



The impact of forest management plans on trees and carbon: Modeling a decade of harvesting data in Cameroon



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ABSTRACT

By 2010, about 25% (180 million ha) of The International Tropical Timber Organization (ITTO) producer countries' permanent forest estate was being managed using an approved forest management plan (FMP). While the existence of a FMP is often used as evidence of sustainable forest management (SFM), State officials mandated to monitor and verify FMPs' implementation often lack the technical knowledge and political incentives to assess the changes that have been introduced, notably in terms of harvested volumes and species. Among tropical timber producers, Cameroon is considered to be exemplary for its progressive forest regulatory framework. Here we aim to estimate for the first time in sub-Saharan Africa the causal impact of the implementation of FMPs on harvested volumes, species and carbon stocks. We do so by using a 12-year (1998–2009) unbalanced longitudinal data set of a detailed, official harvesting inventory of 81 concessions in Cameroon. Results provide evidence to the theoretical expectations that for many years many practitioners have had on the implementation of SFM, i.e. that FMPs show a substantial opportunity to reduce carbon emissions from forest while presenting logging companies with acceptable financial trade-offs. We explore the technical and political reasons for our findings and conclude that these analyses are important for countries that are underwriting carbon-related schemes in which they propose to reduce their emissions through the effective implementation of SFM. We also demonstrate that producer countries do record useful information that, when effectively used, can help them to inform their policies and improve their sustainable development strategies.

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Introduction

In the Congo Basin over the last two decades, the concept of sustainable forest management (SFM) permeated both the spirit and the letter of the new forest policies and related regulations enacted by national governments across the region (Assembe Mvondo, 2009; de Wasseige et al., 2014). In 1994, the Government of Cameroon was the first to adopt a new forest law based on the principles of the 1992 Earth Summit, in which economic, environmental and social criteria play a pivotal role (Republic of Cameroon, 1994; Karsenty, 2006). It was later followed by the Republic of Congo

(R epublique du Congo, 2000), Gabon (R epublique Gabonaise, 2001), the Democratic Republic of Congo (R epublique D emocratique du Congo, 2002), and the Central African Republic (R epublique Centrafricaine, 2008), which all adopted similar principles, especially with regard to the industrial, large-scale, export-oriented forest sector based on a concessionary regime largely inherited from the colonial past.

To implement SFM, the forest laws mandate the preparation of forest management plans (FMPs) in all forest concessions. FMPs must ensure the sustained production of forest goods and services, without endangering the intrinsic values and the future productivity of the forest, or creating unwanted effects on the physical and social environment within and around the concessions (art.23, Republic of Cameroon, 1994). In theory, FMPs are documents in which the potentialities of the resource are evaluated, the trade-offs

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among the ecological, economic and social aspects of management are assessed, and balanced solutions are proposed.

In practice, such a balance has been difficult to reach. The 1994 law and follow-up regulations state that the development of FMPs is a prerogative of the State (Republic of Cameroon, 1995). However, lack of human and financial resources within the ministry – and possibly weak incentives to resist the historically powerful lobby of the forest industrial sector – led the Cameroonian Government (similar to all the other governments in the region) to delegate the preparation and implementation of FMPs to logging companies: after allocation, the winning company can immediately start harvesting but it has an obligation to prepare a FMP within a maximum period of 3 years. The FMP is then sent to the ministry, who should assess the plan's quality and either approve it or send it back to the company with a request to review and resubmit it. The logical consequence of such responsibility being left with logging companies, coupled with the historical weak analytical and monitoring capacities within the ministry, has been that the former's economic interests, especially those linked to timber production, have always played a preeminent – and *de facto* largely unchecked – role on management decisions as compared to social or environmental ones.

Since the end of the 1990s, when the first FMPs were being prepared by logging companies in newly attributed concessions, many have lauded the efforts made by the Cameroonian Government toward the implementation of SFM (e.g. IFIA, 2006; ITTO, 2006). Indeed, over the years, the growing number of approved FMPs has often been used as a proxy for improved management (COMIFAC, 2004; CBFP, 2006; GTZ and MINFOF, 2006).

Timber harvesting in logging concessions has provided the Government of Cameroon with continuous and valuable economic benefits (Cerutti et al., 2016a), including about €62 million annually entering the State's coffers as taxes and about 23,000 direct and formal jobs (Cerutti et al., 2016b). Recent data also suggest that harvesting in concessions has not contributed significantly to increasing deforestation (Bruggeman et al., 2014; de Wasseige et al., 2014), notably because infrastructural development – e.g. roads – remains low, and logging is very selective, focused on a handful of valuable species. Concerns remain, however, about the impacts on biodiversity (e.g. Karsenty and Gourlet-Fleury, 2006; Abernethy et al., 2013), the capacity to reduce long-term deforestation trends (Brandt et al., 2016; Karsenty et al., 2016), as well as about the potential of logging operations, even when conducted through FMPs, to improve the livelihoods and more generally the social conditions of the populations living within and around logging concessions (e.g. Vandenhoute and Doucet, 2006; Samyn et al., 2011; Medjibe et al., 2013; Cerutti et al., 2014).

