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An assessment of deforestation and forest degradation drivers in developing countries

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Abstract
Countries are encouraged to identify drivers of deforestation and forest degradation in the development of national strategies and action plans for REDD+. In this letter we provide an assessment of proximate drivers of deforestation and forest degradation by synthesizing empirical data reported by countries as part of their REDD+ readiness activities, CIFOR country profiles, UNFCCC national communications and scientific literature. Based on deforestation rate and remaining forest cover 100 (sub)tropical non-Annex I countries were grouped into four forest transition phases. Driver data of 46 countries were summarized for each phase and by continent, and were used as a proxy to estimate drivers for the countries with missing data. The deforestation drivers are similar in Africa and Asia, while degradation drivers are more similar in Latin America and Asia. Commercial agriculture is the most important driver of deforestation, followed by subsistence agriculture. Timber extraction and logging drives most of the degradation, followed by fuelwood collection and charcoal production, uncontrolled fire and livestock grazing. The results reflect the most up to date and comprehensive overview of current national-level data availability on drivers, which is expected to improve over time within the frame of the UNFCCC REDD+ process.

Keywords: deforestation, forest degradation, tropics, drivers, proximate causes, REDD+, developing countries, forest transition model

1. Introduction

Understanding drivers of deforestation and degradation is fundamental for the development of policies and measures that aim to alter current trends in forest activities toward a more climate and biodiversity friendly outcome. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are developing a mechanism for reducing emissions from deforestation and forest degradation, enhancing forest carbon stocks, sustainable management and conservation of forests (REDD+) in developing non-Annex I countries (UNFCCC 2010). In addition to the discussion on policy incentives and modalities for measurements, reporting and verification (MRV), the issue of identifying drivers and activities causing forest carbon change on the national level for REDD+ monitoring and implementation has received increasing attention in the REDD+ debate (Bendorf *et al* 2007, UNFCCC 2010). The UNFCCC negotiations (UNFCCC 2009, 2010) have encouraged developing countries to identify land use, land use change and forestry activities, in particular those that are linked to the drivers of deforestation and forest degradation, and to assess their potential contribution to the mitigation of climate change. Understanding is needed for assessing not only how much forests are changing but also how to define proper policies, and national REDD+ strategies and implementation plans (Boucher 2011, Rudorff *et al* 2011). Projections of expected developments, such as required for setting forest reference levels (UNFCCC 2011), need to be based on knowledge of context-specific drivers or activities and their underlying causes, and perhaps should be considered separately for deforestation and degradation processes (Huettner *et al* 2009). Thus, in addition to the fundamental importance of national data on forest area change and associated changes in forest carbon stocks to estimate emissions and removals, the need for national data on type and relative importance of deforestation and degradation drivers is rising to an almost equal level of relevance to support national REDD+ activities.

Despite this relevance, quantitative national-level information on drivers and activities causing deforestation and forest degradation are widely unknown. For example, the question of how much or what fraction of deforestation (emissions) in a country is caused by a specific driver (i.e. expansion of agriculture versus infrastructure) cannot be answered for many developing countries. Scientific research in the past (Geist and Lambin 2001) has mainly been based on local-scale studies or regional to global assessments (De Fries *et al* 2010, Boucher *et al* 2011). They have highlighted the importance of differentiating between proximate or direct drivers and underlying or indirect causes. Proximate or direct drivers of deforestation are human activities that directly affect the loss of forests and thus constitute proximate sources of change, that result from complex interactions of underlying forces in social, political, economic, technological and cultural domains (Geist and Lambin 2001). Direct drivers can be grouped into different categories such as agriculture expansion, expansion of infrastructure and wood extraction (Geist and Lambin 2001). Although agricultural expansion has been determined as the key driver of deforestation in the tropics (Gibbs *et al* 2010), drivers vary regionally and change over time (Rudel *et al* 2009, Boucher *et al* 2011).

The forest transition (FT) model identifies characteristic, human-induced changes and varying drivers of forest cover dynamics over time at the national scale (Rudel *et al* 2005, Lambin and Meyfroidt 2010). Mather (1992) introduced the FT concept to explain the transition from decreasing to expanding forest cover that has taken place in many developed countries. The model has subsequently been tested in several developing countries (Rudel *et al* 2005, Kauppi *et al* 2006) and it was found that forest cover at the national level followed

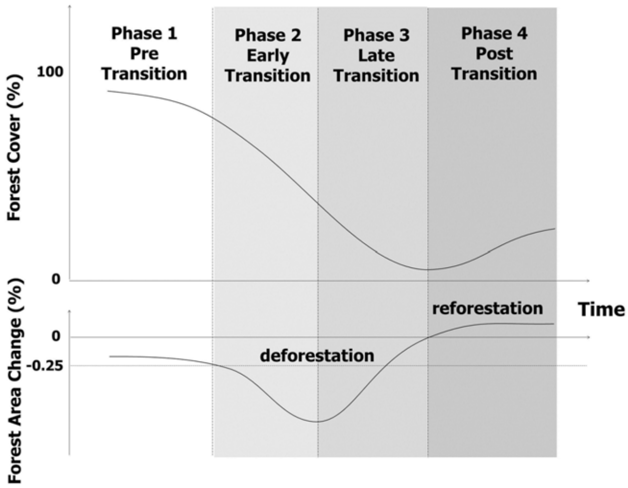

Figure 1. Four phases of the FT model as applied in this study.

an inverse J-shaped curve over time, based on empirical observation (figure 1). Mustard *et al* (2004) and De Fries *et al* (2004) expanded the concept to incorporate the intensification of agriculture and urbanization that generally occurs in the course of economic development and accompanies the forest transition.

