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THE EFFICIENCY OF FOREST MANAGEMENT PRACTICES IN CAMEROON 30 YEARS AFTER THE ADOPTION OF A NEW LEGAL FRAMEWORK

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Practices in sustainable forest management are ruled by national forest policies. Legal standards of forest management applied in Central African region display increasing risks of long-term depletion of timber resources. This review aims to assess the effectiveness of sustainable logging practices by highlighting the strengths and weaknesses of the forest management rules applied in Cameroon. The management of the populations of timber tree species is based on population dynamics traits and on measures imposed by national forestry policies. Before any exploitation in natural forest concessions, a management plan must be approved to define the various activities and the potential impacts on the forest. Despite many relevant principles, nearly three decades of forest management in Cameroon have exhibited gaps that need to be addressed in the legal standards of forest management. Proposals for improvement relate to procedures for determining the recovery rate and how considerations on density and seed tree populations should be included into the legal management policies. These suggestions depend on the knowledge of demographic dynamics and the reproductive ecology of the timber taxa as well as a more rapid integration of scientific results into the legal forest management standards.

Keywords: Central Africa, forest policy, timber harvesting, tropical tree species, sustainable forest management

INTRODUCTION

The management of natural forests has now become the guiding principle of forest policies in tropical countries. Sustainable forest management, which defines the management model prior to the exploitation, is gradually becoming the focus of attention. Its aim is to seek a balance between satisfying demand and ensuring the sustainability of forest resources (Leroy et al. 2013, Bigombe Logo 2015). In natural timber-producing forests, sustainable management is based on the results of the management inventory and standards imposed by forest legislation. The resulting management plan defines the operations to be carried out on the forest area concerned (Durrieu de Madron et al. 1998, Eba'a Atyi 2001).

Since the implementation of forest management plans in forest policies in Central African countries in the early 1990s, it is now widely recognised that sustainable management has made a significant contribution to improving forest management, particularly in terms of biodiversity conservation, which remains at a good level in forest management units (FMUs), compared with the protected areas in the same environment (Edwards et al. 2014, Lhoest et al. 2020). However, volumes of timber harvested have decreased significantly since the early 2000s as opposed to the 1980–2000 period (Cerutti et al. 2016). This is due to a series of measures imposed on forestry companies, which include a clear delimitation of the boundaries and functions of forest (land use for various purposes e.g. production, conservation, protection, agriculture); respect of the minimum cutting diameter (MCDL) defined per species; a rotation (cutting cycle) period imposed by the forest legislation; a plotting of the area exploited taking into account the rotation period; an obligation to ensure that a certain fraction (50%) of the initial stock in terms of number of trees of key species is reconstituted (recovery rate); etc. (Picard et al. 2012). Compared to tropical Asia region for example, Central Africa, with Cameroon as the driving force behind these changes and evolutions, has a better record in terms of maintaining ecological functions and ecosystem services of logging forests (Putz et al. 2012, Edwards et al. 2014). Sustainable management of natural tropical forests in Central Africa integrates different ecological considerations, and it imposes theoretically economic, social, and environmental constraints (Cerutti et al. 2008). Environmental constraints concern both waste management and ecological aspects. Ecological aspects encompass a wide range of measures against soil erosion, pollution of the hydrographic network and the limitation of damage caused to the forest canopy during the felling of trees.

This article focuses on the ecological aspects related to the long-term maintenance of exploited populations of woody species in Cameroon. After almost 20 years of implementation of management plans, the results are far from perfect, and many observers decry the increased risks of depletion of exploited resources, if current standards and practices are maintained (Karsenty & Gourlet-Fleury 2006, Putz et al. 2012, Zimmerman & Kormos 2012, Brandt et al. 2016). Indeed, while the basic rules of management remain relevant, many shortcomings have been highlighted in the standards set around these rules, particularly when comparing these standards with those imposed by forest certification councils (Burivalova et al. 2017). The problem is more crucial given that the African timber trade is focused only around 20 species, despite the great woody diversity of these forests. Three species (*Aucoumea klaineana*, *Entandrophragma cylindricum*, *Triplochiton scleroxylon*) account for 69% of the volume harvested in the Congo Basin region, and eight species (*A. klaineana*, *E. cylindricum*, *T. scleroxylon*, *Erythrophleum ivorense*, *Lophira alata*, *Cylicodiscus gabunensis*, *Milicia excelsa*, *Pterocarpus soyauxii*) represent 93% of the total volume (FRMi 2018). In Cameroon, two species: *T. scleroxylon* (ayous) and *E. ivorense* (tali), represent 53% of total exports (Cerutti et al. 2016, Mahonghol et al. 2016). The pressure exerted on the populations of these species is therefore a great concern in Cameroon.

