capacities participated in more capacity building initiatives than countries that did not increase in capacities. Targeted programmes, such as those from FAO projects seem to be very effective with a success rate of 86%. Also, the engagement in REDD+ capacity development initiatives had a positive impact on country forest monitoring capacity. This clearly shows the importance of capacity building programmes and the need for further capacity development. Further investments will enable countries to obtain accurate and reliable data and information on forest area and forest resources which provides the necessary input to refine policies and decisions to track drivers of deforestation, to conserve forests and to further improve forest management.

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## Appendix A

This table contains the values for the three indicators "Forest area change monitoring and remote sensing capacities", "Forest inventory capacities" and "Carbon pool reporting capacities" for all 99 tropical Non-Annex I countries of this study. The codes correspond to the following indicator values: – – Low; – Limited; 0 Intermediate; + Good; ++ Very good

| Country | Forest area change monitoring & remote sensing capacities | | | Forest inventory capacities | | | Carbon pool reporting capacities | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2010 | 2015 | 2005 | 2010 | 2015 | 2005 | 2010 | 2015 |
| Angola | – – | – – | – – | – | – | – | – | 0 | 0 |
| Antigua and Barbuda | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| Argentina | + | + | ++ | + | + | ++ | 0 | 0 | 0 |
| Bahamas | – – | – – | – – | – | – | – | – – | – – | – – |
| Bangladesh | – | + | ++ | + | + | + | – | – | 0 |
| Belize | + | + | + | – – | – | – | – | – | – |
| Benin | – | – | 0 | – – | + | + | – – | 0 | 0 |
| Bhutan | 0 | 0 | + | + | + | + | 0 | 0 | 0 |
| Bolivia | ++ | ++ | ++ | + | + | + | – | 0 | 0 |
| Botswana | + | + | + | – | – | – | – | 0 | 0 |
| Brazil | ++ | ++ | ++ | 0 | 0 | 0 | + | + | ++ |
| Burkina Faso | – – | – – | – | 0 | 0 | 0 | – | 0 | 0 |
| Burundi | – – | – – | – – | – – | 0 | 0 | – – | 0 | 0 |
| Cambodia | + | + | + | – | – | – | – | 0 | 0 |
| Cameroon | 0 | 0 | 0 | + | ++ | + | – | 0 | 0 |
| Cape Verde | – – | – – | – – | – | – | + | – | 0 | – |
| Central African Republic | – – | – – | – | – | – | – | – | 0 | 0 |
| Chad | – – | – – | – – | – | – | – | – | 0 | 0 |
| China | ++ | ++ | ++ | ++ | ++ | ++ | – | – | – |
| Colombia | ++ | ++ | ++ | – – | – | + | – | – | – |
| Comoros | – | – | – | + | + | + | 0 | 0 | ++ |
| Congo | + | + | + | + | ++ | + | – | 0 | 0 |
| Costa Rica | ++ | ++ | + | – | – | + | – | – | ++ |
| Côte d'Ivoire | + | + | + | 0 | 0 | 0 | 0 | 0 | 0 |
| Cuba | – – | – – | – – | + | + | + | ++ | – | ++ |
| Democratic Republic of the Congo | 0 | + | ++ | – | 0 | 0 | 0 | 0 | 0 |
| Dominica | – | – | – | – – | – – | – – | – – | – – | – – |
| Dominican Republic | – – | + | + | – – | – – | – – | – | – | 0 |
| Ecuador | + | + | ++ | – – | – – | + | – – | – – | – – |
| El Salvador | + | + | + | – – | – – | – – | – – | – – | – – |
| Equatorial Guinea | – – | – – | – – | – | – | – | – | 0 | 0 |