Given the current gap in knowledge and understanding of drivers on national, regional and global levels, the research presented in this letter aims to provide an assessment of proximate drivers of deforestation and forest degradation by synthesizing empirical data from tropical and sub-tropical developing (non-Annex I) countries. While national data on proximate drivers have commonly not been available in the past, the recent efforts for REDD+ readiness, and national REDD+ plan and strategy development, have generated new information provided by countries. For example, all countries participating in the World Bank Forest Carbon Partnership Facility (FCPF 2011) are asked to develop readiness plan proposals that include an assessment on deforestation and degradation drivers. Similar efforts are ongoing as part of the UN-REDD program (www.un-redd.org) and some research projects. Based on this information, the research efforts presented here follow two objectives.

(1) Derive and, as far as possible, quantify deforestation and degradation drivers from existing national REDD+ reports and studies.
(2) Assess the relative importance and patterns of different deforestation and forest degradation drivers reflecting approximately the period 2000–2010, to study driver variability in space (by continent) and time (using the FT model).

The results provide the first comprehensive and comparative assessment of drivers on the national level and provide input to the ongoing UNFCCC REDD+ negotiations, where the issue and importance of drivers is still subject to considerable debate (UNFCCC 2010).

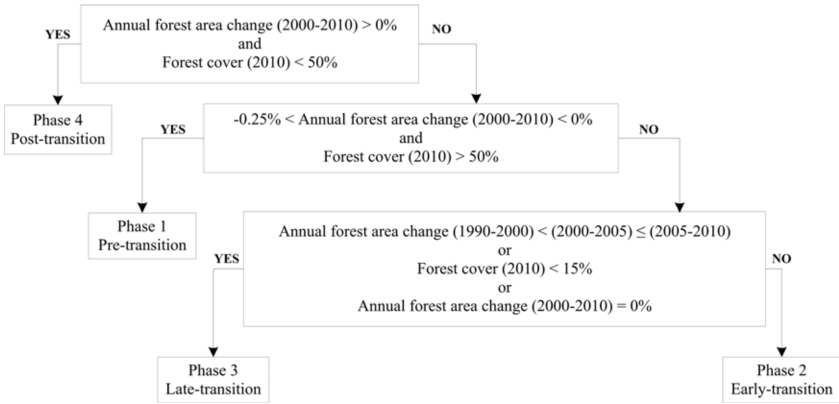

Figure 2. Decision tree for FT categorization.

2. Data and methodology

2.1. The forest transition model

All 100 non-Annex I countries in this study were grouped into four FT phases (figure 1) based on two factors: percent forest cover and rate of forest area change. The four FT phases are pre-transition, early transition, late transition and post-transition, which generally represent a time sequence of national development. Pre-transition countries have high forest cover and low deforestation rates. In early-transition countries, forest cover is lost at an increasingly rapid rate. Late-transition countries with a rather small fraction of remaining forests exhibit a slowing of the deforestation rate and eventually come into the post-transition phase, where the forest area change rate becomes positive and forest cover increases through reforestation. The FT model reflects a broad-scale typology of tropical developing countries, applicable as a proxy for analyzing the temporal variability of drivers of deforestation and forest degradation.

In general, our methodology followed the one described by da Fonseca *et al* (2007), where developing countries were stratified into four categories based on remaining forest cover and deforestation rate. A decision tree (figure 2) was developed for categorizing all 100 countries into four FT phases using the percentage forest cover of 2010 and forest area change rates based on the 2010 Global Forest Resources Assessment (FRA) by FAO (FAO 2010). Forest area change rates were calculated based on the amount of annual forest change relative to forest cover in 1990 for four periods: 1990–2000, 2000–05, 2005–10 and 2000–10. An annual forest area change rate of −0.25% was used to separate between pre- and early-transition countries as this is the annual average of 2005–10 for our study area. A forest area change rate of 0% and forest cover of 15% and 50% were selected as additional thresholds.

2.2. Definitions and types of drivers

The definition of drivers of deforestation and forest degradation in the REDD+ debate are often not clear. In scientific literature, there is a common separation of proximate/direct or underlying/indirect causes. It is often more difficult to establish clear links between underlying (or predisposing) factors and deforestation than between direct causes and deforestation. In this study, we will analyze data on the proximate or direct drivers, i.e. human activities that directly affect the loss of forests, and use the term 'driver' to indicate proximate drivers. This choice is based on available data and the way countries are reporting data on drivers.

The drivers are considered separately for deforestation and forest degradation. Deforestation in this letter denotes the (complete) removal of trees and the conversion from forest into other land uses such as agriculture, mining etc, with the assumption that forest vegetation is not expected to naturally regrow in that area. Forest degradation denotes thinning of the canopy and loss of carbon in remaining forests, where damage is not associated with a change in land use and where, if not hindered, the forest is expected to regrow. In some specific cases multiple proximate drivers work in combination, i.e. forest clearing for timber followed by land use change for agriculture. In this case and to avoid double counting, the land use change (to agriculture) has been identified as the primary cause of deforestation. Five deforestation drivers (table 1) and four forest degradation drivers (table 2) were considered in

Table 1. Categories of deforestation drivers.

Category	
Agriculture (commercial)	• Forest clearing for cropland, pasture and tree plantations • For both international and domestic markets • Usually large to medium scale
Agriculture (subsistence)	• For subsistence agriculture • Includes both permanent subsistence and shifting cultivation • Usually by (local) smallholders
Mining	• All types of surface mining
Infrastructure	• Roads, railroads, pipelines, hydroelectric dams
Urban expansion	• Settlement expansion

Table 2. Categories of forest degradation drivers.

