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# Exploring different forest definitions and their impact on developing REDD+ reference emission levels: A case study for Indonesia

Erika Romijn<sup>a,\*</sup>, John Herbert Ainembabazi<sup>b</sup>, Arief Wijaya<sup>a</sup>,  
Martin Herold<sup>c</sup>, Arild Angelsen<sup>d</sup>, Louis Verchot<sup>a</sup>, Daniel Murdiyarso<sup>a</sup>

<sup>a</sup> Center for International Forestry Research, Jl. CIFOR, Situgede, Bogor 16115, Indonesia

<sup>b</sup> International Institute of Tropical Agriculture (IITA), PO Box 7878, Kampala, Uganda

<sup>c</sup> Laboratory of Geo-Information Science and Remote Sensing, Wageningen University, PO Box 47, 6700 AA Wageningen, The Netherlands

<sup>d</sup> School of Economics and Business, Norwegian University of Life Sciences (UMB), PO Box 5003, 1432, Ås, Norway

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## ABSTRACT

Developing countries participating in the mitigation mechanism of reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+), need to determine a national forest reference emission level (REL) as part of their national monitoring system, which serves as a benchmark to measure the impact of their REDD+ actions. Using data from Indonesia, we show that the choice of a forest definition can have a large impact on estimates of deforestation and forest degradation areas, on assessment of drivers of deforestation and on the development of a REL. The total area of deforestation between 2000 and 2009 was 4.9 million ha when using the FAO definition, 18% higher when using a 'natural forest definition' and 27% higher when using the national definition. Using the national and natural forest definitions, large areas (>50%) were classified as shrubland after deforestation. We used regression models to predict future deforestation. Deforestation was much better predicted than degradation ( $R^2$  of 0.81 vs. 0.52), with the natural forest definition giving the best prediction. Apart from historical deforestation and initial forest cover, gross domestic product and human population were important predictors of future deforestation in Indonesia. Degradation processes were less well modeled and predictions relied on estimates of historical degradation and forest cover.

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## 1. Introduction

The magnitude of greenhouse gasses (GHG) emissions from deforestation and forest degradation and the contribution of different activities to the deforestation processes have

implications on the design and implementation of climate change mitigation policies under the umbrella of REDD+ (reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks). The REDD+ mechanism aims at diminishing, halting and reversing forest

\* Corresponding author. Tel.: +31 317 481 834, fax: +31 317 419 000.

E-mail addresses: [erika.romijn@wur.nl](mailto:erika.romijn@wur.nl), [erika.romijn@gmail.com](mailto:erika.romijn@gmail.com) (E. Romijn), [J.Ainembabazi@cgiar.org](mailto:J.Ainembabazi@cgiar.org) (J.H. Ainembabazi), [a.wijaya@cgiar.org](mailto:a.wijaya@cgiar.org) (A. Wijaya), [martin.herold@wur.nl](mailto:martin.herold@wur.nl) (M. Herold), [arild.angelsen@umb.no](mailto:arild.angelsen@umb.no) (A. Angelsen), [l.verchot@cgiar.org](mailto:l.verchot@cgiar.org) (L. Verchot), [d.murdiyarso@cgiar.org](mailto:d.murdiyarso@cgiar.org) (D. Murdiyarso).

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cover loss and carbon emissions in developing countries (UNFCCC, 2010, 2011a). For measurement and reporting of REDD+ activities, countries need to establish a robust and transparent national forest monitoring system, which uses a combination of remote sensing and ground based forest carbon inventory approaches for measurement of forest area changes and forest carbon stocks and changes (UNFCCC, 2009).

As part of this, countries need to clearly define what constitutes a forest in their national context, because the choice of a definition affects estimates of deforestation and forest degradation areas and consequently assessments of drivers of deforestation and carbon emissions (GOFCC-GOLD, 2012; Magdon and Kleinn, 2012). Globally, there is a large amount (>100) of definitions of forest, based on landcover; landuse; declared, legal, or administrative unit; or other properties. These definitions vary from international, to national, to state, province and local scales (Lund, 2007). Further, REDD+ may include financial incentives, and clear and consistent use of national definitions of forest, deforestation and forest degradation are considered to be fundamental for the legitimacy of the system (Putz and Redford, 2010). For national GHG inventories that are reported to the UNFCCC, forest definitions vary from country to country according to the parameters laid out in the Marrakech Accords, which give countries latitude in applying different thresholds for minimum area, canopy cover and tree height (Lund, 2002). Diverse remote sensing methods applying different types of datasets with varying resolutions can help to differentiate between forest definitions to monitor land cover change (Lambin, 1999; Achard et al., 2007; DeFries et al., 2007; Herold et al., 2011).

The use of forest/non-forest definitions in practice appeared to be rather difficult during the implementation of afforestation and reforestation activities under the Clean Development mechanism in the Kyoto protocol (Verhot et al., 2007; Murdiyarto et al., 2008; Van Noordwijk and Minang, 2009). Sasaki and Putz (2009) argue that a definition of forest should at least differentiate between natural forest and forest plantation, which will promote protecting biodiversity and contribute to sustainable development. However, there is no consensus amongst scientists (Guariguata et al., 2009).

The national monitoring system includes identifying drivers of deforestation and establishing forest reference levels (RLs) and forest reference emission levels (RELs). These will serve as a benchmark for assessing a country's performance in implementing REDD+ activities (UNFCCC, 2010, 2011a), and possibly also form the basis for payments (reference levels being used as crediting baselines, cf. Angelsen, 2008). A distinction is often made between proximate or direct drivers and underlying or indirect causes of deforestation (Geist and Lambin, 2001; DeFries et al., 2010; Boucher et al., 2011). Direct drivers are the human activities that affect forest loss, while underlying causes of deforestation can be population growth, economic development, demand for timber, timber products, estate crops and mining commodities, political interests and poor governance (Sunderlin and Resosudarmo, 1996).

While the distinction between a REL and RL is not always clear in the debate, we define REL as gross carbon emissions from deforestation and forest degradation (REDD), while a RL

also includes net removals from deforestation, forest degradation, forest conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+) (Scheyvens, 2010). We use the term REL to mean a projection of emissions (in tCO<sub>2</sub>/year) from deforestation and forest degradation in the absence of the REDD action, i.e., the business-as-usual baseline against which actual emission reductions are measured. REDD+ payments are based on the country's performance in reducing emissions, but additional considerations may also apply (Meridian Institute, 2011; UNFCCC, 2011b). RELs are calculated based on historical data of forest cover change (ha/year) and may be adjusted for national circumstances such as the stage in forest transition, income levels, human population density, road network and sub-national deforestation drivers to improve reliability (Herold et al., 2012a, 2012b). Countries may follow a step-wise approach for developing a REL, thereby improving the estimates as the quality and availability of data and the knowledge and understanding of forest change drivers improve in order to better estimate REDD+ performance and links to financial incentives (Herold et al., 2012a, 2012b). This encourages broad participation from different countries and reduces emissions uncertainties over time. Countries need to report on the data, methodologies and procedures as well as the definition of forest they used to construct the REL and the information should be transparent, complete, consistent and accurate (UNFCCC, 2011b; Herold et al., 2012a, 2012b).