Notwithstanding these latter caveats, FMPs are still one of the most important practical and necessary indicators used to measure progress toward the adoption of SFM. For instance, many plans require logging companies not only to carry out the standard silvicultural procedures (such as forest inventories), but also require social and community involvement and the mapping of various types of protected forests within the concession area (FAO, 2015). Yet, in addition to the existence and official approval of a growing number of FMPs, it is also necessary to understand in more detail their impact on the ground.

Indeed, in times where tropical timber producing countries are increasingly requested to establish and monitor baselines on their deforestation and forest degradation rates and report those to international conventions (e.g. UNFCCC, UNCBD), FMPs should start to be assessed for the impacts they have on forest resources and carbon stocks. In this paper, we thus test the hypothesis that the implementation of FMPs in the Congo basin leads to more trees left standing and thus to increased carbon stocks as compared to a situation without FMPs. We focus here on forest stands, timber and carbon,

but are aware that the impacts on residual stands and timber harvesting are but one of the many parameters that must be assessed, such as social demands, livelihoods, tenure and resource rights, non-timber forest products (NTFPs), wildlife, biodiversity, etc.

Our objective is to quantitatively assess the causal impact of FMPs on harvesting levels by applying a standard difference-in-difference model, which uses a fixed effect estimation method, to a longitudinal data set with a reduced form econometric model. We then use the results to deduce the impacts in terms of carbon sequestered. The analysis focuses on Cameroon because, among the countries of the Congo Basin, it has the oldest legal framework mandating FMPs and thus a relatively longer time available to observe their effects. Logging concessions in Cameroon started to be auctioned in 2000. Subsequent auctions took place from 2001 to 2013. By 2015, all available concessions had been granted at least once. The first management plans were approved by the ministry in 2004 and, as of 2015, the country had about 6.2 million ha of forest allocated into 90 concessions (each concession averages about 68,000 ha) and 67 of them (about 5.5 million ha, or 74% of existing concessions) were operating under an approved FMP (Cerutti et al., 2014; MINFOF, 2015). In comparison, the Republic of Congo and Gabon currently have about 13% and 31% of active concessions managed by approved plans, respectively, and the Democratic Republic of the Congo only recently approved the first management plans (Cerutti et al., 2016b). Our aim is thus also to derive policy recommendations that could be applied beyond Cameroon and to the region's future forest policies, especially to those countries that are seemingly still experiencing difficulties in extending FMPs to all their production forests.

To the best of our knowledge, no similar quantitative impact evaluation has been carried out for two main reasons. First, official harvesting data are difficult to obtain from both governments and private logging companies. Second, as they are rarely controlled and analyzed, they often present major inconsistencies that make assessments difficult to perform. To overcome these constraints, the data used in this paper are derived from ongoing efforts over a period of a decade working in collaboration with the Cameroonian Government, as well as regular annual checks with logging companies, to detect whether major discrepancies exist between official data from the government and original data provided by logging companies.

Methodology

Data collection and validation

Harvesting data were provided by the ministry on an annual basis between 1998 and 2009. The data cover all 81 logging concessions that were operational in the country over that period. Data were generally presented in tabular format, per concession, company and species. For harvested species, both the number of trees and volumes – as declared to MINFOF – were collected.¹ Several controls were regularly used to check for possible mistakes e.g. year-on-year controls, to check for large, unexplained variations in harvesting in concessions, as well as the volume/number of trees ratios.

Where controls indicated the presence of possible mistakes, three further controls were applied. First, the original declarations

¹ In theory, for the purposes of paying the stumpage fee on the total harvested volumes, logging companies should declare on the official forms (called DF10 in Cameroon) the total volume of the felled tree (volume *abattu*). It is standard practice, however, to declare on the DF10 only the volumes that are eventually taken out of the forest (volume *roulé*). Logging companies do this in order to pay for stumpage and other fees of only the timber that is actually processed; this is tolerated by the administration.

provided by logging companies to the ministry were located, where possible. Declarations are usually provided by logging companies in paper format to the decentralized offices of the ministry before being centralized in the capital city, Yaoundé. For various reasons, it sometimes happens that declarations are not entirely or timely registered at the central level. However, original paper copies remains scattered among several offices of the ministry. These copies were searched for where possible.

Second, where original copies could not be found in the ministry, logging companies were contacted and asked if they were willing to provide their original harvesting declarations. Only in three instances over four years, a concerned company could not find the original declaration. In those cases, their records were not considered for the analysis in the missing years.