Category	
Timber/logging	• Selective logging • For both commercial and subsistence use • Includes both legal and illegal logging
Uncontrolled fires	• Includes all types of wildfire
Livestock grazing in forest	• On both large and small scales
Fuelwood/charcoal	• Fuelwood collection • Charcoal production • For both domestic and local markets

this study. We use these broad categories to provide a set of driver types for comparative analysis that allow for the variation in detail and quality of information reported by countries.

2.3. Data sources and analysis of drivers

Since countries have not been obliged to report on drivers, there are no comprehensive, recent and quantitative assessment data available concerning drivers of deforestation and forest degradation on a national level. Thus, this study builds upon new and useful REDD+ readiness related data sources to help fill this gap including 26 Readiness Preparation Proposals (R-PP) and ten Readiness Plan Idea Notes (R-PIN) prepared for the World Bank Forest Carbon Partnership Facility (FCPF 2011) by hosting countries. It is important to note that these data are basically self-reported by countries and they were taken on board independent of what these reports are based on. As another source of data, Matthews *et al* (2010) describe proximate drivers of deforestation throughout history for 25 tropical countries by reviewing existing literature and data. In addition, we used several CIFOR country profiles (http://www.forestclimatechange.org/) that include driver and activity information for deforestation and forest degradation, and UNFCCC National Communications and other reports that have recently become available. Most of these data sources were developed between 2008 and 2011 and reflect more or less the period of 2005–2010 or 2000–2010 when the report has time series data. In total, driver data were available for 46 of the 100 (sub)tropical non-Annex I countries (appendix). These 46 countries account for 78% of the total forest area (in 2010), and 81% of forest loss (in 2000–2010) of the 100 countries under consideration, according to 2010 FAO FRA data (FAO 2010), and cover a range of FT phases in each continent (table 3). However, for some continent–FT phase combinations there are no or limited data available, namely for post-transition countries in Africa and Latin America and pre-transition countries in Asia.

The different data sources were analyzed and summarized to provide the current 'best' estimate of the relative importances of different drivers. First, all data were categorized given the driver categories listed in tables 1 and 2. The

Table 3. Availability of national datasets per continent and FT phase (dark gray, no national datasets available; light gray, limited national datasets available (≤2)).

	Amount of national datasets available/total datasets		
Forest transition phase	Africa	America	Asia
Pre-transition	3/3	4/6	0/4
Early transition	10/19	6/11	6/9
Late transition	4/18	5/9	3/6
Post-transition	0/6	2/4	3/5

relative importance of a driver within a country is reported in different formats in the different sources, either as a ratio scale (quantitative information), an ordinal scale (ranking) or a nominal scale (listing). The aim was to get as much quantitative information as possible about the relative importance of deforestation and forest degradation drivers as a national fraction (e.g., commercial agriculture was at 40% the most important cause of deforestation on the national level). Table 4 shows how different data scales were processed to allow for comparison. Depending on the scale of the source data, the same approach was used for all countries to ensure consistency. When ratio-scale data were available, this value was directly used. Ordinal data were quantified by assigning ratios (e.g. 3:2:1) in order of decreasing importance and assuming an equal interval. In the case of more than one dominant driver, the estimation procedure was adapted accordingly with the same weight for drivers reported as equally important (see example in table 4). For nominal-scale data the values for attributing ratios were assumed equal. In cases where multiple and different-scale data sources exist for a country we prioritized the most quantitative data, so ratio data were preferred over ordinal data and ordinal data over nominal data. When multiple but same-scale data sources were available for a country, the average values were used. As shown in table 4, countries with the highest quality ratio-scale data reflect 47% of the total forest loss (of 100 countries) and ordinal-scale data are available for countries responsible for 20% of the total forest loss. Although 19 countries have only nominal-scale data, these countries tend to be smaller in size and with lower contributions to forest loss (14% of total forest loss).

2.4. Estimations for countries without driver data

The country driver data were aggregated for different continents and FT phases and also analyzed in that context (see sections 3.2 and 3.3). The aggregation by continents and forest transition phases can be used as suitable proxies to describe the country circumstances in terms of active deforestation and degradation drivers; i.e., it can be assumed that a country (without current data on drivers) will have a similar situation to other countries on the same continent and the same FT phase where empirical data are available. Thus, building upon the continent and FT model proxies, the study has derived estimates for situations where currently limited country data have been reported (see table 3). For situations with sufficient driver data, the driver data were averaged.

Table 4. Method of quantifying the national fraction of drivers (A, B and C are examples of drivers) with respect to three scales of source data.

Scale of data source	Example	Quantification	No. countries	Total forest loss for 100 countries (FAO 2010) (%)
Ratio scale (quantity)	Drivers $A = 60\%, B = C = 20\%$	$A = 60\%, B = C = 20\%$	12	47
Ordinal scale (ranking)	Drivers $A > B > C$ $\rightarrow$ A:B:C = 3:2:1 Drivers $A = B > C$ $\rightarrow$ A = B:C = 2:2:1	$A = 50\%$ (3/6), $B = 33.3\%$ (2/6), $C = 16.7\%$ (1/6) $A = 40\%$ (2/5), $B = 40\%$ (2/5), $C = 20\%$ (1/5)	15	20
Nominal scale (listing)	Main drivers are A, B and C	$A = B = C = 33.3\%$ (1/3)	19	14

Table 5. Data availability and data estimation procedures for situations with limited or no driver data using proxy information (see table 6).