One international forest definition that is proposed in the guidelines of the International Panel on Climate Change (IPCC) for reporting of forest cover loss and GHG emissions to the United Framework Convention on Climate Change (UNFCCC), is based on the vegetation classification system from the Food and Agriculture Organization of the United Nations (FAO) (IPCC, 2006). Forest is defined by the FAO as land spanning more than 0.5 ha with more than 10% tree canopy cover and trees higher than 5 m (or having the potential to reach a height of 5 m). Land predominantly under agricultural or urban land use regimes is not included as forest because the definition also considers land use (FAO, 2000). Alternatively, the UNFCCC defines thresholds of 0.5–1.0 ha forest land, 10–30% tree canopy cover and 2–5 m of tree height and does not consider land use. National forest definitions often differ from these definitions. In Indonesia, one land cover classification was based on the UNESCO terminology which defines forest as vegetation cover dominated by intertwined tree crowns with canopy cover of more than 60% (Digital land cover map from the MoF, 2011). Vegetation cover dominated by trees, with canopy cover between 25 and 60% is defined as bush. Within these definitions, a forest plantation (e.g. *Acacia*, *Eucalyptus* and *Teak*) is considered forest.

Similarly, there are no globally agreed definitions of deforestation and forest degradation within the UNFCCC (Lund, 2009; Simula, 2009). Deforestation is defined by the FAO as the permanent conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold (FAO, 2000). This can be a human-induced change, or a change caused by a natural disaster. Temporarily unstocked areas where the forest is expected to regenerate in the medium/long-term are not considered deforested. Indonesia defines deforestation as land cover change from forested land

to non-forested land, which includes estate crops, settlements, industrial areas, etc. (MoF, 2009). Forest degradation, on the other hand, can within the REDD+ context be defined as a reduction of carbon stocks in forests remaining forests (Herold and Skutch, 2011). Degradation definitions vary greatly, depending on the topic of interest (e.g. biodiversity, biomass or productivity), and can include parameters related to forest structure, species composition or forest functions. The FAO defines forest degradation as a reduction of the canopy cover or carbon stock within a forest, provided that the canopy cover stays above 10% (FAO, 2000).

Great variation in forest cover, deforestation activities and socio-economic circumstances across the archipelago have made Indonesia an interesting and relevant country to explore how different forest definitions might affect estimates of forest area change, assessment of deforestation drivers and estimates of RELs. Indonesia is experiencing one of the highest rates of deforestation in the world, and in particular in Sumatra and Kalimantan large areas of forest have been cleared and degraded over the past three decades (Acharid et al., 2002; Hansen et al., 2009). Land use change and forestry are the sectors that contribute most (85%) to the GHG emissions in Indonesia, split between peat fire (53%), peat drainage (20%), deforestation (22%) and palm oil and timber plantation establishment (5%) according to the Ministry of Environment (2010). Agricultural expansion and timber harvest are the most important causes of deforestation in Indonesia. Both large scale activities, such as oil palm plantations and small scale farming contribute to the

agricultural expansion (Zhao et al., 2006; Laurance, 2007; Rudel et al., 2009; Gibbs et al., 2010).

The aim of this study is to show the impact of different forest definitions on measurement and reporting of REDD+ activities. For this purpose, we use three definitions of forest, which are most relevant to consider for Indonesia in the context of REDD+. First, we employ the FAO forest definition, which is a quasi-global standard for international forest reporting. It is an internationally accepted definition and it is recommended by the IPCC for forest monitoring purposes. Second, we use the current national definition of the Indonesian Ministry of Forestry. As we observed, neither of these definitions discriminate between natural forest and forest plantation, so we decided to use a third definition that also accounts for natural forest: the “natural forest definition”. The “natural forest definition” is indicated to potentially become important in the UNFCCC REDD+ negotiations. This type of definition is often used by conservation agencies such as World Resources Institute (WRI) and International Union for Conservation of Nature (IUCN) (Dudley and Phillips, 2006; Islam et al., 2007) and emphasizes the difference between natural forest (dominated by a composition of a variety of native species) and forest plantation (planted forests with single-, often non-native species). We examine the differences in calculating areas of deforestation and degradation, assessing drivers of deforestation and developing national RELs; and the implications this may have for national and international REDD+ policy implementation.

**Table 1 – Classification of land cover classes into primary forest, degraded forest and non-forest types, according to the three different forest definitions that were used to calculate deforestation and degradation areas.**

|                 | International Forest Definition FAO                                                                                                                                                                                                                                | National Forest Definition Indonesia                                                                                                                                                                                                                                                                  | Natural Forest Definition                                                                                                                                                                                                                                                                                                                                                       |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Primary Forest  | Primary Upland Forest<br>Primary Mangrove Forest<br>Primary Swamp Forest                                                                                                                                                                                           | Primary Upland Forest<br>Primary Mangrove Forest<br>Primary Swamp Forest                                                                                                                                                                                                                              | Primary Upland Forest<br>Primary Mangrove Forest<br>Primary Swamp Forest                                                                                                                                                                                                                                                                                                        |
| Degraded Forest | Secondary Upland Forest<br>Secondary Mangrove Forest<br>Secondary Swamp Forest<br>Forest plantation (i.e. <i>Eucalypt</i> ,<br><i>Acacia</i> , <i>Teak</i> )<br>Bushes/Shrubland<br>Bushy swamp                                                                    | Secondary Upland Forest<br>Secondary Mangrove Forest<br>Secondary Swamp Forest<br>Forest plantation (i.e. <i>Eucalypt</i> ,<br><i>Acacia</i> , <i>Teak</i> )                                                                                                                                          | Secondary Upland Forest<br>Secondary Mangrove Forest<br>Secondary Swamp Forest                                                                                                                                                                                                                                                                                                  |
| Non-Forest      | Plantation (oil palm)<br><br>Savanna<br>Upland Agriculture<br>Upland Agriculture Mixed with Bush<br>Rice Field<br>Cultured Fisheries/Fishpond<br>Settlement/Developed Land<br>Transmigration<br>Open Land<br>Mining/Mines<br>Water Body<br>Swamp<br>Airport/Harbor | Bushes/Shrubland<br><br>Bushy swamp<br>Plantation (oil palm)<br>Savanna<br>Upland Agriculture<br>Upland Agriculture Mixed with Bush<br>Rice Field<br>Cultured Fisheries/Fishpond<br>Settlement/Developed Land<br>Transmigration<br>Open Land<br>Mining/Mines<br>Water Body<br>Swamp<br>Airport/Harbor | Forest plantation (i.e. <i>Eucalypt</i> ,<br><i>Acacia</i> , <i>Teak</i> )<br>Bushes/Shrubland<br>Bushy swamp<br>Plantation (oil palm)<br>Savanna<br>Upland Agriculture<br>Upland Agriculture Mixed with Bush<br>Rice Field<br>Cultured Fisheries/Fishpond<br>Settlement/Developed Land<br>Transmigration<br>Open Land<br>Mining/Mines<br>Water Body<br>Swamp<br>Airport/Harbor |

## 2. Methodology

### 2.1. Data

A land cover dataset from the Indonesian MoF was used for this study. This dataset was generated from visual classification of mosaic Landsat TM/ETM+ data (30 m × 30 m resolution) for the years 2000, 2003, 2006 and 2009. The entire classification process from image pre-processing and image classification to validation was undertaken by the forest management unit (BPKH) at sub-national levels. The results were then submitted and compiled by the MoF (pers. com., MoF, 2012).