MATERIALS AND METHODS

Systematic literature review (SLR) is the main method used in this research. SLR may give a less biased answer to the research question, suggest the direction of further research, and provide evidence-based information for policy and practices (Petticrew & Roberts 2008). In this research, documents dealing with policy governance, legal framework, and sustainable forest management practices in Cameroon published in peer-reviewed journal articles, theses, legal and regulatory documents, reports, and technical documents from the international organisations were used for the SLR. All the documents collected were limited to those written in French or in English.

The searched documents were scanned by title and abstracts, then screened first by introduction and conclusion, and next by the whole text. Those that were finally selected (60 documents in total) were coded and analysed. The extraction and analysis of data focused on (1) regulations and laws on sustainable forest management, (2) forest governance frameworks, and (3) standards and practices of sustainable forest management and their impacts on the ground.

RESULTS AND DISCUSSION

Relevant sustainable forest management principles

The international commitment made by tropical countries at the Rio de Janeiro Summit in 1992 prompted Cameroon to reform its forestry policy in 1993. The promulgation of law No. 94/01 on 20 January 1994, regarding the regime of Cameroon was quickly followed by a series of decrees, orders and circulars, setting, among other things, the standards for the management of the woody species exploited. For the forest manager, the most important of these legal texts is the order establishing the procedures for elaborating, approving, monitoring, and controlling the implementation of management plans of forests in the permanent forest estate, as well as its technical sheets.

Permanent forest estate consists of forest concessions subdivided into one or more publicly auctioned, and communal forests, i.e. FMUs (MINEF 2001). After allocation of a concession, the winning company can immediately start harvesting but has an obligation to prepare a forest management plan within a maximum period of three years. Based on the legal framework (Order No. 0222/A/MINEF) applied in Cameroon, the sustainable management of exploited tree populations is based on a set of technical considerations. These include: (1) the obligation to inventory the entire area of the forest concession at a legally defined minimum sampling rate; (2) take into account in the calculation of the rate of reconstitution a rotation of 30 years, as the time necessary to allow the reconstitution of the initial exploitable stock between two logging operations on the same surface; and (3) the obligation to harvest only trees that have reached a MCDL. This MCDL, set by the national forestry administration, varies from one species to another, with values ranging from 50 to 100 cm DBH (diameter at breast height); (4) divide the forest concession into six unit called blocks. Each block must be exploited during five years and is therefore subdivided into five sub-blocks designated annual cutting area. The blocks are delimited to contain similar volumes of exploitable wood to guarantee the economic sustainability of the activity; and (5) systematically carry out the calculation of the rate of reconstitution for each of the main exploitable species. This rate is expressed as the percentage of the exploitable stock at the end of a rotation compared with the exploitable stock at the beginning of the rotation. Its calculation is the key aspect of the ecological management of exploited species. The principle of ensuring recovery is mentioned in official decrees, but these do not clearly set a minimum threshold to be reached. Figure 1 illustrates the principle of calculating the rate of reconstitution. Its detailed formula considers the diametric growth of trees, the rates of natural mortality and felling damage (Durrieu de Madron et al. 1998).

It took several years for forestry companies to produce the first management plans. The year 2004 corresponds to the planning peak of sustainable forest management in Cameroon (Figure 2). In 2019, 91% (6279.5 ha) of the area covered by existing FMUs in Cameroon was managed sustainably (WRI/MINFOF 2020).