Annotation in table 6	Availability driver data	Proxy estimation
(no)	Sufficient driver data: three or more countries belonging to the same continent and FT phase exist	Driver data are averaged
a	Few (<3) countries belonging to the same continent and FT phase exist but similar data are available from countries belonging to the continent with similar drivers and the same FT phase	Driver data of these countries and countries belonging to the continent with similar drivers and FT phases are averaged
b	Few (<3) countries belonging to the same continent and FT phase exist and no similar data are available	Driver estimation is based on average of less than three countries belonging to the same continent and FT phase
c	No driver data but similar data are available from countries belonging to the continent with similar drivers and the same FT phase	Driver data of countries belonging to the continent with similar drivers and FT phases are averaged
d	No driver data and no similar data available	Driver data for countries with the same FT phase of all continents are averaged

Table 5 explains the data estimation procedures for situations with limited or no driver data using proxy information.

3. Results

3.1. Categorization of 100 tropical non-Annex I countries into FT phases

The 100 non-Annex I (sub)tropical countries are categorized into four FT phases (see the appendix) using the decision tree (figure 2). Exceptions on the decision tree were made for Thailand and Costa Rica. These countries, while just not fulfilling the criteria, clearly belong in the post-transition phase. Of the 100 non-Annex I countries, 13 countries are in the pre-transition phase, 39 in early transition, 33 in late transition and 15 in post-transition. Thus the majority (72) of the 100 countries are either in early or late transition, which are the phases of rapid deforestation. The spatial distribution of FT phases across the (sub)tropics (figure 3) shows that many pre-transition countries in Africa and America are located around the equator, surrounded by early-transition countries, and with late-transition countries mostly located in sub-tropical regions.

Forest cover (FAO 2010) and intact forest area values (Potapov *et al* 2008), both for 2005, were averaged for each FT phase for all 100 countries (figure 4). The forest cover transition follows the conceptual framework shown in figure 1. Intact forest area follows a similar FT curve to forest cover but the change in intact forest cover from the late- to post-transition phase remains quite small, suggesting that a large proportion of forests in post-transition countries remains degraded. The difference between forest cover and intact forest area, i.e. the disturbed forest area fraction, is an important indicator of degraded forest area.

3.2. Analysis of drivers for each continent

The driver data are summarized and analyzed for three continents, Africa, America and Asia (including Oceania) (figure 5(A)). Agriculture is the main driver of deforestation, but with differences in geographic distribution of the importance of commercial versus subsistence agriculture. Commercial agriculture is the most important driver in Latin America (68%), while in Africa and Asia it contributes to around 35% of deforestation. Local and subsistence agriculture is quite equally distributed among the continents (27–40%), which makes sense since this type of land use (change) remains widespread in all areas in the tropics and sub-tropics. Overall, agriculture reflects around 80% of deforestation worldwide, which is in line with estimates provided by Geist and Lambin (2002) for the 1980s and 1990s. Mining plays a larger role in Africa and Asia than in Latin America. Urban expansion is most significant in Asia. De Fries *et al* (2010) state that further urban population

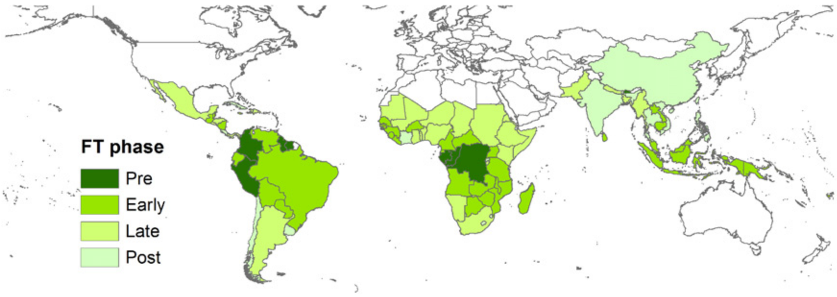

Figure 3. Spatial distribution of national FT phases.

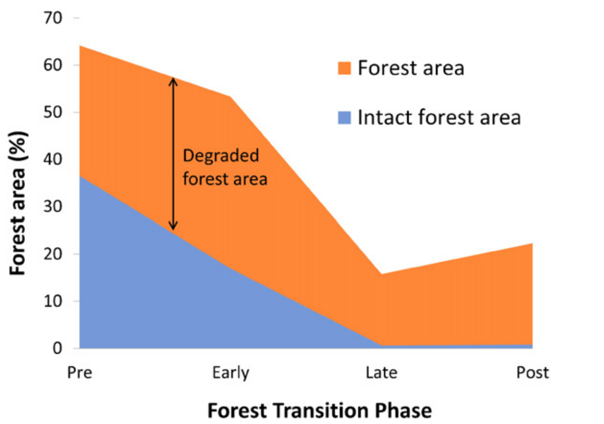

Figure 4. Average forest cover (FAO 2010) and intact forest area in 2005 for each FT phase.

growth is expected across the tropics, which will likely be associated with increased pressure on tropical forests.

Timber extraction and logging account for more than 70% of total degradation in Latin America and Asia (figure 5(C)). Fuelwood collection and charcoal production is the main degradation driver for the African continent, and is of small to moderate importance in Asia and Latin America. Uncontrolled fires are most prominent in Latin America. In terms of absolute net forest area change over the period 2000–10 (figure 5(B)), the largest driver remains commercial agriculture, with the largest deforested area located in Latin America. In Africa and Asia, subsistence and commercial agriculture contribute roughly equally to forest area change.