The land cover map consisted of 22 land cover classes (Table 1), including six natural forest classes: upland forest (forest on mineral soil), swamp forest and mangrove forest, with separation between primary and secondary forest types. Primary forest types were described as forests which do not show evidence of logging or other disturbances, while secondary forest types show evidence of logging, slash and burn or forest fire. The forest plantation class consisted of trees that have been planted for commercial purposes or afforestation, e.g. *Eucalyptus*, *Acacia*. The two classes “bushes/shrubland” and “bushy swamp” represented former forest land (upland, mangrove or swamp forest), that is re-growing but not yet fully stocked. These areas may contain naturally sparse trees or natural low vegetation. The MoF classified these classes as non-forest. MoF described bush as vegetation coverage dominated by trees, with 25–60% canopy cover and shrubland as shrubs with height of more than 0.5 m and more than 25% coverage. According to the FAO forest definition (with a threshold of 10% tree canopy cover and trees able to reach a height of 5 m) the “bushes/shrubland” and “bushy swamp” classes may be categorized as “forest”. Furthermore, the land cover dataset consisted of a wide range of non-forest classes including various cultivated land use types.

Data on logging concessions and commercial agriculture, generated from forest allocation and provincial spatial planning maps, were collected from MoF for the year 2005. Other datasets on gross domestic product (GDP) growth rate, GDP from the agricultural sector, total population and road

network density were collected and/or generated using National Statistics Bureau (BPS) data for the year 2006. Data were aggregated at district level. The total number of districts was 372.

### 2.2. Methods

The land cover classes from the MoF land cover dataset were categorized as primary forest, degraded forest or non-forest types according to three different forest definitions (Table 1). This was done for the international forest definition from the FAO (FAO, 2000), for the national forest definition from MoF as described in the forestry statistics of Indonesia (MoF, 2009) and for the “natural forest definition”, which considered only natural forests and excluded all forest plantations from the forest class. Areas of deforestation and forest degradation were calculated by analysing the land cover changes for each time step between 2000–2003, 2003–2006 and 2006–2009 and for the entire period 2000–2009. Deforestation was defined as the change from primary forest or degraded forest to non-forest classes, whereas forest degradation was defined as the change from primary forest to degraded forest.

As a next step, we assessed drivers of deforestation for the time period 2000–2009. When investigating drivers of deforestation, it is important to note the difference between proximate drivers which are linked to direct activities of deforestation and underlying causes, which reflect the socio-economic circumstances and national policies that form the indirect cause of deforestation (Hosonuma et al., 2012; Kissinger et al., 2012). We analysed the land use following deforestation, which we defined as the “post-forest land use” and used this to determine the direct activities of deforestation.

For each of the three forest definitions, the different types of land use and land cover were grouped into specific classes of post-forest land use that reflect different drivers of deforestation (Table 2). These included commercial agriculture, subsistence agriculture, urban and infrastructure, mining, aquaculture and open land for all three definitions. The national and natural forest definitions also included shrubland as post-forest land use, and the natural forest definition

**Table 2 – Grouping of land cover classes into different categories of post-forest land use for the three different forest definitions.**

| Post-forest land use    | Included for definition: 1 = FAO definition; 2 = National definition; 3 = Natural forest definition | Land cover class                                                        |
|-------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Commercial agriculture  | 1,2,3                                                                                               | Plantation (oil palm)<br>Upland agriculture<br>Rice field               |
| Subsistence agriculture | 1,2,3                                                                                               | Upland agriculture mixed with bush                                      |
| Urban & Infrastructure  | 1,2,3                                                                                               | Settlement/developed land<br>Transmigration<br>Airport/harbor           |
| Mining                  | 1,2,3                                                                                               | Mining/mines                                                            |
| Aquaculture             | 1,2,3                                                                                               | Cultured fisheries/fishpond                                             |
| Open land               | 1,2,3                                                                                               | Open land                                                               |
| Shrubland               | 2,3                                                                                                 | Bushy swamp<br>Bushes/shrubland                                         |
| Forest plantation       | 3                                                                                                   | Forest plantation (i.e. <i>Eucalypt</i> , <i>Acacia</i> , <i>Teak</i> ) |

included forest plantation as well. Shrubland and open land do not directly refer to typical activities of deforestation, but occurred many times as post-forest land use. For these cases, we made an additional analysis and investigated for areas deforested between 2000 and 2003, what the post-forest land use was in the year 2009, to be able to make further differentiation between drivers of deforestation.

RELs can be established through predicting future deforestation, taking into account the rates and trends of forest conversion. To predict future deforestation and forest degradation, we used standard ordinary least squares (OLS) multivariate regression analysis at district level. The OLS approach has been widely used in empirical studies based on the predictive models of Fama and French (1988) and Hodrick (1992). Compared to analytical tools like simulations, the use of OLS regression is particularly important in testing key hypotheses concerning the political and institutional determinants of economic policies and development (Beck and Katz, 1995).

The estimated regression model was:

$$Def_{idt} = \alpha_1 HD_{id} + \alpha_2 FS_{id} + \alpha_3 GP_i + \alpha_4 AGP_i + \alpha_5 PP_i + \alpha_6 RN_i + \alpha_7 AT_i + \alpha_8 AC_i + \varepsilon_i \quad (1)$$

where  $Def_{idt}$  is the dependent variable and denotes deforestation area (ha) or forest degradation area (ha) in district  $i$  using forest definition type  $d$  (FAO, national or natural forest definition) for a future time period  $t$ .  $HD_{id}$  is the historical deforestation area (ha) or forest degradation area (ha).  $FS_{id}$  is the initial forest cover area (ha) according to definition  $d$ .  $GP_i$  is the gross domestic product (GDP) (million Rupiah).  $AGP_i$  is the agricultural GDP (million Rupiah).  $PP_i$  is the human population density (people/km<sup>2</sup>).  $RN_i$  is the road network (total km in a district).  $AT_i$  is the area covered by trees meant for timber consumption (ha).  $AC_i$  is the area of commercial agriculture (ha).  $\alpha_1$ – $\alpha_8$  are coefficients to be estimated which can be used as predictors of deforestation or degradation for future periods and  $\varepsilon_i$  is the error term. The data we use come from different time periods. We use the observed 2006–2009 deforestation area for  $Def_{idt}$ ,  $FS_{id}$  data from 2006,  $HD_i$  data from 2003–2006 and data from 2005/2006 as input for the rest of the variables. In this analysis, we focus on the structure of the model and the estimated parameters. We did not take the model a step further to predict future deforestation and degradation, i.e., using the estimated regression equation and inserting future values of the independent variables.