Third, the ministry and companies' declarations were compared with volumes declared at the Ministry of Finance for tax purposes, notably stumpage fees. The Ministry of Finance rarely recorded the number of harvested trees, thus volumes were used instead. In the case of discrepancies, the ministry or companies were asked again whether they could locate the origin of such discrepancies.

Finally, data were assessed by considering the number and volume of: (i) all harvested timber species, and (ii) the five most harvested timber species per company. This was done because previous analyses have shown that most companies focus their harvesting on a small number of species (Cerutti et al., 2008), so we wanted to test whether the implementation of management plans had different impacts on the most harvested timber species compared to the entire harvested volumes. When all logging concessions were grouped together over a decade, the top five harvested species covered 83% of total production, confirming that harvesting remains very selective, and they were: *ayous* (*Triplochytton scleroxyton*, 41%), *sapelli* (*Entandrophragma cylindricum*, 26%), *tali* (*Erythroleum ivorense*, 8%), *azobé* (*Lophira alata*, 5%) and *fraké* (*Terminalia superba*, 4%).

A similar procedure has been used to find annual harvesting areas (or annual allowable cut, [AAC], in hectares). In general, the ministry publishes AACs on an annual basis, but it is sometimes unclear whether the declared trees and volumes refer to the annual AAC or to AACs spanning two years. This may lead to mistakes in calculation of the harvested trees and volumes per hectare per year. In effect, companies are legally authorized to use a single AAC for a maximum period of two years. In other words, if the authorized volumes in year X have not been entirely harvested, companies may be required to keep harvesting the same area in year X + 1. In parallel, they may start harvesting the new AAC granted in year X + 1. Controls of original documents and clarifications with logging companies helped to solve those cases where values – after a manual check – were found to be different from the previous or from following years.

In total, the resulting data set consists of 619 coupled concession-year lines, spanning from harvesting year 1998/1999 to 2009, covering about 1.8 million hectares of AAC ($n = 578$) and a total production of about 15 million cubic meters. The number of considered AAC ($n = 578$) is lower than the coupled concession-year lines because only complete lines were used in the calculations, i.e. those for which the number of trees, the volumes and the AAC were present (see Table 1). Despite our best efforts, the longitudinal data are unbalanced, with data from the 1998–2000 harvest largely missing. Therefore, we mainly rely on data from 2001 onwards in the analysis below.

The model

To estimate the outcomes of concession, we applied a standard difference-in-differences model that uses a fixed effect estimation

Table 1

Summary statistics of the total and the five most harvested timber species in 81 logging concession considered for this study (managed and non-managed) in Cameroon.

	Mean	Std dev	N
Area (ha)	3031.3	1468.7	507
<i>Total harvest</i>			
Trees harvested	2351.4	1503.5	463
Volume harvested (m ³)	29,955.3	20,580.4	465
Volume per ha harvested	10.4	6.4	465
<i>Five most harvested species</i>			
Trees harvested	1991.4	1343.2	414
Volume harvested (m ³)	26,120.6	19,357.2	416
Volume per ha harvested	9.1	6.2	416

method to the longitudinal data set with a reduced form econometric model:

$$y_{it} = \alpha + \beta FMP_{it} + \gamma_i + \eta_t + \varepsilon_{it} \quad (1)$$

where y_{it} is outcomes of concession i in year t . In other words, we compared what happens to several variables linked to harvesting activities, after the introduction of FMPs. To do so, our difference-in-differences model compares trends both between FMUs (those with and without FMPs) and within FMUs (before and after a particular FMU had an FMP).

In this paper, we use seven outcome variables: area harvested (hectare), number of trees harvested (total and five most harvested species), total volume harvested (total and five most harvested species, in m³), and volume per hectare harvested (total and five most harvested species, in m³/ha). Meanwhile, FMP_{it} is a dummy variable that is equal to one if concession i has an approved forest management plan in year t , and zero otherwise. Finally, γ_i is concession fixed effect, η_t is year fixed effects, and ε_{it} is the error term.

The model in Eq. (1) is a fixed effects model that takes advantage of the longitudinal data set. It controls for time-invariant unobserved heterogeneity and time trends, which could cause biased estimates. The first forest management plan was approved and became operational in 2004. Assuming common trends between concessions that have a management plan and those that do not, the estimated coefficient β is the causal impact of the forest management plan on the outcome variables.