3.3. Analysis of drivers for each FT phase

The driver data are summarized and analyzed for four FT phases (figure 6). The relative area contribution of commercial agriculture rises until the late-transition phase, after which it decreases again (figure 6(A)). The relative importance of subsistence agriculture remains fairly stable throughout the different phases, while the relative importance of urban expansion and infrastructure is largest in the post-transition phase. The total area deforested, however, is largest in the early-transition phase and is driven by agriculture expansion (figure 6(B)). This is in line with the FT model, where forest area change rates level off toward the later transition stages, and so total deforested area decreases as well. Intensification of agriculture and urbanization is expected in the course of economic development and decelerating deforestation, that generally accompanies the FT model (Mustard *et al* 2004, De Fries *et al* 2004). Mining seems to play an important role in deforestation in the pre-transition phase, but this is likely due to the presence of some resource-rich countries with large remaining forest cover in this phase (e.g. Guyana, Democratic Republic of the Congo).

Regarding degradation (figure 6(C)), the relative degraded area caused by timber and logging activities is most pronounced in all phases but decreases in the late-transition phase. In the late-transition phase, fuelwood and charcoal as well as uncontrolled fires are much more prominent. This can be attributed to the fact the forest timber resources maybe largely exploited in the late transition and the remaining forest area receives increasing pressure for wood fuel, in particular in many African woodland countries that are in the late-transition phase. In the post-transition phase, economic development will likely cause a decline in fuelwood collection and charcoal production as other energy sources become available, and timber extraction is usually better managed in this phase, which will cause a decline in the prevalence of fires.

3.4. Considerations and estimations for countries without driver data

Overall, the patterns of deforestation drivers are quite similar in Africa and Asia, while degradation patterns are more similar in Latin America and Asia (figure 5). Building upon this relationship and the usefulness of the continent and FT model proxies, the study has derived estimates for situations where currently limited country data have been reported, in particular for post-transition countries in Africa and Latin America, and the pre-transition countries in Asia. This provides an approach for incorporating all countries and can provide useful best current estimates for global policy development. The aim of the results presented in table 6 is to estimate the importance of deforestation and degradation drivers, based on currently available data, for all 100 countries and thus to provide a pan-tropical assessment. It also highlights some of the remaining data gaps (estimates with an annotation, see table 6) that will be potentially filled as countries progress in the REDD+ readiness phase. Table 5 in the methodology section indicates the procedures followed for annotated estimates with no or limited data availability.

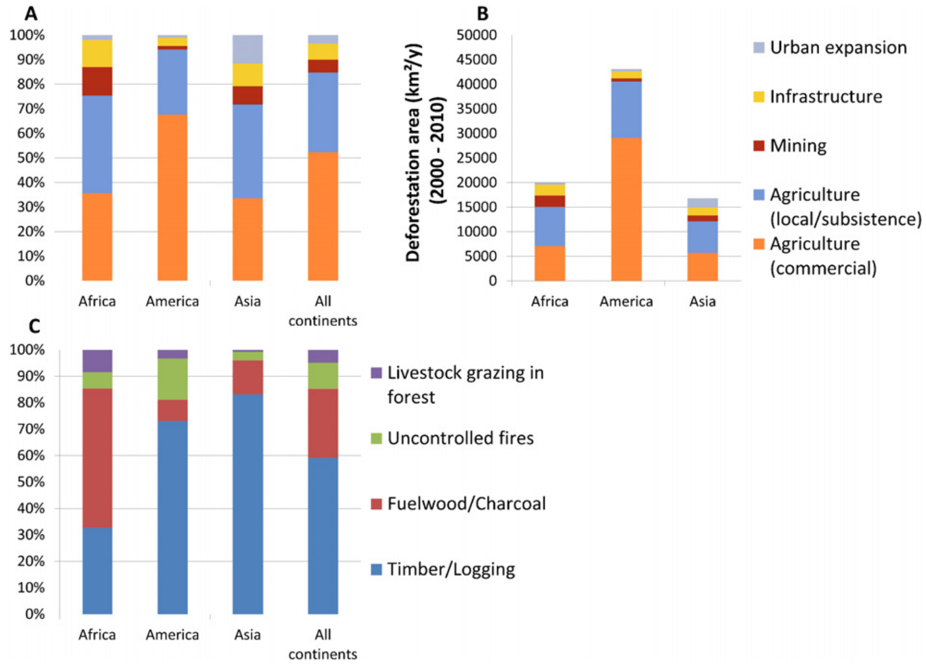

Figure 5. Continental-level estimations of the relative area proportion (A) and absolute net forest area change ($km^2\ yr^{-1}$; FAO 2010) for the period 2000–10 (B) of deforestation drivers; and of the relative disturbed forest area fraction of degradation drivers (C), based on data from 46 tropical and sub-tropical countries.