Regressions using Eq. (1) were performed with either deforestation or degradation as the dependent variable. Each of the two sets consisted of three regressions according to the FAO, the national and the natural forest definitions. Note that in Eq. (1) we excluded the intercept to be able to determine how well a given variable, holding all else constant, predicts RELs (Santilli et al., 2005).

### 3. Results and discussion

#### 3.1. Deforestation and forest degradation in Indonesia

Table 3 depicts the deforestation and forest degradation for the time steps 2000–2003, 2003–2006, 2006–2009 and the whole

period 2000–2009, for the main islands in Indonesia. Between 2000 and 2009 the total area of deforestation was largest when the national definition was used: 6.2 million ha, compared to 4.9 million ha when using the FAO definition and 5.8 million ha when using the natural forest definition. This is due to how the different definitions capture deforestation or forest degradation.

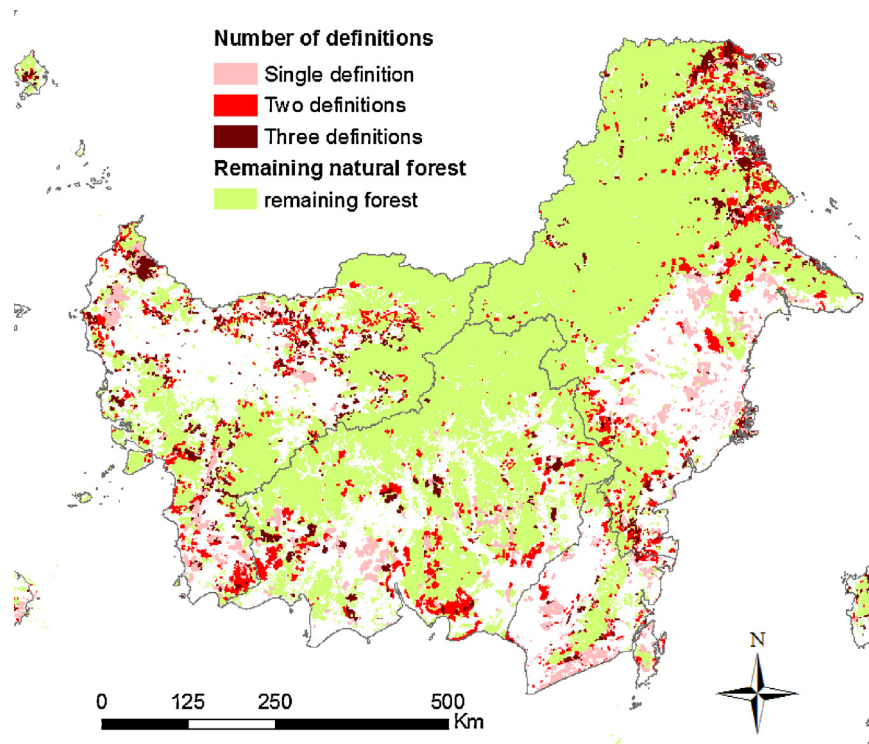
In Kalimantan and Sulawesi, from 2003–2006, deforestation numbers were almost twice as high for the national and natural forest definitions as for the FAO definition. This is because large areas of secondary forest types were converted into bush and shrubland or bushy swamp (shrublands) which was counted as deforestation by the national and natural forest definitions, while for the FAO this was a change between two degraded forest types and thus not captured as deforestation or degradation. In Sumatra, from 2006–2009, total areas of deforestation were 807 000 ha, 932 000 ha and 1 063 000 ha for the FAO, national and natural forest definitions, respectively. Change from secondary forest types to shrublands were captured by the national and natural forest definitions; natural forest types (swamp, mangrove or upland forest) that were converted into forest plantations were only captured as deforestation by the natural forest definition. Estimates for Java, which has little remaining primary forest, were overall low, except for the time step 2003–2006, when the FAO and national definitions reported about 650 000 ha of deforestation. This “Java effect” was caused by conversion of forest plantations into upland agriculture, which does not imply deforestation of natural forests. In Bali and Nusa Tenggara deforestation numbers were overall low and increasing over time when using the FAO definition, while they were decreasing when using the other two forest definitions. These differences were due to the fact that the national and natural forest definitions captured the changes from upland forest into shrublands as deforestation in the time steps 2000–2003 and 2003–2006 in diverse parts of these islands, while the FAO definition captured further transitions from shrublands into other types of land use in the time step 2006–2009 as deforestation. In Papua and Maluku deforestation estimates and trends were exactly the same when the national and natural forest definitions were applied. However, the FAO definition showed deforestation estimates for Papua from 2006–2009 that were almost 3.5 times lower, which was again due to changes from secondary forest types into shrublands that were only captured as deforestation by the national or natural forest definitions.

Variations in forest definitions had little effect on the estimates of forest degradation, showing relatively small differences: 5.2 million ha for the FAO definition and 5.0 million ha for the national and natural forest definitions between 2000 and 2009. The main difference was seen in Papua, where we estimated 130 000 ha (17%) more degradation for the FAO definition compared to the other two definitions. This was mainly due to conversion of primary swamp forest into bushy swamp in south Papua from 2006–2009, which was considered as degradation by the FAO definition, while the national and natural forest definitions captured this as deforestation.

The difference in how the definitions capture deforestation is represented in Fig. 1 for Kalimantan. Only a relatively small part was considered deforested by all three definitions. This occurred when there was a change from primary or secondary

**Table 3 – Deforestation and forest degradation results in Indonesia for the FAO, the national and the natural forest definitions.**