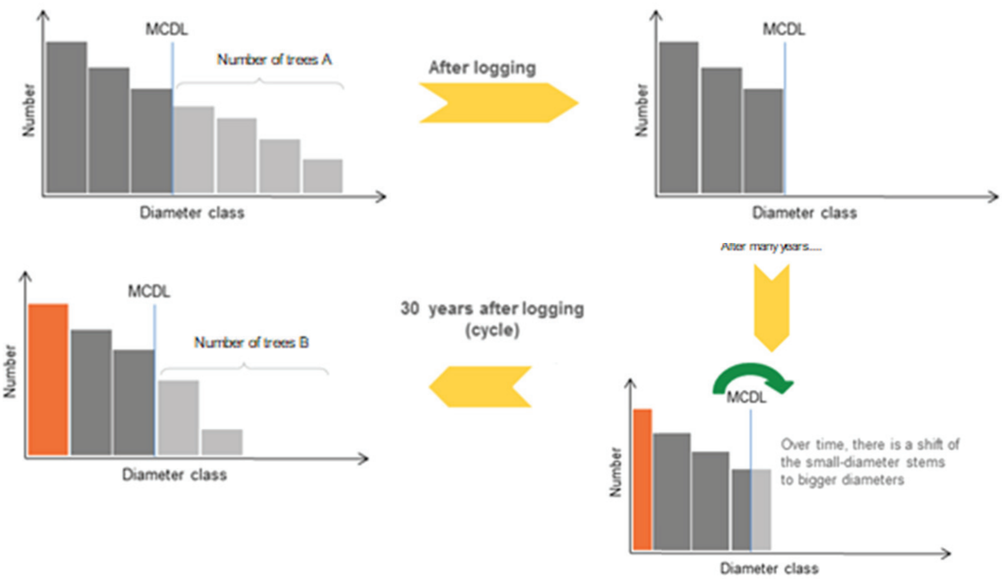


Figure 1 Illustration of the principle of the recovery rate in forest management plans; MCDL = minimum cutting diameter limit; dark grey bars = stems to be logged in the future, light grey bars = exploitable stems at a given time, orange bars = young trees that integrate the adult population, recovery rate = 100 × B/A

Limits of the forest management inventory in its implementation

The sustainable management approach imposed by new regulatory framework in Cameroon requires careful planning of logging based on a precise knowledge (quantity, quality and spatialisation) of tree species populations. Such knowledge is achieved by one or several forest inventories carried out at sampling rates that will ensure the acquisition of reliable data through acceptable human, material, and time investments.

Whatever the country and the type of forest, a systematic inventory is almost the rule for such large areas (Rondeux 2021). In Cameroon, the method of continuous bands subdivided into plots is used. The contiguous plots are each 250 m long and 20 m wide, leading to a plot unit of 0.5 ha. The threshold diameter for the inventory is fixed at 20 cm DBH by a ministerial decree (ONADEF 1991). The minimum sample rate is fixed at 0.5–1% depending on the area of the concessions. The definition of these rates was based on the results of similar experiments carried out in some Central African countries (TEREA 2007). Overall, the systematic sampling approach and sampling rate values are not questionable (Réjou-Méchain et al. 2011) although these low values often generate high rates of error around the estimated average values.

Despite the low sampling rate, inventories take a long time to complete, depending on the size of the concession, and have a substantial cost. Depending on the country, the cost of inventory and subsequent data analyses is estimated at €4–5 ha^{-1} (Forni & Bayol 2004, Samyn et al. 2011). This high cost is not within the reach of small-scale operators at the beginning of entrepreneurial activity, unlike companies supported by large amounts of capital. Hence, specialists reported that, in practice, many management plans were based on incomplete inventories or quasi-plagiarism data (Verbelen 1999, Réjou-Méchain et al. 2011). This problem has been also reported in Brazilian forests (Lacerda & Nimmo 2010). More rigorous administrative control (Cerutti et al. 2008), or even an execution of these inventories by an independent structure, could remedy this.

The 30-year rotation period: the right compromise

Cameroon is the only country in the Congo Basin which has set the rotation period at 30 years (Perthuisot & Durrieu de Madron 2008); other countries in the region have adopted shorter rotation periods. This value is commonly observed in other tropical countries outside Africa (Schulze et al. 2008, Zimmerman & Kormos 2012). The relevance of this value is, however, open to criticism because it would not allow a reconstitution of the harvested stock, nor would it guarantee the economic sustainability of the activity (Bayol & Borie 2004, Karsenty & Gourlet-Fleury 2006). In the Amazon, Mazzei