We used the reduced form model to test the common trends assumption:

$$y_{it} = \alpha + \beta FMP_i + \eta_t + \sum_{t=2002}^{t=2003} \delta_{it}(FMP_i \times \eta_t) + \varepsilon_{it} \quad (2)$$

where y_{it} and η_t are the same as in Eq. (1), and FMP_i is equal to 1 if concession i eventually has an approved management plan in the data set, and zero otherwise. Meanwhile, $FMP_i \times \eta_t$ is the interaction term. In this model, estimated coefficients $\hat{\beta}$, $\hat{\eta}_{2002}$ and $\hat{\eta}_{2003}$ show the differences in timber harvests between the *eventually treated* concessions and the *never treated* concessions. If these variables are not significantly different from zero, then there is no evidence of the common trends assumption being violated.

Before presenting the results, it is important to mention that there might exist relevant time-variant factors that could affect managed and non-managed concessions differently and that, if included as controls in the model, could improve its outputs. It is possible, for example, that precipitation, accessibility, timber prices, or population dynamics, could impact managed and non-managed concessions in non-homogeneous ways. Because both managed and non-managed concessions (i) are scattered over the entire national territory, (ii) are largely served by the same main

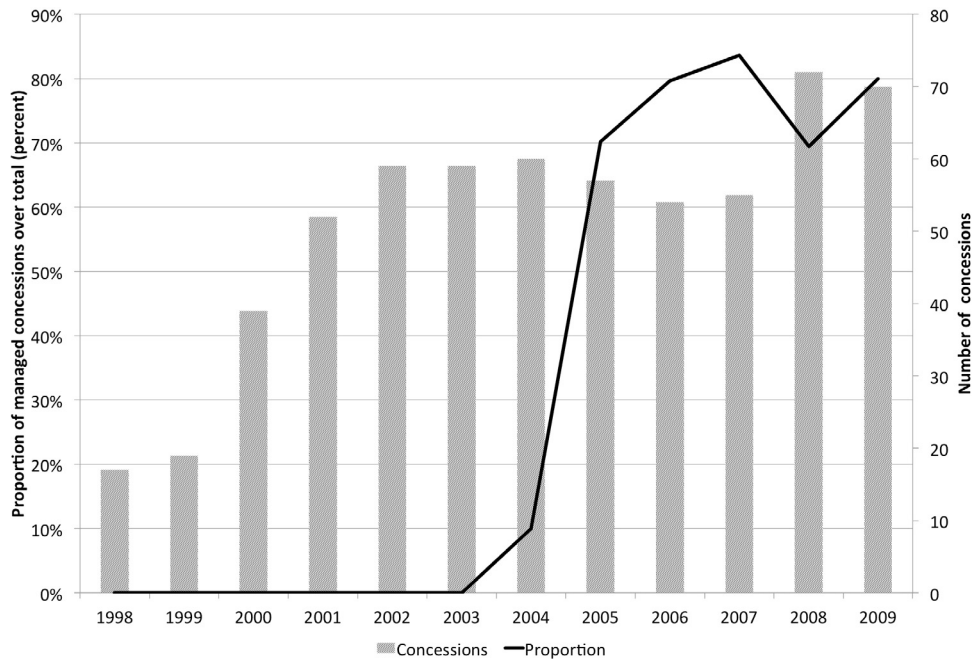


Fig. 1. Proportion of logging concessions with management plans and valid concessions (1998–2009).

roads along which villages neighboring both types of concessions are located, and (iii) serve similar consumer markets (e.g. Europe for sawn-wood and Asia for logs), we believe the differential impacts of these time-variant factors are unlikely to radically change the results presented below. Yet, as soon as more accurate data and information on those factors become available for each year and for each concession's specific annual harvesting area, and hopefully as transparency becomes a shared value among all logging companies, further research will have to be conducted that could improve our results.

Results

Summary statistics

Table 1 shows the summary statistics of the outcome variables. Fig. 1 shows the proportion of logging concessions with a forest management plan by year.

As said, the first forest management plan was approved and became operational in 2004, and by 2009 more than 80% of the attributed concessions considered for this analysis had an approved management plan (Fig. 1). The remaining 20% of attributed concessions were either in the 3-years period after attribution during which they should legally prepare the FMP, or their submitted FMPs were under review by the ministry.

Testing the common trends assumption

The key identifying assumption in our model, which will allow us to claim causality between the management plan and timber harvest, is common trends. The assumption is that without a management plan, the trend in timber harvests of the treated concessions – i.e. the treatment or concessions with management plans – will be similar to the trend in the control concessions – i.e. the control group or concessions without management plans.²

There is no formal test for the common trends assumption. Our approach to informally test the assumption is by comparing pre-2004 trends in timber harvests between the *eventually treated* concessions and the *never treated* concessions (Galvani et al., 2005). Specifically, we compare trends between 2001 and 2003. If the differences in timber harvests between these two groups are already statistically significant before any management plans came into effect, then it is likely that the common trends assumption has been violated.