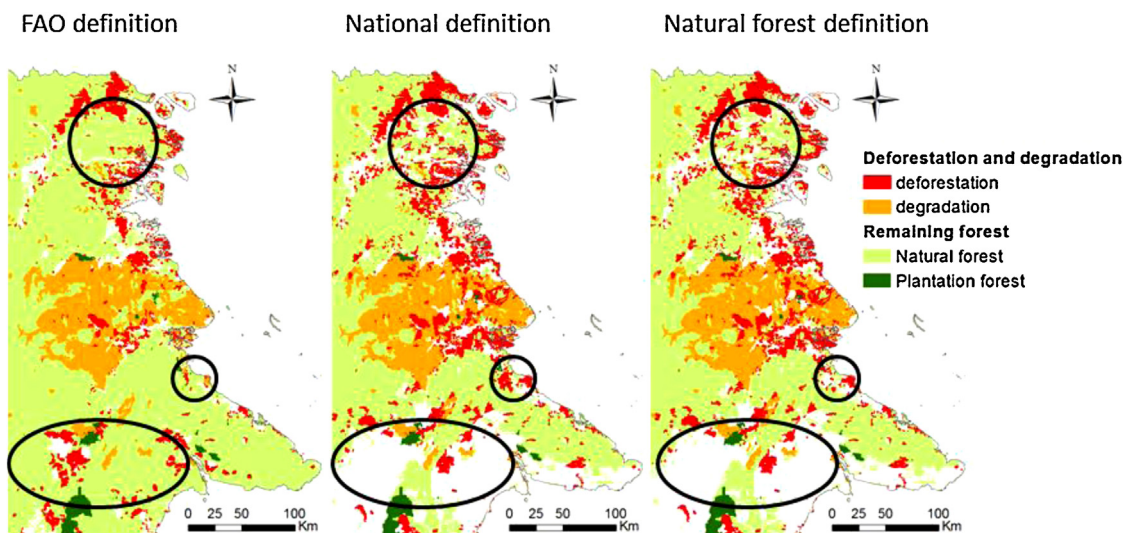
| Island         | FAO definition                   |                |                |                | National definition              |                |                |                | Natural forest definition        |                |                |                |
|----------------|----------------------------------|----------------|----------------|----------------|----------------------------------|----------------|----------------|----------------|----------------------------------|----------------|----------------|----------------|
|                | Area of deforestation (×1000 ha) |                |                |                | Area of deforestation (×1000 ha) |                |                |                | Area of deforestation (×1000 ha) |                |                |                |
|                | 2000–2003                        | 2003–2006      | 2006–2009      | 2000–2009      | 2000–2003                        | 2003–2006      | 2006–2009      | 2000–2009      | 2000–2003                        | 2003–2006      | 2006–2009      | 2000–2009      |
| Sumatra        | 206.83                           | 578.76         | 806.98         | 1484.66        | 311.65                           | 705.22         | 931.93         | 1863.61        | 278.95                           | 709.89         | 1063.01        | 2046.13        |
| Java           | 1.49                             | 649.63         | 49.15          | 696.73         | 1.13                             | 656.12         | 52.01          | 704.92         | 0.27                             | 51.05          | 2.92           | 54.24          |
| Bali & Nusa T. | 3.58                             | 25.97          | 73.29          | 102.07         | 45.10                            | 43.65          | 4.30           | 93.05          | 45.10                            | 38.52          | 3.74           | 87.36          |
| Kalimantan     | 353.65                           | 553.46         | 806.88         | 1685.98        | 372.39                           | 974.94         | 712.30         | 1995.27        | 367.24                           | 963.60         | 705.48         | 1983.92        |
| Sulawesi       | 213.24                           | 151.57         | 83.71          | 430.85         | 200.25                           | 283.22         | 50.07          | 532.56         | 200.25                           | 283.48         | 49.62          | 532.37         |
| Maluku         | 5.23                             | 12.42          | 33.96          | 44.31          | 24.24                            | 24.32          | 18.09          | 66.18          | 24.24                            | 24.30          | 18.09          | 66.63          |
| Papua          | 59.70                            | 186.23         | 211.36         | 445.38         | 79.14                            | 186.78         | 728.10         | 993.75         | 79.15                            | 186.78         | 728.10         | 993.75         |
| <b>TOTAL</b>   | <b>843.72</b>                    | <b>2158.04</b> | <b>2065.32</b> | <b>4889.98</b> | <b>1033.90</b>                   | <b>2874.24</b> | <b>2496.81</b> | <b>6249.33</b> | <b>995.20</b>                    | <b>2257.62</b> | <b>2570.96</b> | <b>5764.41</b> |
| Island         | FAO definition                   |                |                |                | National definition              |                |                |                | Natural forest definition        |                |                |                |
|                | Area of degradation (×1000 ha)   |                |                |                | Area of degradation (×1000 ha)   |                |                |                | Area of degradation (×1000 ha)   |                |                |                |
|                | 2000–2003                        | 2003–2006      | 2006–2009      | 2000–2009      | 2000–2003                        | 2003–2006      | 2006–2009      | 2000–2009      | 2000–2003                        | 2003–2006      | 2006–2009      | 2000–2009      |
| Sumatra        | 0.00                             | 5.03           | 109.47         | 114.05         | 0.00                             | 5.02           | 106.11         | 109.86         | 0.00                             | 5.02           | 101.66         | 103.60         |
| Java           | 9.08                             | 66.61          | 0.00           | 75.32          | 9.08                             | 66.55          | 0.00           | 75.26          | 9.08                             | 64.32          | 0.00           | 72.95          |
| Bali & Nusa T. | 7.04                             | 4.01           | 54.10          | 65.15          | 3.25                             | 3.34           | 54.08          | 59.09          | 3.25                             | 3.31           | 54.08          | 59.06          |
| Kalimantan     | 827.24                           | 310.65         | 76.30          | 1204.07        | 825.38                           | 304.11         | 74.57          | 1182.86        | 825.38                           | 304.11         | 74.57          | 1182.86        |
| Sulawesi       | 233.18                           | 1662.00        | 53.15          | 1922.96        | 230.08                           | 1655.13        | 52.95          | 1910.15        | 230.07                           | 1655.13        | 52.95          | 1910.14        |
| Maluku         | 8.51                             | 10.67          | 0.22           | 19.38          | 8.48                             | 10.67          | 0.22           | 19.35          | 8.48                             | 10.67          | 0.22           | 19.35          |
| Papua          | 298.69                           | 638.10         | 907.03         | 1826.03        | 298.20                           | 634.67         | 777.23         | 1658.52        | 298.20                           | 634.66         | 777.24         | 1658.52        |
| <b>TOTAL</b>   | <b>1383.76</b>                   | <b>2697.08</b> | <b>1200.28</b> | <b>5226.96</b> | <b>1374.47</b>                   | <b>2679.48</b> | <b>1065.18</b> | <b>5015.09</b> | <b>1374.46</b>                   | <b>2677.22</b> | <b>1060.72</b> | <b>5006.48</b> |



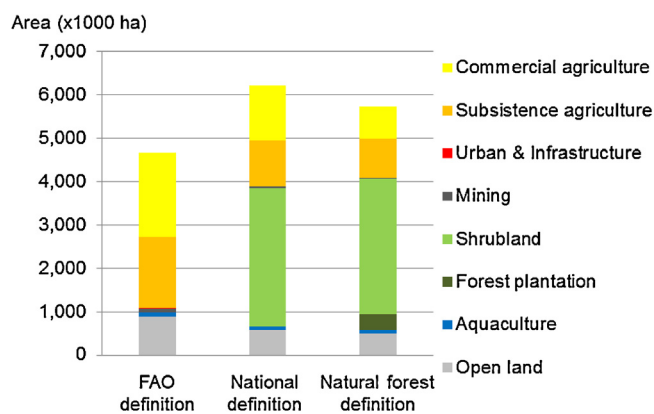
**Fig. 1 – Number of forest definitions capturing a deforestation event in Kalimantan. The gradual red colored areas represent areas of deforestation, which were captured by one, two or three different forest definitions between 2000 and 2009. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)**

forest types to all other land uses, excluding shrublands and forest plantation (759 065 ha). A larger area (1.21 million ha) was captured as deforestation by two different definitions; this was associated with the change from primary or secondary forest into shrublands for both the national and natural forest definitions (1.2 million ha) and a conversion of forest plantation into non-forest or non-shrublands for both the FAO and national definitions (9677 ha). A significant area was only considered deforested by a single forest definition