**Appendix A** (*continued*)

| Country | Forest area change monitoring & remote sensing capacities | | | Forest inventory capacities | | | Carbon pool reporting capacities | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2010 | 2015 | 2005 | 2010 | 2015 | 2005 | 2010 | 2015 |
| Eritrea | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| Ethiopia | + | + | + | – – | – – | – – | – | 0 | 0 |
| Fiji | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| Gabon | – – | – – | – – | – | – | – | – | 0 | 0 |
| Gambia | – | – | – | – | – | + | – | 0 | 0 |
| Ghana | + | + | + | – | 0 | 0 | – | 0 | ++ |
| Guatemala | ++ | ++ | ++ | – | – | – | – | – | ++ |
| Guinea | – – | – – | – – | – – | 0 | 0 | – | – | – |
| Guinea-Bissau | 0 | 0 | 0 | – – | – – | – – | – | 0 | 0 |
| Guyana | – – | – – | ++ | – – | – | 0 | – | 0 | ++ |
| Haiti | – – | – – | – – | – – | – – | – – | 0 | 0 | 0 |
| Honduras | – – | – – | – – | – – | – | – | – – | – | – |
| India | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ |
| Indonesia | ++ | ++ | ++ | + | + | ++ | – | – | – |
| Jamaica | + | + | + | – | – | 0 | 0 | 0 | ++ |
| Kenya | – – | – – | ++ | – | 0 | + | – | 0 | 0 |
| Lao People’s Democratic Republic | + | + | + | + | + | + | – | – | – |
| Lesotho | 0 | 0 | 0 | – – | – – | – – | – – | 0 | 0 |
| Liberia | 0 | 0 | 0 | – | – | – | – | 0 | 0 |
| Madagascar | 0 | 0 | + | + | + | + | – | 0 | 0 |
| Malawi | – | – | 0 | – | – | – | – | 0 | 0 |
| Malaysia | ++ | ++ | ++ | ++ | ++ | ++ | – | – | – |
| Mali | – – | – – | – – | 0 | 0 | 0 | – | 0 | 0 |
| Mauritania | – – | – – | – – | – | – | – | – | 0 | 0 |
| Mauritius | – – | – – | – – | – | – | – | – | 0 | 0 |
| Mexico | ++ | ++ | ++ | ++ | ++ | ++ | – – | 0 | ++ |
| Micronesia (Federated States of) | – – | + | + | – | 0 | 0 | – – | – | – |
| Mozambique | 0 | – | – | – | – | – | – | 0 | 0 |
| Myanmar | ++ | ++ | ++ | ++ | ++ | ++ | – | – | + |
| Namibia | – | 0 | 0 | + | + | + | – | 0 | 0 |
| Nepal | + | + | + | + | + | + | 0 | – | ++ |
| Nicaragua | + | + | + | – | + | + | – | – | ++ |
| Niger | – – | – – | – – | 0 | 0 | 0 | 0 | 0 | 0 |
| Nigeria | – – | – – | – – | – | – | – | – | 0 | 0 |
| Pakistan | – – | – – | – | – | – | – | – | – | – |
| Palau | 0 | 0 | 0 | – | 0 | 0 | – – | – | ++ |
| Panama | + | ++ | ++ | + | + | + | 0 | – | – |
| Papua New Guinea | 0 | 0 | + | 0 | 0 | + | – – | – | – |
| Paraguay | 0 | 0 | + | – – | – – | – – | – – | – – | – – |
| Peru | ++ | ++ | ++ | + | + | + | – – | 0 | 0 |
| Philippines | – – | + | ++ | ++ | + | + | – | 0 | 0 |
| Rwanda | – – | – – | + | + | + | + | 0 | 0 | 0 |
| Saint Lucia | 0 | 0 | 0 | 0 | 0 | 0 | – – | – – | – – |
| Saint Vincent and the Grenadines | – – | – | – | – – | – – | – – | – – | – – | – – |
| Samoa | + | + | + | – – | – – | – – | – – | – – | – – |
| Sao Tome and Principe | – – | – – | – – | – | – | 0 | – | 0 | 0 |
| Senegal | + | + | + | + | + | + | – | – | 0 |
| Sierra Leone | – – | – – | – – | – – | – | – – | – – | 0 | 0 |
| Singapore | – – | – – | – | – – | – – | – – | – – | – – | – – |
| Solomon Islands | – – | – – | – – | – – | 0 | 0 | – – | – | – |
| Somalia | – – | – – | – – | – – | – – | – – | – | – | – |
| South Africa | + | + | + | – – | – – | – – | – | 0 | 0 |
| Sri Lanka | + | + | ++ | + | + | ++ | – | – | – |
| Sudan | 0 | 0 | + | – | 0 | 0 | – | 0 | 0 |
| Suriname | + | + | ++ | – | – | 0 | – | 0 | 0 |
| Swaziland | – | – | – | + | + | + | – | 0 | 0 |
| Thailand | + | + | + | + | + | + | – | – | – |

(*continued on next page*)

**Appendix A** (*continued*)

| Country | Forest area change monitoring & remote sensing capacities | | | Forest inventory capacities | | | Carbon pool reporting capacities | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2010 | 2015 | 2005 | 2010 | 2015 | 2005 | 2010 | 2015 |
| Timor-Leste | + | + | + | – – | – – | – – | – – | – – | – – |
| Togo | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| Trinidad and Tobago | + | + | + | + | + | + | – | 0 | 0 |
| Uganda | – | + | + | + | + | + | – | 0 | 0 |
| United Republic of Tanzania | 0 | 0 | + | – | – | + | – | 0 | 0 |
| Uruguay | + | + | + | – – | – – | – | – – | – – | – – |
| Vanuatu | – | – | – | – – | – – | – – | – – | – – | – – |
| Venezuela | + | + | ++ | – – | – – | – – | – – | – – | – – |
| Viet Nam | – | – | ++ | + | ++ | ++ | 0 | 0 | 0 |
| Zambia | – | – | + | – | – | + | – | 0 | ++ |
| Zimbabwe | 0 | 0 | 0 | – | 0 | 0 | – | 0 | 0 |

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