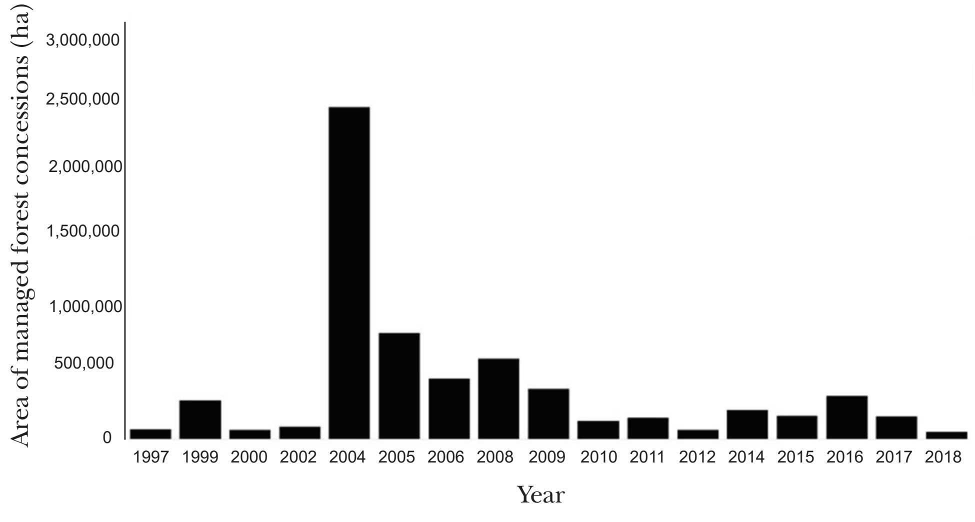


Figure 2 Dynamics of managed concessions in Cameroon after the release of the new national forestry law in 1994

et al. (2010) estimate that the full recovery of exploited volumes can be achieved in 30 years only if harvested rates (number of cut trees relative to the potentially exploitable population) were reduced by about half.

In Cameroon, an increase in rotation length would not be economically viable, given the small size of concessions, i.e. estimated at 68,000 ha on average (Bayol & Borie 2004). In addition, increasing rotation length has a limited effect on the reconstitution rate. The case of Ghana is a clear illustration of this issue. In this country, the rotation length is set at 40 years, which is considerably longer than in Cameroon. However, this measure does not allow for a total reconstitution of the exploited stock. Durrieu de Madron L (personal communication) maintains that extending the length of rotation could improve the rate of recovery. This finding was based on a simulation carried out on data obtained in two FMUs in the Republic of Congo and using recent values for mortality and growth rates of species, without modifying the values of the minimum cutting diameters. The limits of systematically using a mortality rate of 1% is highlighted in Table 1. Recent research shows that, for most species exploited, the annual mortality rate is around 0.5% year^{-1} (Ligot et al 2022). Consequently, increasing rotation and maintaining a mortality rate of 1% result in a reduction in the exploitable stock.

In general, simulations did not question the maintenance of a 30-year rotation period. As shown by Karsenty and Gourlet-Fleury (2006) for two of the most exploited species in the Central African Republic, *E. cylindricum* (sapelli) and *T. scleroxylon* (ayous), the solution is to act on the harvest or logging rate, which should be integrated into the calculation of the rate of reconstitution, whereby the fewer trees removed, the better the recovery.

Minimum cutting diameter limit for preservation of seed trees

The MCDL values set by the administration appear sufficiently high (≥ 50 cm) for a significant fringe of exploitable tree populations. Biologically, the MCDL should be set based on the effective fruiting diameter (EFD) of the species, to maintain sufficient seed trees (Fargeot et al. 2004). The identification of EFD in forest tree species remains rather controversial. The EFD refers to the minimum diameter of trees that have a high probability of fruiting regularly (Kouadio 2009, Bourland et al. 2012, Daïnou et al. 2012). However, there is no consensus on the minimum probability of fruiting to be considered. Wright et al. (2005) and Ouédraogo et al. (2018) proposed 50%, Doucet (2003) and Kouadio (2009), 70% and Durrieu de Madron and Daumerie (2004), 80%. The scientific community eagerly awaits for a consensus. In Cameroon, there are few studies devoted to the determination of EFD for logged tree populations. Table 2 summarises the related knowledge from Ouédraogo et al. (2018) and Daïnou et al. (2019) and highlights three scenarios:

(1) EFD < MCDL: this is the ideal scenario because the number of seed trees is greater than those that can be exploited. Fortunately, it is the case for 8 of the 10 species listed in Table 2.