(963 616 ha). Several cases accounted for this, including the conversion of natural forest types into forest plantations for the natural forest definition (17 626 ha), conversion of forest plantations into shrublands for the national definition (28 990 ha), and conversion of shrublands into other non-vegetated land uses for the FAO definition (917 000 ha). The differences in deforestation and degradation areas between the three definitions for northeast Kalimantan are illustrated in Fig. 2, with the most upper circle indicating the areas with



**Fig. 2 – Deforestation and degradation areas in northeast Kalimantan between 2000 and 2009 using the FAO, the national and the natural forest definitions.**



**Fig. 3 – Distribution of post-forest land use categories for the deforested areas in Indonesia between 2000 and 2009, using the three different forest definitions.**

change from secondary forest types to shrublands, which was not captured as deforestation by the FAO definition and the middle circle indicating conversion of forest plantation into shrublands, which was only captured as deforestation by the national definition. The lower circle shows the difference in remaining natural forest area which was much larger for the FAO definition, because it also consisted of shrublands.

### 3.2. Drivers of deforestation in Indonesia

Fig. 3 shows the distribution of different post-forest land use categories for areas deforested between 2000 and 2009, most of which can be directly linked to activities (proximate drivers) of deforestation. This assessment does not consider pathways or mechanisms of deforestation, but considers the land use category as determined in 2009 to be associated with drivers of deforestation. Whereas other studies often have not been national or focused only on one type of conversion process, for example oil palm (Carlson et al., 2012a, 2012b), our study provides a comprehensive overview of deforestation drivers at the national level for whole Indonesia, based on an empirical analysis.

Important drivers of deforestation for all three definitions were commercial and subsistence agriculture. Together they accounted for 3.6 million ha for the FAO definition (77% of total deforested area in Indonesia), 2.3 million ha for the national definition (39%) and 1.6 million ha for the natural forest definition (42%). Most large scale activities were due to reallocation of forest land or change in forest functions, permitted by MoF (Indrarto et al., 2011; MoF, 2009). The biggest share of commercial agriculture included large scale conversion of peat swamp forests into oil palm plantations in the provinces North Sumatra, Riau and Jambi and along the southwestern borders of Kalimantan, thereby emitting a large amount of GHG to the atmosphere (Uryu et al., 2008; Murdiyarso et al., 2010; Hergoualc'h and Verchot, 2011; Koh et al., 2011).

The natural forest definition captured conversion of natural forests into forest plantations, which accounted for 6.5% (373 000 ha) of the total deforested area. This mainly

happened in Sumatra where large patches of unprotected tropical peat swamp forests in the Riau and Jambi provinces and upland forests in North Sumatra were converted into large scale plantations with mono-culture species such as *Acacia* and *Eucalyptus* for the pulp and paper industry (Uryu et al., 2008; Miettinen et al., 2011).

Two post-forest land use categories that did not directly refer to a specific driver were open land and shrubland. For the national and natural forest definitions, shrubland took up more than half of the deforested areas (51% and 54%). When investigating the post-forest land use in 2009 for the areas that were deforested between 2000 and 2003 and were covered by shrubland in 2003, we found that 14.9% of the area was used for subsistence agriculture and only 5.1% of the area was converted into commercial agriculture (Table 4). The biggest part however (74.6%), remained shrubland in the year 2009. Similar results were found by Miettinen et al. (2011) for Sumatra and Kalimantan who argued that areas which were deforested for the purpose of plantations could still be largely detected as open land or mosaic areas, which showed similarities to our shrubs class. For open land we found a different pattern: 25.1% of the areas were further converted into commercial agriculture and 16.7% into forest plantations. 9% of the open areas were invaded by shrubland or secondary forest. 47.1% of the area remained open land in the year 2009. Logging is often followed by conversion to plantations of oil palm or pulpwood, which indicates that the open land may be only one step in the complete land use change trajectories (Boucher et al., 2011). Another reason for these large areas of shrubland and open land could be that licenses that were meant for tree crop plantations were often abused. Companies obtained the subsidies that were meant to establish plantations, cleared the forest to sell timber, but then abandoned the land without replanting it (Casson, 1999; Kartodihardjo and Supriono, 2000).

Mining, urban areas and infrastructure, and aquaculture occupy smaller parts of deforested areas and together accounted for 4.5%, 1.8% and 1.7% of the area changes based on the FAO, the national and the natural forest definitions, respectively. Mining often occurred with lease-unit permits, but there are also many illegal small-scale mining areas in the forests (Resosudarmo et al., 2009).

Table 5 shows the post-forest land use categories per forest type. In the upland, swamp and mangrove forests, the largest part of the deforested area was shrubland, where the

**Table 4 – Distribution of post-forest land use in 2009 for areas which were deforested in the time period 2000–2003 and remained shrubland or open land in 2003.**

| Post-forest land use 2009  | Post-forest land use in 2003 |               |
|----------------------------|------------------------------|---------------|
|                            | Shrubland (%)                | Open land (%) |
| Commercial agriculture     | 5.1                          | 25.1          |
| Subsistence agriculture    | 14.9                         | 1.9           |
| Urban and Infrastructure   | 0.1                          | 0.0           |
| Mining                     | 0.1                          | 0.0           |
| Shrubland/secondary forest | 74.6                         | 9.0           |
| Forest plantation          | 1.0                          | 16.7          |
| Aquaculture                | 1.9                          | 0.2           |
| Open land                  | 2.3                          | 47.1          |

**Table 5 – Post-forest land use in deforested areas between 2000 and 2009 for each type of forest.**

| Post-forest land use    | Area per forest type (%) |                  |                     |                       |               |
|-------------------------|--------------------------|------------------|---------------------|-----------------------|---------------|
|                         | Upland forest (%)        | Swamp forest (%) | Mangrove forest (%) | Forest plantation (%) | Shrubland (%) |
| Commercial agriculture  | 11.2                     | 17.3             | 2.0                 | 61.0                  | 40.1          |
| Subsistence agriculture | 23.0                     | 3.7              | 0.4                 | 18.8                  | 36.0          |
| Urban & Infrastructure  | 0.2                      | 0.0              | 0.2                 | 1.2                   | 0.5           |
| Mining                  | 0.5                      | 0.1              | 0.4                 | 0.4                   | 3.2           |
| Shrubland               | 56.9                     | 49.8             | 57.9                | 9.8                   | –             |
| Forest Plantation       | 2.6                      | 13.9             | 1.0                 | –                     | –             |
| Aquaculture             | 0.0                      | 0.1              | 37.0                | 0.0                   | 2.1           |
| Open land               | 5.6                      | 15.2             | 1.1                 | 8.7                   | 18.2          |

drivers were unclear. The main drivers of deforestation in upland forests were subsistence agriculture (23.0%) and commercial agriculture (11.2%); in swamp forests they were commercial agriculture (17.3%) and forest plantation (13.9%); and in mangrove forests aquaculture (37.0%). In swamp forests, quite large areas remained as open land (15.2%). Forest plantations were often converted into commercial agriculture (61.0%). Shrubland was converted into commercial agriculture for 40.1% and into subsistence agriculture for 36.0% of the land use changes. A small portion (18.2%) of the shrublands degraded further and changed into open land.