Table 2 shows the estimation results. For all seven outcome variables, concessions that eventually obtained a management plan had a larger area and harvested more in 2001 (FMP line in Table 2). As said, auctions for logging concessions started in 2000. Hence, for the purpose of this analysis, 2001 could be considered a 'special' year because it was the first one in which formal concessions began operating under the prescriptions of the 1994 law, i.e. implementing large-scale harvesting. In practice, this could have meant that companies that planned to comply with the law (i.e. that planned to prepare a FMP) exploited a last window of opportunity and requested – and were indeed authorized by the ministry – larger harvesting areas and higher volumes than those forthcoming under the more stringent rules of the FMP. Such interpretation is also supported by the fact that the statistically significant difference found in 2001 disappeared in 2002 and 2003 for all outcome variables, with the exception of trees harvested in 2002, where concessions that eventually obtained a management plan (FMP × 2002 line in Table 2) had a statistically significant lower harvest. This difference, however, is reflected neither in the trees and volumes harvested among the top five species, which as said accounted for the vast majority of the production, nor in the other variables (volumes and areas) that account for all harvested species. Therefore, we can confidently assume that in the two years prior to the first management plan being approved, there were no significant differences in harvests and area between the eventually treated concessions

² The number of concessions in the treatment and control group changes over the years, as more FMPs are approved. These changes (i.e. variation) are used to measure

the impact of FMPs. Such logic may not hold if those changes were non-random, but from what we can tell from the data, they seem to be random.

Table 2
Summary statistics for the test conducted on the common trend assumptions.

	Area	Trees harvested	Trees harvested – Top 5 species ^a	Volume harvested	Volume harvested – Top 5 species	Tree per hectare harvested	Tree per hectare harvested – Top 5 species	Volume per hectare harvested	Volume per hectare harvested – Top 5 species
	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se
FMP	802.174*** (270.646)	1012.256*** (308.063)	845.183*** (310.225)	13,161.89***	11,620.860***	0.224**	0.187*	3.204***	2.891**
2002	333.000 (290.145)	633.643** (283.324)	431.679 (332.077)	4290.943 (3657.490)	2727.589 (4232.091)	0.206 (0.142)	0.153 (0.155)	1.388 (1.484)	1.671
2003	699.000* (405.674)	–180 (461.958)		–3168.617 (4319.473)		–0.083 (0.214)		–1.751 (1.794)	
FMP × 2002	–449.460 (330.478)	–809.711** (352.134)	–566.279 (373.929)	–4242.878 (4432.644)	–2379.033 (4778.577)	–0.264 (0.161)	–0.210 (0.167)	–1.569 (1.777)	–1.018 (1.890)
FMP × 2003	–782.957 (435.842) [†]	–336.058 (520.969)		–1296.187 (5234.370)		–0.079 (0.226)		0.220 (2.014)	
Constant	2376*** (184.642)	1646.5*** (184.208)	1432.75 (216.455)	18,753.1*** (1716.843)	16,334.91*** (2227.713)	0.642*** (0.075)	0.561*** (0.090)	7.317*** (0.718)	6.401*** (0.946)
Number of observations	160	153	104	153	104	153	104	153	104
R ²	0.021	0.042	0.016	0.044	0.024	0.038	0.010	0.040	0.014
F	2.790**	4.930***	2.590*	4.040***	3.530**	3.470***	1.170	2.980**	1.780

Notes: Standard errors in parentheses, clustered at concession level.

^a The top 5 species vary from one concession to another (see main text for the most harvested species for all concessions).

* .1.

** .05.

*** .01.

and never treated concessions. This is indirect evidence that the common trends assumption may be valid.

The impact of management plan on timber harvests

Table 3 shows the impact of management plan on harvests, using the model in Eq. (1).

Management plans reduced timber harvests by an average of 688 trees per concession, which translates to an average of 6453 m³ lower production per concession. This is an economically large impact, as it is equivalent to 0.46 and 0.3 standard deviations for trees and volume, respectively. When we examine the harvests of the five most harvested species, we find a statistically significant impact for management plans. On average, concessions with a management plan harvested 594 fewer trees among the top five species, equivalent to 5083 m³. Similar to its impact on total harvests, management plans also had an economically large impact on the top five species, by about 0.44 and 0.26 standard deviations, respectively for trees and volume.

Almost 80% of the concessions eventually received an approved forest management plan. As a robustness check, we remove the 20% of concessions that never had an approved management plan and re-estimated the results. This estimation therefore only relies on the variation in the year the concessions first received a management plan to identify the impact of management plan on timber harvests. The results (shown in Appendix A) are not statistically different from the results in Table 3.