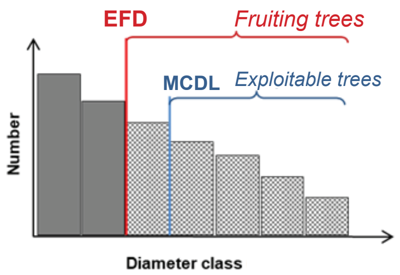
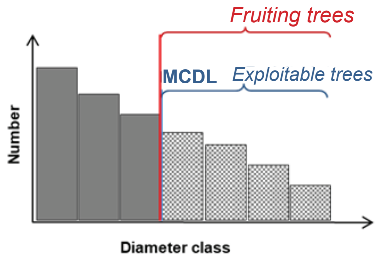
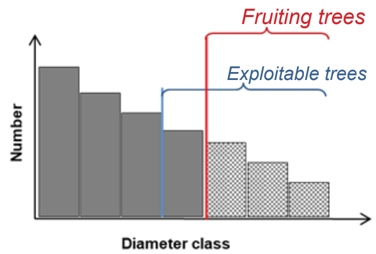
(2) EFD = MCDL: here, the maintenance of seed trees will depend on the rate of harvesting timber trees (example of *C. gabunensis* or okan in Table 2).

(3) EFD > MCDL: this scenario is critical as sustainable ecological requirement will lead to the adoption of a low harvest rate to save enough seed trees but there would be a clear risk of lower economic profitability. This is the case of *E.*

Table 1 Variation in the reconstitution rate as a function of the lengthening of the rotation period in two Congo Forest Management Units

Forest Management Unit	Reconstitution rate obtained (%)								Number of species used
1	0	30	37	45	53	60	68	75	17
2	0	18	23	27	32	37	41	46	13
Rotation period (years)	0	20	25	30	35	40	45	50	

Table 2 Legal minimum cutting diameter limit (MCDL) and effective fruiting diameter (EFD) of some important Cameroonian timber species

<table>
<tr><th>Population structure including EFD and MCLD positions</th><th>Species</th><th>Commercial name</th><th>Legal MCDL (cm)</th><th>EFD (cm)</th></tr>
<tr><td rowspan="8">
</td><td>Baillonella toxisperma*</td><td>Moabi</td><td>100</td><td>65</td></tr>
<tr><td>Entandrophragma cylindricum**</td><td>Sapelli</td><td>100</td><td>66</td></tr>
<tr><td>Lophira alata*</td><td>Azobe</td><td>60</td><td>23</td></tr>
<tr><td>Mansonia altissima*</td><td>Bete</td><td>60</td><td>18</td></tr>
<tr><td>Milicia excelsa*</td><td>Iroko</td><td>100</td><td>52</td></tr>
<tr><td>Pericopsis elata*</td><td>Assamela</td><td>90</td><td>36</td></tr>
<tr><td>Pterocarpus soyauxii**</td><td>Padouk rouge</td><td>60</td><td>35</td></tr>
<tr><td>Terminalia superba**</td><td>Frake</td><td>60</td><td>43</td></tr>
<tr><td>
</td><td>Cylicodiscus gabunensis**</td><td>Okan</td><td>60</td><td>60</td></tr>
<tr><td>
</td><td>Erythrophleum ivorense*</td><td>Tali</td><td>50</td><td>61</td></tr>
</table>

* = Ouédraogo et al. (2018) and ** = Daïnou et al. (2019); light grey bars represent the exploitable stock, while the dark grey bars correspond to regeneration, or future harvestable trees potential

ivorense (tali) in Table 2. For this timber species, a simple solution would be the increase of the MCDL to a value equal or higher than 70 cm.

To better set the MCDL, forestry research priorities in Cameroon and in the Congo Basin in general should integrate the determination of EFDs for all species exploited. Such studies should be conducted in different ecological regions as EFD may vary from one region to another (Ouédraogo et al. 2018). The EFD is typically estimated using phenological monitoring techniques established in only a few forestry concessions. Ideally, phenological plots should be implemented by each concession owner to provide local values of EFD and for adapting MCDL to the local forest environment (Fargeot et al. 2004). National research institutions should also take an interest in this type of research.

Limits of the practice of dividing concessions into annual felling areas

Based on the management inventory data and timber volumes calculated for a group of species in this review, the concession must be divided into six 5-year blocks of equal timber volume. Then, each block must be subdivided into five annual cutting areas. Prior to this division, the inventory data must be analysed using an official software called TIAMA (inventory processing applied to forest management modelling) (MINEF 2001) and volumes are estimated using official allometric equations.