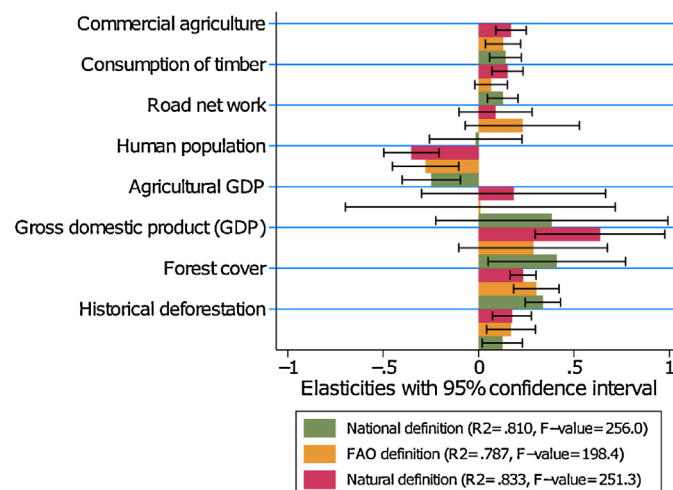
### 3.3. Modeling future deforestation and forest degradation in Indonesia: Inferences made from elasticity estimates of predictors of deforestation and forest degradation for REL establishment

In Figs. 4 and 5 the regression results from Eq. (1) for estimating future deforestation and future forest degradation are graphically represented for the three different forest definitions. Each bar in the figures represents the size of the coefficient of the designated variable and the black lines show the 95% confidence interval of the coefficient estimate, which indicates that the coefficient estimate is not significant up to 5% level of significance if the line crosses the zero mark on the horizontal axis. Note that  $R^2$  refers to R-squared (coefficient of determination), which is a measure of how well the regression

explains and predicts future deforestation. All variables included in the regression are collectively key determinants of the respective dependent variables as evidenced by the F-value statistic (significant at 1% in all estimations). Both the dependent and independent variables were transformed using natural logarithms. This corrects for any violation in the assumption of normal distribution of the data points that would potentially bias regression estimates, and also reduces the impacts of any outliers. Further, it makes the interpretation of coefficients easier as they can be interpreted as elasticities or as the sensitivity of the dependent variable to changes in the independent variables. In this context, this means the percentage change in the rate of future deforestation (or degradation) in response to a one percent change in a given covariate, holding all other covariates constant.

Deforestation was much better predicted than degradation, with an average  $R^2$  for all three definitions of 0.81 for deforestation and 0.516 for degradation. The natural forest definition yielded best predictions of future deforestation with an  $R^2$  of 0.833, while predictions of future degradation were lowest for this definition ( $R^2$  of 0.508). Similarly, best predictions of future degradation were obtained with the FAO definition ( $R^2$  of 0.529), while this definition had the lowest predictions for future deforestation ( $R^2$  of 0.787). This is not surprising, because both predictions are linked through one definition.

For predicting future deforestation, the variables “historical deforestation” and “forest cover” were significant, but

**Fig. 4 – Predictors of deforestation in Indonesian districts.**

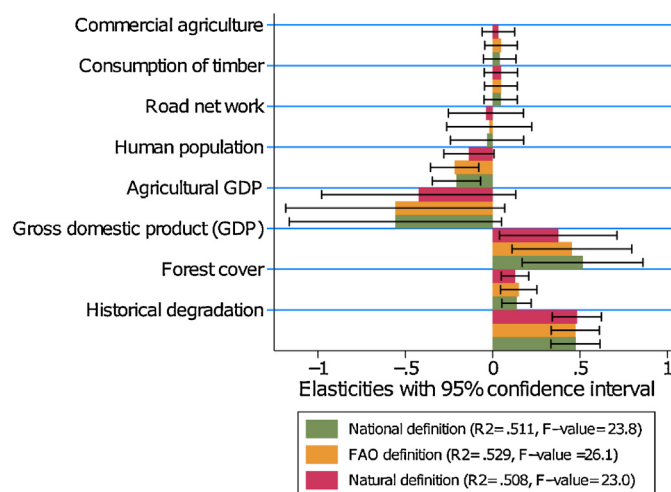


Fig. 5 – Predictors of degradation in Indonesian districts.

several other factors can explain the deforestation trend. Human population and GDP had a relatively large influence on predicted deforestation, while commercial agriculture and consumption of timber had a smaller influence. Other factors, like road network and agricultural GDP were not significant. For predicting future degradation, on the other hand, historical degradation was the most important variable. Forest cover, GDP and human population had a slightly significant contribution to future degradation. Other factors, which included commercial agriculture, consumption of timber, road network and agricultural GDP, did not have significant coefficients. Reason for this could be that the degradation processes are less well understood so there is not a clear link with predictors.

Elasticity estimates for historical deforestation varied across the three forest definitions (Fig. 4). A 1% increase in deforested area in the past would increase future deforestation with 0.12% when using the national definition, with 0.17% when using the FAO definition, and with 0.18% when using the natural forest definition. Although the estimates of the coefficients are different, the confidence intervals for the three definitions are overlapping, thus we cannot conclude that they are significantly different from each other. The different forest definitions, however, did not lead to large differences in historical degradation rates (Fig. 5): 0.47% influence for the FAO and national definitions and 0.48% for the natural forest definition. A 1% increase in initial forest cover accelerated future deforestation by 0.30% when using the FAO definition, by 0.34% when using the national definition, and by 0.23% when using the natural forest definition, but the estimated effects on increased degradation contributed by initial forest cover were nearly similar across the definitions: FAO definition (0.15%), national definition (0.14%), and natural forest definition (0.13%).

Fig. 4 shows that an increase in GDP significantly increased future deforestation rates. However, we notice substantial differences in the elasticity estimates across the three definitions. GDP accelerated deforestation rate more under the natural forest definition, followed by the national definition, while the increase under the FAO definition was lowest. Following the definitions used for this analysis, changes from

natural forest into forest plantations were only considered deforestation activities for the natural forest definition. Indonesia's growth in GDP is partly due to forestry, wood manufacturing and pulp and paper industry, which depend on large scale forest plantation development (ITS Global, 2011), and thus was only captured by the natural forest definition. Furthermore, the change from natural forest into shrubland, which is explained in the previous paragraph as a result of timber harvest, was included as deforestation for the national and natural forest definitions. This activity also contributes significantly to GDP (Kartodihardjo and Supriono, 2000) and could explain the higher elasticity estimates of GDP for the national and natural forest definitions (but also raises issues of the direction of causality, although this is less of a concern in predictive models).