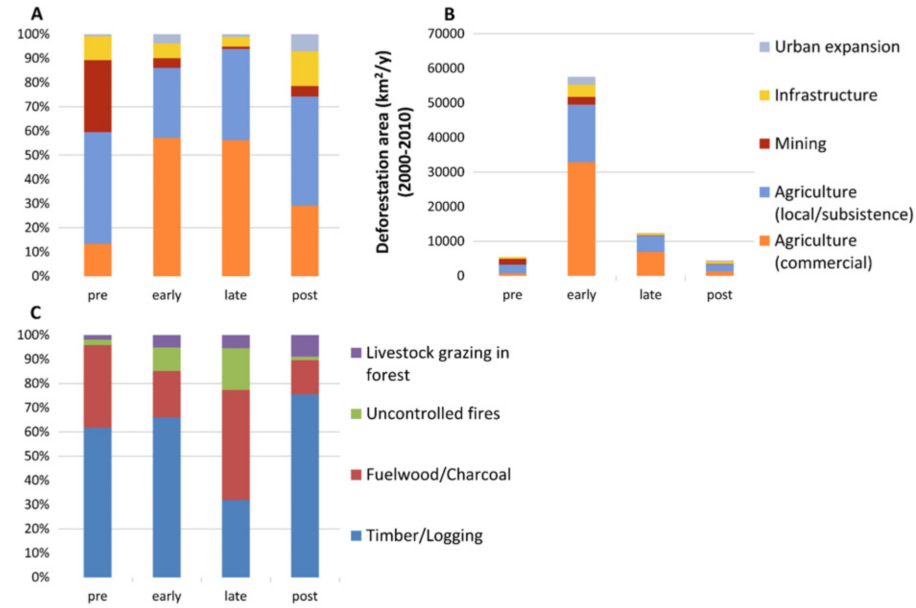

Figure 6. Forest transition phase estimations of the relative area proportion (A), and absolute net forest area change ($km^2\ yr^{-1}$; FAO 2010) for the period 2000–10 (B) of deforestation drivers, and of the relative disturbed forest area fraction of degradation drivers (C), based on data from 46 tropical and sub-tropical countries.

4. Discussion and conclusion

The study analyzed national data from 46 tropical and sub-tropical countries (reflecting ~78% of the forest areas, and 81% of forest loss (in 2000–10) of all 100 tropical and sub-tropical countries, see the appendix) on drivers of deforestation and forest degradation that have been provided as part of REDD+ readiness documents and activities. Data on the drivers have been derived from national-level data, but, given the variability and different levels of confidence for these data, the analysis presented here uses aggregate averages with FT phases and continents as a

Table 6. Estimates of the fraction of deforestation and forest degradation attributable to each driver for 100 countries for each FT phase and continent. Estimates marked with an annotation have been derived using the procedures described in section 2.4.

Country		Deforestation causes					Degradation causes			
		Agriculture (commercial)	Agriculture (local/ subsistence)	Mining	Infrastructure	Urban expansion	Timber/ logging	Fuelwood/ charcoal	Uncontrolled fires	Livestock grazing in forest
Africa	Pre	0.08	0.33	0.27	0.12	0.19	0.67	0.33	0.00	0.00
	Early	0.32	0.42	0.12	0.09	0.05	0.31	0.49	0.08	0.12
	Late	0.72	0.10	0.02	0.15	0.02	0.33	0.58	0.00	0.08
	Post	0.48[c]	0.36[c]	0.07[c]	0.09[c]	0.00[c]	0.67[d]	0.19[d]	0.03[d]	0.11[d]
Latin America	Pre	0.31	0.26	0.33	0.11	0.00	0.44	0.34	0.16	0.06
	Early	0.58	0.33	0.01	0.09	0.00	0.47	0.31	0.22	0.00
	Late	0.50	0.32	0.05	0.00	0.13	0.45	0.17	0.22	0.17
	Post	0.67[b]	0.17[b]	0.00[b]	0.00[b]	0.17[b]	0.67[a]	0.19[a]	0.03[a]	0.11[a]
Asia (incl. Oceania)	Pre	0.08[c]	0.33[c]	0.27[c]	0.12[c]	0.19[c]	0.44[c]	0.34[c]	0.16[c]	0.06[c]
	Early	0.33	0.32	0.10	0.13	0.12	0.90	0.06	0.05	0.00
	Late	0.11	0.56	0.00	0.17	0.17	0.63	0.30	0.00	0.07
	Post	0.48	0.36	0.07	0.09	0.00	0.85	0.10	0.01	0.04

proxy. As the need to report on drivers of deforestation and degradation is a new requirement for developing countries, the quality of the country data varies. Thus, the presented results are only based on aggregated data that allow for a pan-tropical assessment of the importance of different drivers, stratified by phases of the forest transition model and by continent.

The results highlight that commercial agriculture is the most prevalent deforestation driver, accounting for 40% of deforestation and most prominent in the early-transition phase. The other important land use is local/subsistence agriculture, which is related to 33% of deforestation. Other drivers are of less importance, with mining accounting for 7%, infrastructure for 10% and urban expansion for 10% of the total. Thus, according to this study, agriculture alone causes 73% of all deforestation, which is in line with findings of Geist and Lambin (2002). The importance of deforestation drivers varies for the different FT phases and for different continents. For decades the common view was that growing populations of shifting cultivators and smallholders were the main driver of forest changes. More recently, it has been argued that commercial actors play an increasingly larger role in the expansion of agriculture into the forest (Geist and Lambin 2002). This seems at least to be valid for the Amazon region and Southeast Asia. Here agribusinesses, producing for international markets (cattle ranching, soybean farming and oil palm plantations), were identified as main drivers of post-1990 deforestation (Rudel *et al* 2009, Boucher *et al* 2011). Looking at the development of deforestation drivers through time (figure 6) the contribution of commercial agriculture increases. Currently, deforestation in Africa is still largely driven by small-scale subsistence activities (De Fries *et al* 2010, Fisher 2010), but this might change in the coming years. While the four African countries with the largest forest areas (Democratic Republic of the Congo, Angola, Zambia and Mozambique) (FAO 2011) are still in the pre- and early-transition phase, forest loss rates and the influence of commercial globalized agriculture are expected to increase, as these countries move to the next phase.