The impact of management plan on the carbon sequestered: a conservative estimation

Here we use the estimated impacts of management plans on timber harvests to estimate the amount of carbon sequestered as a result of the lower harvests. Indeed, lower harvests are not the only variable affecting sustainability, and more research is needed to understand the multiple and complex relations that exist between harvesting levels and other characteristics at the stand level. Yet, harvesting levels can be a useful proxy for other important variables also affected by logging, such as species' regeneration and growth of economically valuable species. For example, there exists a linear relationship between the harvesting intensity and the amount of

damages to the residual stand, which translates in improved carbon sequestration (Nasi and Forni, 2006).

There are two major ways through which lower timber harvests lead to more biomass left standing and hence higher carbon sequestration. First, a lower harvest means more trees are left uncut. This is related not only to the lower amount of timber extracted from the forest and declared by logging companies, but also to: (i) the biomass that is normally abandoned in the forest because it is not economically viable for the logging companies (e.g. sections of the trunk that are of insufficient quality), (ii) branches and leaves, and (iii) belowground biomass (i.e. roots). Second, the impact of lower forest damage caused by the lower number of trees cut means less damage to surrounding vegetation, less secondary and tertiary logging roads built to reach the trees, etc.

Estimating the amount of carbon stored in the trees is a complex process. Without individual parameters on the harvested trees or the trees left standing, it is not possible to measure the exact amount of carbon that was left standing in the forest through the implementation of management plans. We therefore use indirect methods and err on the conservative side. The IPCC (2006) considers that the relationship between biomass and carbon is

$$C_w = 0.47 B_w$$

where C_w is carbon in wood and B_w is the biomass of the tree.

In order to obtain an estimate of the biomass (B_w), we use the impact estimates on volume per hectare harvested (Column 6, Table 3), -2.016 m³/ha, or -0.18 trees/ha. We assume average wood density of 640 kg/m³ (Djomo et al., 2010). Multiplying the two figures, we arrive at 1290 kg/ha of biomass, which is equivalent to 0.6 tC/ha.

Based on our data, the total annual allowable cut under management plan in Cameroon between 2004 and 2009 is 720,706 ha. Therefore, the amount of carbon stored (or rather left standing in the forest) as a result of lower harvest of economically viable timber (i.e. the portion of the resource that is eventually extracted and declared by the logging companies, and on which stumpage fees are paid) is 437,045 tons [metric tons] of carbon (tC) over the entire period (Table 4).

To estimate the amount of timber that is left in the forest after the trees have been felled, one needs to make several assumptions.

Table 3
Impact of management plans on harvest.

	Area	Trees harvested	Trees harvested – Top 5 species	Volume harvested	Volume harvested – Top 5 species	Volume per hectare harvested	Volume per hectare harvested – Top 5 species
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
FMP	119.375 (137.674)	–688.414** (295.591)	–593.641** (251.631)	–6452.988* (3391.682)	–5083.214* (2786.978)	–2.016* (1.115)	–1.870* (1.056)
Concession fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	506	463	414	465	416	465	416
R ²	0.630	0.572	0.622	0.637	0.686	0.499	0.569

Notes: Standard errors in parentheses, clustered at concession level.

* .1.
** .05.
***.01.

Table 4
Detail of results on living biomass left standing.

Living biomass left standing	tC
Lower timber harvest	437,045
Sections of the trunk normally abandoned in the forest	200,312
Branches and leaves	140,219
Belowground biomass (roots)	186,618
Lower forest damage	845,561
Total tC	1,809,756

For instance, high-value tree species that are used to produce sawn wood generally command higher recovery rates (i.e. timber extracted as logs over total trunk volume, up to the first big branch) than lower value tree species that are generally used to produce veneer and plywood. This is because the number of imperfections (e.g. bending, spots, holes, etc.) that may affect the latter species is higher than those that may affect the former species. Here we assumed a 50:50 ratio between sawn wood and veneer/plywood species and we applied a recovery rate of 80/20 (logs/waste) to sawn wood and of 60/40 to veneer/plywood (Durrieu de Madron et al., 1998). This leads to an estimate of 200,312 tC left standing.

Similarly, the literature provides standard ratios that could be applied to the estimate of the biomass of branches, leaves and roots. Here we applied an expansion factor for tropical moist forests from trunk to total aboveground biomass (branches and leaves) of 0.22 (Djomo et al., 2010), and from above to belowground biomass (roots) of 0.24 (IPCC, 2006; Durrieu de Madron et al., 2011). This leads to an estimate of 140,219 tC and 186,618 tC left standing, respectively.