The variable "human population" also had a large impact on future deforestation estimates. All three definitions showed that higher human population density was associated with reduced deforestation rates, with the natural forest definition having a larger elasticity estimate than the FAO definition, which in turn was slightly larger than the elasticity estimate using the national definition. The negative correlation is related to the distribution of deforestation and human population throughout the archipelago. Java has a high population density and low deforestation rate, because there are almost no natural forests left, while Kalimantan has a low population density and a high deforestation rate, and also a high amount of forest left. Murdiyarso et al. (2008) found a similar result that 63% of the variation in forest cover in 1990 could be explained by population density, while a high forest cover was associated with low population density. For change in forest cover (deforestation), the estimated effect is the opposite.

### 3.4. On the choice of a forest definition for REDD+ monitoring

The magnitude of the rate of deforestation varied significantly for the three forest definitions. Compared to area estimates for the FAO definition, deforestation areas were 874 430 ha and

1359 350 ha higher when using the natural forest definition and the national definition, respectively. Assuming that forested regions in tropical Asia store 151 t C/ha on average (Acharid et al., 2004), the difference in C emission estimates would vary from 132.04 Mt C to 205.26 Mt C when applying different definitions. This may have large implications on emission reduction estimates when using different definitions in constituting RELs.

The IPCC guidelines recommend to use the internationally accepted FAO definitions of forest (IPCC, 2006); however, it is countries' sovereignty to decide how to define their forest and how to calculate RELs. As observed from the Indonesia case, different forest definitions can have large implications for monitoring and reporting of REDD+ activities. In this context, we do not want to give a recommendation on the choice of the definition to be used for Indonesia's REDD+ monitoring system. Our aim was to present the study results in an objective way and to show the implications of certain decisions that can be made when choosing a forest definition. Policy makers then have to evaluate the differences and decide on the forest definition to use for monitoring their tropical forests.

However, it is important that the methodology and definitions used capture the major emissions from land use changes in a country and that they can be validated independently following international carbon accounting verification standards (UNFCCC, 2011b). To monitor forest cover change accurately countries should at least have medium resolution satellite data available (Herold and Johns, 2007; Hansen et al., 2009; GOC-GOLD, 2012). This allows them to make a land cover classification which differentiates between different forest types and other important land cover classes to detect deforestation, forest degradation and drivers of deforestation.

Further, it is vital to have a separate class of forest plantation to capture the conversion from natural forest into forest plantation as this has major emission implications. In this analysis, conversion of natural forest into forest plantations was only detected as deforestation by our natural forest definition, but as degradation by the other two definitions. Establishing plantations in natural forests causes large CO<sub>2</sub> emissions, especially on peatlands. Forest plantations only contribute to emission reductions when they are planted on degraded land with initially lower carbon densities (Verchot et al., 2010). Therefore, it is important that these CO<sub>2</sub> emissions are captured, either as deforestation or as degradation, depending on the definition used.

Finally, it is critical to harmonize forest definitions in a single country. The same forest definition should be used throughout the country and for different years for REDD+ monitoring, deforestation and degradation area estimates, estimates of drivers of deforestation and RELs.

#### 4. Conclusions

This paper highlights that countries need to take great care in choosing a forest definition for monitoring and reporting of REDD+ activities. Our analysis showed that different definitions can result in varying deforestation and forest degradation area estimates, distributions of deforestation drivers, and REL estimates.

The total estimated area of deforestation between 2000 and 2009 was smallest when using the FAO definition (4.9 million ha), 16% higher when using the natural forest definition (5.8 million ha) and 25% higher when using the national definition (6.2 million ha). Total forest degradation area estimates did not show much difference: 5.0 million ha for the national and natural forest definitions and 5.2 million ha for FAO forest definition.

Consequently, the definitions also had an impact on defining and estimating drivers of deforestation, using post-forest land use as the determinant for proximate drivers of deforestation. Largest drivers of deforestation in terms of area change were commercial agriculture and subsistence agriculture, taking up 3.6, 2.3 or 1.6 million ha of deforested land according to the FAO definition, the national definition and the natural forest definition, respectively. Forest plantations were only spotted as deforestation driver when using the natural forest definition, they occurred on 6.5% of the deforested area between 2000 and 2009, mainly in Riau and Jambi provinces in Sumatra, where peat swamp forests were converted into plantations for the pulp and paper industry. Urban development and infrastructure, mining and aquaculture were less important drivers in terms of area change. Using the national and natural forest definitions, shrubland occurred on more than 50% of the total deforested area between 2000 and 2009 as post-forest land use. This did not happen for the FAO definition, because shrubland was defined as degraded forest for this definition. The driver of deforestation for these areas is rather uncertain. Detailed analysis for areas deforested between 2000 and 2003 showed that these areas were further converted into subsistence agriculture (14.9%) and commercial agriculture (5.1%), while 74.6% of these areas remained shrubland in 2009. An area of 9% to 19% of the deforested land remained open land after deforestation, depending on the definition used. Further analysis showed that 25.1% of this area was deforested for commercial agriculture and 16.7% for forest plantations, while 9.0% became shrubland or secondary forest and 47.1% remained open land in 2009. More detailed analysis is needed in order to determine the exact distribution of drivers of deforestation for shrubland and open areas. The methodology proves that remote sensing is capable of detecting proximate drivers of deforestation from space. However, to detect the dynamics of landuse and land cover change, for example certain land use trajectories like conversion of forest into open land, followed by a further conversion into commercial agriculture in later years, better remote sensing data, with finer resolution and higher temporal coverage and on the ground analysis are needed.

The different forest definitions caused significant variations in elasticity estimates of predictors of deforestation which are needed to establish deforestation RELs. Future deforestation (average  $R^2$  of 0.81) was much better predicted than future degradation (average  $R^2$  of 0.516). The natural forest definition gave the best results for predicting future deforestation with an  $R^2$  of 0.833, however future degradation predictions were lowest for this definition. The difference in definitions of forest, however, did not cause significant differences in establishing degradation RELs.

We found that apart from historical deforestation and initial forest cover, GDP and human population were

important predictors of future deforestation in Indonesia and therefore a change in one of these variables would have a considerable impact on the REL estimates. Degradation processes are less well understood and therefore predictions of future degradation rely mainly on estimates of historical degradation and forest cover.

The findings of this research underscore that the criterion used in defining forest, especially when choosing a forest canopy cover threshold and in- or excluding forest plantations from the forest class need to be considered thoroughly. The most important is that countries harmonize their definitions, that the definition used captures all major C emissions and that the methodology is well elaborated so it can be verified independently within the REDD+ context.

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