However, TIAMA has many limitations: (1) it is only available through an old version of Access® module of Microsoft Office XP; (2) it is impossible to modify the equations transforming diameters into volume, although these equations need to be reviewed as they are biased (Tchatat et al. 2008, Ligot et al. 2019); and (3) TIAMA does not offer any tool for dividing the concession into blocks and annual cutting area. Hence, the delimitation of these blocks and annual cutting area is a complex and time-consuming task made manually whereas it should be automated. Due to that complexity, forest administration is almost unable to control the respect of the major technical rule behind the blocks (the delimited blocks must have same wood volumes). Legal texts do not exclude the possibility of using other softwares and other allometric equations if they are authorised by the forest administration but no authorisation has ever been issued by the administration.

The importance of revising the reconstitution rate

The rate of reconstitution makes it possible to assess the sustainability of exploited tree populations (Figure 1). Cameroon legal rules impose a minimum of 50% of the rate of reconstitution for each exploited species. Conventionally, when this threshold is not attained for a given species, the forest manager gradually increases the MCDL (by 10, then by 20, then by 30 cm) to attain this threshold but, just like the procedure for calculating the rate of reconstitution in Cameroon, this 50% threshold is challenging/questioning in several ways. It considers only a limited number of essential vital ecological parameters of species, it does not always increase with diameter classes, and it is not sensitive to the number of trees above the cut-off diameter (Picard et al. 2012). The reconstitution rates calculated in forest management plans in Cameroon are often incorrect and overestimated. In fact, we observed that of the more than 2000 rates of reconstitution mentioned in forest management plans, almost half (47%) were incorrect and overestimated. MCDL and other tree specific management parameters should thus consider the types of forest to avoid this problem.

For natural forests that have not yet been exploited, the reconstitution of the total exploitable population could be at odds with economic imperatives (Bayol & Borie 2004). Cameroon is the only country in the region to apply a minimum threshold of 50% for each managed species. Gabon imposes 75% only for *A. klaineana* (okoumé). On the other hand, a reconsideration is necessary for forests that have already undergone logging. Specialists agree to suggest that the minimum reconstitution rate imposed from the second rotation should be close to 100% for real ecological and economic sustainability (Bayol & Borie 2004). The reconstitution rate corresponds to the initial volume exploited which will be available at the next rotation; but in a heavily degraded forest, there is nothing left to restore. The initial state considered in the calculation of the rate of reconstitution must therefore be based on the intact part of the forest. However, if this is no longer available, it is necessary to resort to data from the literature and there are previous inventories that can be used. This implies to encourage the use of methods of calculation carried out at the regional level or forest type in order to take into account the geographical distribution areas of the managed species and the optimal climatic conditions for their growth (Todou et al. 2014), and not the current one which is limited to the scale of a forest concession, and which uses inventory data from very local planning.

In Cameroon, a species is said to be managed when it has been the subject of an estimate of its rate of reconstitution in the management plan. The Order No. 0222/A/MINEF imposes the management of a minimum of 20 exploitable species (among a pre-established list of 50 species or top 50) representing at least 75% of the available volume. The main flaw in this legal text is that it does not constrain the management of species of interest to the forest operator. In practice, and legally, the forest managers tend to exclude many heavily exploited species from the calculation when the rate of reconstitution is less than 50%; in this way they avoid increasing the MCDL. These species are placed in the categories called complementary or promotional species, which are cut at the diametric threshold corresponding to the MCDL.

Cerutti et al. (2008) showed that in 2006, unmanaged but exploited species in Cameroon at legal MCDL represented almost a quarter of the recorded annual production. According to these authors, the overall rate of reconstitution of these species, in terms of numbers, would only be 13%. Putz et al. (2012) estimated on a pantropical scale that only 35% of the volume of tropical species currently exploited would be available in the next rotation.

To compensate this lack in Cameroonian legislation, it should be imposed that no species can be exploited without meeting the minimum recovery criterion. Better, to ensure the sustainability of the activity, the planning after the first rotation should also focus on the reconstituted volumes, and not only at the number of trees.

The problem of using the "bonus" to calculate the rate of reconstitution

According to the Order No. 0222/A/MINEF, the numbers of trees with a diameter greater than MCDL + 40 cm should not be taken into account when calculating the rate of recovery. They constitute the "bonus" (Figure 3). The main limitation of this notion bonus is that the calculation of the rate of reconstitution does not consider the total number of harvestable stems. Cameroon is the only country in the Congo Basin region granting the tree bonus (Perthuisot & Durrieu de Madron 2008). This approach which artificially overestimate the replenishment rate should simply be removed, especially as most of the concession are already entering the second rotation phase (Ngomin et al. 2015).