In order to measure the damage ‘spared’ to the forest, we use (Durrieu de Madron et al., 2011) who suggest that (i) the damage caused by harvesting activities on the residual standing stock and harvesting waste is equal to 0.46 tC/m³, and (ii) for each harvested tree an harvesting track of about 200 m is built in the forest: each meter of such track (with an average width of 4.5 m) releases about 0.00683 tC. By using the impact estimates on volume per hectare harvested (Column 6, Table 3), –2.016 m³/ha, the damage ‘spared’ to the residual standing stock equals 0.93 tC/ha, or a total of 668,354 tC over the AACs of the managed concessions. Similarly, by using the total number of spared trees over the AACs of the managed concessions (0.18 tree/ha * 720,706 ha = 129,727 trees), we estimate the length of avoided harvesting road building at about 25,945 km, which translates into about 177,207 tC left standing. In summary, avoided damage adds up to about 845,561 tC.

Therefore, the impact of management plans in Cameroon between 2004 and 2009 in terms of carbon left standing as healthy, living trees is 1,809,756 tC (Table 4). If all concessions were managed according to a management plan, this would have resulted in about 591,000 tC left standing per year (assuming about

7 million ha of logging concessions were managed with FMPs). Similarly, assuming all current logging concessions in the Congo Basin (for a total area of about 49 million ha) were managed with an FMP, a total of about 4.1 million tC would be left standing each year when compared to standard harvesting.

Given the existing uncertainties in available public and large-scale data on carbon stocks and deforestation rates, particularly in the countries of the Congo basin, it is difficult to put our findings in context. Yet, for example, in its recently submitted Intended Nationally Determined Contribution (INDC), the Cameroonian government adopted a scenario of reference for 2010 of about 39 MtCO₂e of emissions (République du Cameroun, 2015). Hence, the adoption and implementation of FMPs could contribute a reduction of about 6% to the current total emissions of the country.³ Similarly, net deforestation across the Congo basin has recently been estimated at about 181,500 ha annually (Mayaux et al., 2013), which corresponds to an annual loss of about 123 MtCO₂e (using a conversion factor of about 185 tC/ha, as found by Nasi et al., 2009). Hence, the adoption and implementation of FMPs across the Congo basin could contribute to reduce current annual emissions by about 12%. Such values are of course only indicative and they can surely be improved with further research and better data. For instance, one underlying assumption in our calculations is that avoided carbon emissions through FMPs are permanent and perpetual. Although this can be considered a safe assumption on the short- to medium-term, notably given the systematic lower impacts and longer rotation cycles in managed concessions, further research is needed to better quantify and qualify what actually will happen in a second rotation cycle. Nonetheless, those values do highlight the importance of FMPs as a policy measure that could bear many fruits if coherently and broadly implemented and improved over time.

Discussion and conclusion

Forest management plans implemented in Cameroon between 2004 and 2009 have forced companies to reduce the number of trees and the volumes they harvest. This result, based on a novel analysis of a decade of harvesting inventory data, provides evidence to the theoretical expectations that many practitioners have had on the implementation – albeit still partial – of forest policies and of their effectiveness in the Congo basin (e.g. Durrieu de Madron et al., 2011).

³ We estimate that 590,855 tC are left standing. These correspond to about 2,168,439 tCO₂e, which can then be compared to the reference emissions level for Cameroon.

Changes in managed vs. non-managed concessions may be brought about by several factors related to the adoption and implementation of the relevant regulations aiming at sustainably managing the timber stocks. For example, the law mandates several formulae to be applied to calculate the minimum diameters at which species can be harvested sustainably (Lumet et al., 1993). For many species, the minimum diameters established after applying those formulae are higher than those applied for the same species in non-managed concessions. Companies are thus forced to apply larger harvesting diameters than would be the case without management plans (Fargeot et al., 2004; Durrieu de Madron et al., 2011), engendering a reduction in the annual harvestable volumes (Cerutti et al., 2008). In turn, a lower number of harvested trees means reduced damage to both the residual standing stock around the harvesting area (i.e. the logging gap that the tree would have made when harvested) and the vegetation between the nearest major logging road and the trees, which would have been cleared in order to reach and harvest the latter (Durrieu de Madron et al., 2011). Also, companies are mandated to protect and exclude from harvesting buffer zones around rivers and other sensitive areas, and designated high value conservation forests, which results in a further reduction in the harvestable area.

Not all managed concessions are the same though (Bayol and Borie, 2004). In particular, the reductions applied in each concession – albeit in theory linked to clear formulas to be applied – depend on the characteristics of the concession (e.g. the types of forests and the mix of species present) and, more importantly, on the negotiating power that each logging company has with respect to the relevant ministries. In fact, in an environment where transparency is not the norm and where such negotiations occur largely behind closed doors, several logging companies are still allowed to apply reductions below those mandated by the law (Cerutti et al., 2008). Yet, on average, results indicate that the trend has been a positive one, with rules on harvesting affecting more and more companies over the years, in terms of both the total harvest and the five most harvested species, compared to the same companies *before* the implementation of their FMP, and to companies with non-managed concessions. In other words, financial sustainability maintains a preponderant role in SFM, but the implementation of management plans has been effective in counteracting (at least partially) such financial pressures.