Regarding forest degradation, timber extraction and logging are related to about 52%, fuelwood collection and charcoal production 31%, uncontrolled fire 9% and livestock grazing 7% of forest degradation. The most prominent degradation driver for the Latin American and Asian continents is timber extraction and logging (>70%). Fuelwood collection and charcoal is the main degradation driver for the African continent (48%). This emphasizes that local small-scale activities (fuelwood collection, charcoal production and livestock grazing in forests) are the most relevant in large parts of Africa, while in the majority of the other country cases forest degradation is dominated by commercial wood extraction. The importance of the fuelwood/charcoal driver decreases in the post-transition phase. This can be explained by urbanization tied to economic development, and a progressing reliance on other energy resources. Commercial timber and logging activities on the other hand become more important in the post-transition phase.

The results presented here offer a first synthesis of REDD+ driven national-level data reported by countries on forest change, supported by data from other sources, to generate new understanding for national estimates of drivers of forest loss and degradation. It highlights that the availability of quantitative data on drivers is variable and still uncertain in many countries' cases, with only 12 of 100 countries being able to provide quantitative data, also highlighting the current limitations and data gaps. This study used national estimates of forest loss based on the FAO Forest Resource Assessment (FAO 2010). However, other data sources are available, such as the remote sensing based estimates of Hansen *et al* (2010), which might divert from the FAO estimates. One avenue of further research is assessing the sensitivity of driver estimation to uncertainties related to these different datasets. In addition, within the REDD+ context, the national driver data should ultimately be linked to emissions. In a recent study by Houghton (2012), emission factors are linked to specific drivers, and this can be used as a starting point for further research on national emissions categorized by drivers.

Thus, this study focus on a larger area synthesis and also provided first coarse estimates using the continent and FT model as a proxy in countries where no data have been available so far: mainly to support current global policy synthesis. While the UNFCCC (2010) encourages countries to further identify and describe REDD+ activities and drivers, it is expected that such national data will improve over time. In particular, the increasing use of satellite remote sensing tools for national monitoring will be a key data source that will allow for a better national-level tracking of deforestation and forest degradation events and types, and the activities that cause them (Hansen *et al* 2010, Gibbs *et al* 2010).

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Appendix

Table A.1. Database of categorization and data sources for 100 tropical non-Annex I countries. (Note. Data sources written in italics were available but not used due to the coarser data scales. R-PIN: a Readiness Plan Idea Note is a report for the REDD+ financing mechanism of the Forest Carbon Partnership Facility (FCPF). R-PP: a Readiness Preparation Proposal is a report which the selected countries have to prepare as a follow up to the R-PIN (http://forestcarbonpartnership.org/fcp/). CIFOR: country profile report focused on socio-economic context of REDD, by Center for International Forestry Research (CIFOR). Matthews *et al*: country analysis of deforestation and forest degradation drivers by Department of Energy and Climate Change (DECC) of UK government (Matthews *et al* 2010). NC: National communication to the UNFCCC.

Country	Continent	Forest transition phase	Data source	Scale of data source
Angola	Africa	Phase 2 (early transition)	Matthews *et al*	Nominal
Antigua and Barbuda	America	Phase 3 (late transition)	—	—
Argentina	America	Phase 3 (late transition)	R-PP Matthews *et al*	Ratio
Bahamas	America	Phase 1 (pre-transition)	—	—
Bangladesh	Asia	Phase 3 (late transition)	—	—
Belize	America	Phase 2 (early transition)	—	—
Benin	Africa	Phase 3 (late transition)	—	—
Bhutan	Asia	Phase 1 (pre-transition)	—	—
Bolivia	America	Phase 2 (early transition)	R-PIN CIFOR (*Matthews et al*)	Ratio
Botswana	Africa	Phase 2 (early transition)	—	—
Brazil	America	Phase 2 (early transition)	NC Mongabay (*Matthews et al*) *CIFOR*	Ratio
Burkina Faso	Africa	Phase 2 (early transition)	—	—
Burundi	Africa	Phase 3 (late transition)	—	—
Cambodia	Asia	Phase 2 (early transition)	R-PP Matthews *et al*	Ordinal
Cameroon	Africa	Phase 2 (early transition)	CIFOR Mongabay (*R-PIN*) (*Matthews et al*)	Ratio
Cape Verde	Africa	Phase 4 (post-transition)	—	—
Central African Republic	Africa	Phase 2 (early transition)	R-PP	Ordinal
Chad	Africa	Phase 3 (late transition)	—	—
Chile	America	Phase 4 (post-transition)	R-PIN	Nominal
China	Asia	Phase 4 (post-transition)	—	—
Colombia	America	Phase 1 (pre-transition)	R-PP	Ratio
Comoros	Africa	Phase 3 (late transition)	—	—
Congo	Africa	Phase 1 (pre-transition)	R-PP	Ordinal
Costa Rica	America	Phase 4 (post-transition)	R-PP	Nominal
Cote d'Ivoire	Africa	Phase 4 (post-transition)	—	—
Cuba	America	Phase 4 (post-transition)	—	—
Democratic Republic of the Congo	Africa	Phase 1 (pre-transition)	R-PP Matthews *et al*	Ordinal
Dominica	America	Phase 3 (late transition)	—	—
Dominican Republic	America	Phase 3 (late transition)	—	—
Ecuador	America	Phase 2 (early transition)	Matthews *et al*	Nominal

Table A.1. (Continued.)