The need to improve estimates of the rate of recovery

The main challenge for the forest manager seeking to calculate the rate of reconstitution of a species is to consider all the parameters of its population dynamic (B in Figure 1). This dynamic is mainly reflected by the annual diameter growth of each species, its annual mortality rate, and damage due to logging activities. Estève (2016) estimated the damage rates were between 5.5–8.5% in exploited areas in Africa, similar to Picard et al. (2012). In Cameroon, the value adopted in the forest management plans falls within this range, i.e. 7%.

The National Office of Forestry Development has set and imposed annual diameter growth values for each species (ONADEF 1991) for Cameroonian forest managers while in other countries of the Congo Basin, values from local scientific experiments can be used. The species annual diameter growth values imposed in Cameroon are open to criticism. Annual diameter growth can vary significantly depending on the type of vegetation and maturity of forest stands. The results of DynAfFor project, for example, is devoted to studying tree

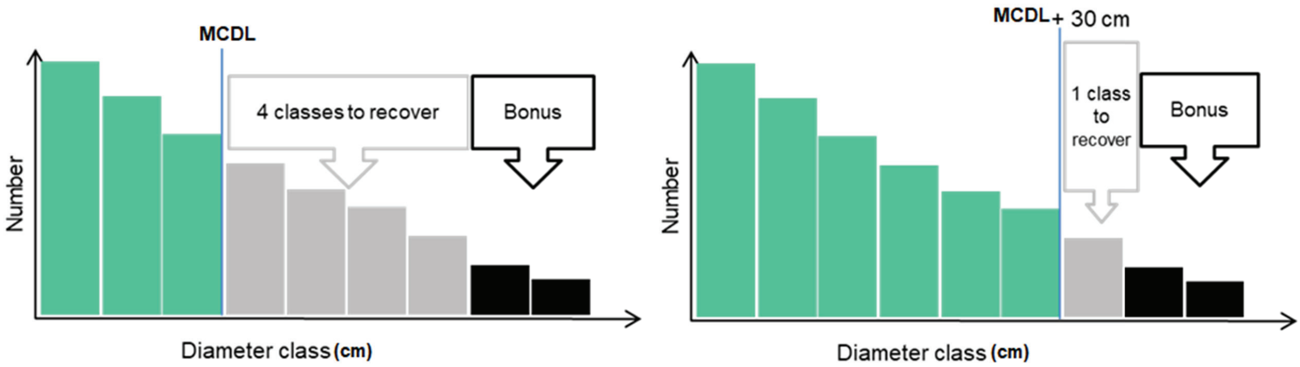


Figure 3 Representation of the concept of "bonus" in the Cameroonian forestry view of recovery rate; trees beyond "MCDL + 40 cm" constitute the bonus so that the number of exploitable trees to recover always comes from 1–4 diameter classes following the minimum cutting diameter limit (MCLD); green bars correspond to regeneration, i.e. the different classes of trees with diameters less than the minimum operating diameter, grey bars are the trees that can be harvested, i.e. the four classes of trees whose diameters are greater than or equal to the MDCL, these trees are also trees that will be managed and reconstituted at the end of a 30-year rotation, black bars correspond to the bonus classes, which can be harvested without any requirement for the reconstitution of the harvestable stock

population dynamics and has revealed many significant deviations (Table 3) from ONADEF values (Forni et al. 2019). Similarly, recent findings for tree mortality rates exhibited significant deviations from the usual value of 1% per year used throughout the Congo Basin (Ligot et al. 2022). Globally, it turns out that the values of the demographic parameters used in the calculation of the rate of reconstitution in Cameroon are potentially biased. Plots devoted to monitor population dynamics should be multiplied by ecological zone to provide more realistic estimates of the forest management parameters. Table 4 summarises questionable standards in the sustainable forest management principles analysed in this review.

Questionable standards in the sustainable forest management principles

Tree population density should be a management criterion

In tropical America, forest management rules in many countries include consideration of the average population density of each species within the concession. In Brazil, species with a population density of less than 0.03 stem ha^{-1} cannot be exploited while this threshold is raised to 0.10 stem ha^{-1} in Bolivia for an inventory diameter threshold of 20 cm (Schulze et al. 2008).