Results show that, on average, logging concessions with a management plan result in a larger number of standing trees than concessions without an active FMP, corroborating recent results in neighboring Congo (Medjibe et al., 2013). Therefore, FMPs show a substantial opportunity to reduce carbon emissions from forest while presenting logging companies with acceptable financial trade-offs.⁴ As such, FMPs become a very important policy tool that could help countries (in the Congo basin and beyond) to reach their emissions targets. Yet, results also indicate that the full implementation of FMPs, and the related potential to reduce carbon emissions, is a clear disincentive for logging companies with direct negative impacts on their profits. Such disincentive, we argue, could lead to sub-optimal results in terms of volumes harvested and the related reduction of carbon emissions, if all responsibilities to prepare and implement FMPs remain almost entirely in the hands of logging companies, with a very light government oversight or monitoring of pre- and post-harvesting operations.

Because of both the historical limitations in capacities and means within the ministry, the general weak governance in the forest sector (Cerutti et al., 2013), and the political power of logging companies, a complete overhaul of the current system is unlikely

to occur in the short-term. Also, the knowledge about the biology of many tropical timber species (notably about regeneration processes) is still limited and requires expensive research programs that most governments cannot afford (Hall et al., 2003; Fargeot et al., 2004; Karsenty and Gourlet-Fleury, 2006; Medjibe et al., 2014). Yet, the literature suggests several possible options that could allow governments – including those with limited resources – to be wiser in deciding management parameters that ensure species recovery over the long-term (Durrieu de Madron et al., 1998; Forni and Mbarga, 1998; Ntep, 2000; Jonkers and Foahom, 2004). Partial improvements could be within reach if the ministry assumed, for example, the role of preparing FMPs with a priority focus on the environmental impacts (e.g. harvesting diameters, rotation period, etc.), and only at a later stage (e.g. after the concessions have been granted) initiate discussions with logging companies and negotiate trade-offs between the outcomes expected by both parties through the implementation of FMPs. If similar solutions are not at least tested, the almost exclusive focus that logging companies naturally maintain on the maximization of financial returns risks hampering the environmental and social sustainability that must also be embedded in FMPs, and the benefits that forests could bring to the country and its population.

Notwithstanding the above limitations, overall Cameroon has shown that improvements are possible. And there are lessons to be learned from the Cameroonian experience that could apply to other countries in the Congo basin, still struggling to increase the percentage of logging concessions with FMPs. Overall, results indicate that a strong determination by the government can be effective in reducing the pressure on forests and in moving closer to more precautionary levels of harvesting, which could make logging concessions a longer commitment by the more serious logging companies. This is especially so when one considers that management decisions solely based on companies' financial concerns might not be in line with long-term considerations and sustainable use of the resource. Conversely, when such determination by governments is lacking, a crippled dual forest sector is allowed to develop. Companies that are not interested in SFM are allowed to continue business as usual, while companies willing to implement SFM prepare management plans but are under constant (financial) pressure to compete with the former group of companies, generally in an international market that does not yet reward SFM.

Lastly, data availability, checking and assessment could help countries to plan and manage their forests, by giving concerned ministries the capacity to plan ahead, react to market shocks, help companies when needed (possibly by also playing with costs and tax burdens) – or even sanctioning them when parameters are not in line with the expected values – and eventually better managing the overall forest sector. Yet, such analytical performances remain low on the list of priorities of the countries of the Congo Basin. More research and analyses are needed to improve our knowledge of the resource and the way it is managed and used. Also, future research should go beyond the impacts on timber and look at wider environmental, social or financial impacts. But such tasks could be rendered much easier, timely and useful if governments were to make better use of the knowledge they already have, as this article has shown.

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⁴ Four concessions were abandoned *after* the approval and implementation of the management plan, indicating a possible negative financial trade-off.

Appendix A. Robustness test, excluding never treated concessions.

	Area	Trees harvested	Trees harvested – Top 5 species	Volume harvested	Volume harvested – Top 5 species	Tree per hectare harvested	Tree per hectare harvested – Top 5 species	Volume per hectare harvested	Volume per hectare harvested – Top 5 species
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
FMP	55.807 (137.233)	–806.639** (311.109)	–698.631*** (258.863)	–7406.721** (3626.549)	–5869.787** (2909.060)	–0.209* (0.111)	–0.222** (0.104)	–2.374** (1.173)	–2.233** (1.106)
Concession fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	454	419	375	421	377	420	375	421	377
R ²	0.628	0.559	0.611	0.624	0.675	0.406	0.488	0.476	0.552

Note: Standard errors in parentheses, clustered at concession level.

* .1.
** .05.
*** .01.

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