Country	Continent	Forest transition phase	Data source	Scale of data source
El Salvador	America	Phase 3 (late transition)	R-PIN	Ordinal
Equatorial Guinea	Africa	Phase 2 (early transition)	R-PIN	Ordinal
Eritrea	Africa	Phase 3 (late transition)	—	—
Ethiopia	Africa	Phase 3 (late transition)	R-PP Matthews *et al*	Nominal
Fiji	Asia	Phase 2 (early transition)	Carbon Partnership	Ordinal
Gabon	Africa	Phase 1 (pre-transition)	R-PP (*Matthews et al*)	Nominal
Gambia	Africa	Phase 4 (post-transition)	—	—
Ghana	Africa	Phase 3 (late transition)	R-PP	Ratio
Guatemala	America	Phase 2 (early transition)	R-PP	Nominal
Guinea	Africa	Phase 2 (early transition)	—	—
Guinea-Bissau	Africa	Phase 2 (early transition)	—	—
Guyana	America	Phase 1 (pre-transition)	R-PP Interim report	Ratio
Haiti	America	Phase 3 (late transition)	—	—
Honduras	America	Phase 3 (late transition)	R-PIN	Nominal
India	Asia	Phase 4 (post-transition)	—	—
Indonesia	Asia	Phase 2 (early transition)	CIFOR R-PP NC (*Mongabay*) (*Matthews et al*)	Ratio
Jamaica	America	Phase 2 (early transition)	—	—
Kenya	Africa	Phase 3 (late transition)	R-PP	Nominal
Lesotho	Africa	Phase 4 (post-transition)	—	—
Lao People's Democratic Republic	Asia	Phase 2 (early transition)	R-PP Matthews *et al*	Nominal
Liberia	Africa	Phase 2 (early transition)	R-PP	Ordinal
Madagascar	Africa	Phase 2 (early transition)	R-PP Matthews *et al*	Nominal
Malawi	Africa	Phase 2 (early transition)	—	—
Malaysia	Asia	Phase 2 (early transition)	Matthews *et al*	Ratio
Mali	Africa	Phase 3 (late transition)	—	—
Mauritania	Africa	Phase 3 (late transition)	—	—
Mauritius	Africa	Phase 2 (early transition)	—	—
Mexico	America	Phase 3 (late transition)	R-PP Matthews *et al*	Ratio
Micronesia (Federated States of)	Asia	Phase 1 (pre-transition)	—	—
Mozambique	Africa	Phase 2 (early transition)	R-PIN	Nominal
Myanmar	Asia	Phase 3 (late transition)	Matthews *et al*	Ordinal
Namibia	Africa	Phase 3 (late transition)	—	
Nepal	Asia	Phase 3 (late transition)	R-PP Matthews *et al*	Nominal
Nicaragua	America	Phase 2 (early transition)	R-PIN	Nominal
Niger	Africa	Phase 3 (late transition)	—	—
Nigeria	Africa	Phase 3 (late transition)	—	—
Pakistan	Asia	Phase 3 (late transition)	—	—
Palau	Asia	Phase 1 (pre-transition)	—	—
Panama	America	Phase 3 (late transition)	R-PP	Nominal
Papua New Guinea	Asia	Phase 2 (early transition)	R-PP Matthews *et al*	Ratio
Paraguay	America	Phase 2 (early transition)	R-PIN	Nominal
Peru	America	Phase 1 (pre-transition)	R-PP Matthews *et al*	Ordinal
Philippines	Asia	Phase 4 (post-transition)	Matthews *et al*	Ordinal
Rwanda	Africa	Phase 4 (post-transition)	—	—
Saint Lucia	America	Phase 1 (pre-transition)	—	—
Saint Vincent and the Grenadines	America	Phase 2 (early transition)	—	—
Samoa	Asia	Phase 1 (pre-transition)	—	—
Sao Tome and Principe	Africa	Phase 3 (late transition)	—	—
Senegal	Africa	Phase 2 (early transition)	—	—
Sierra Leone	Africa	Phase 2 (early transition)	—	—
Singapore	Asia	Phase 3 (late transition)	—	—
Solomon Islands	Asia	Phase 2 (early transition)	—	—

Table A.1. (Continued.)

Country	Continent	Forest transition phase	Data source	Scale of data source
Somalia	Africa	Phase 3 (late transition)	—	—
South Africa	Africa	Phase 3 (late transition)	—	—
Sri Lanka	Asia	Phase 2 (early transition)	—	—
Sudan	Africa	Phase 3 (late transition)	Matthews *et al*	Nominal
Surinam	America	Phase 1 (pre-transition)	R-PP	Nominal
Swaziland	Africa	Phase 4 (post-transition)	—	—
Tanzania	Africa	Phase 2 (early transition)	R-PP Matthews *et al*	Ordinal
Thailand	Asia	Phase 4 (post-transition)	R-PIN Matthews *et al*	Ordinal
Timor-Leste	Asia	Phase 2 (early transition)	—	—
Togo	Africa	Phase 3 (late transition)	—	—
Trinidad and Tobago	America	Phase 2 (early transition)	—	—
Uganda	Africa	Phase 2 (early transition)	R-PP Matthews *et al*	Ordinal
Uruguay	Africa	Phase 4 (post-transition)	—	—
Vanuatu	Asia	Phase 3 (late transition)	R-PIN	Nominal
Venezuela	America	Phase 2 (early transition)	—	—
Vietnam	Asia	Phase 4 (post-transition)	CIFOR R-PP (*Matthews et al*)	Ratio
Zambia	Africa	Phase 2 (early transition)	Matthews *et al*	Nominal
Zimbabwe	Africa	Phase 2 (early transition)	—	—

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