In Central Africa, only the Central African Republic and the Republic of the Congo impose a similar standard, i.e. between 0.02 and 0.10 stem ha^{-1} depending on the inventory diameter threshold (10 or 20 cm). Nevertheless, in Cameroon, some forestry companies which are aware of the risks of exploiting rare species, choose to adopt an exclusion threshold of 0.05 stem ha^{-1}. This threshold of 0.05 stem ha^{-1} corresponds to that recommended by Bayol and Borie (2004). However, an exclusion threshold of 0.10 stem ha^{-1} (inventory threshold of 20 cm) on a biological basis was suggested by Schulze et al. (2008) and Durrieu de Madron (2004).

Better consideration of natural regeneration problems

Many exploited trees species display lack of natural regeneration (Doucet 2003, Zimmerman & Kormos 2012). This is partly explained by changes in abiotic conditions that have in the past promoted their regeneration (Morin-Rivat et al. 2017). Logging is not the cause of this problem, but it can make matters worse if proper precautions are not taken.

Table 3 Annual diameter growth of some Cameroonian timber species according to ONADEF and the preliminary results of the regional project DynAfFor

Scientific name	Local name	Annual diameter growth (mm year^{-1})		
		Western region of Cameroon (evergreen forest)	Eastern region of Cameroon (semi-deciduous forest)	ONADEF
Pericopsis elata	Assamela		2.9	4.0
Triplochiton scleroxylon	Ayous	4.4	9.8	9.0
Lophira alata	Azobe	4.7	3.9	3.5
Terminalia superba	Frake		4.6	7.0
Baillonella toxisperma	Moabi		4.2	4.0
Cylicodiscus gabunensis	Okan	7.9	4.0	4.0
Pterocarpus soyauxii	Padouk rouge	4.2	3.2	4.5
Bobgunnia fistuloides	Pao rosa		2.7	4.0
Entandrophragma cylindricum	Sapelli		4.6	5.0
Entandrophragma utile	Sipo		3.9	5.0
Erythrophleum ivorense	Tali	5.3	3.6	4.0

Sources: Forni et al. (2019) and ONADEF (1991)

Table 4 Questionable standards in the sustainable forest management principles analysed in this review

Strength	Weakness	Limit	Perspective
Forest management inventory			
Planning of logging	Low sampling rate	Take several semesters	More rigorous administrative control
Carried out by systematic inventory at sampling rates	High rates of means errors Incomplete inventories or quasi-plagiarism on data	Cost is substantial	Execution by an independent structure
The 30-year rotation period			
Rest period of exploited area	Not allow a reconstitution of the harvested stock. Short rotation period	Longer rotation improved the recovering rate	Reduce harvested rates were by about half
Minimum cutting diameter limit (MCDL)			
Appear sufficiently high (MCDL ≥ 50 cm) for exploitable tree populations	Not based on the effective fruiting diameter (EFD) of the species to maintain sufficient seed trees	No consensus on the minimum probability of EFD National research institutions should also take an interest	Forestry research priorities should integrate the determination of EFD for all species exploited Phenological plots should be implemented to provide local values of EFD and for adapting MCDL
Dividing the concession into annual cutting areas (ACAs)			
Planification of exploitation by dividing concession into six 5-year blocks with each in five ACAs	Delimitation is complex and time-consuming task made manually	Unable to control the respect of the major technical rule behind the blocks	Delimitation should be automated
Analysed using an official software called TIAMA and volumes are estimated using official allometric equations	TIAMA used old version of Access® module of Microsoft Office XP, impossible to modify the equations transforming diameters into volume	TIAMA does not offer any tool for dividing the concession into blocks and ACA	Equations need to be reviewed as they are biased

continued

Table 4 Continued

Strength	Weakness	Limit	Perspective
Recovery rate			
Formulae express the percentage of the exploitable stock at the end of a rotation	Do not increase with diameter classes Not sensitive to the number of trees above the cut-off diameter Incorrect and overestimated calculations	Controversial between 50 or 100% recovery rate applying for not intact forest concession It considers a limited essential vital ecological parameter of species	Tree specific management parameters used in the formula should thus consider the types of forest Planning after the first rotation should also focus on the reconstituted volumes, and not only at the number of trees
Applied for a species said to be managed	Allow to exclude from the calculation many highly exploited species when recovery rate is < 50%; hence they avoid the increase of the MCDL		Imposed that no species can be exploited without meeting the minimum recovery criterion
Bonus	Non-integration of all the exploitable diameter classes in the calculation of the recovery rate	Artificially overestimates the replenishment rate	This approach should be removed

TIAMA: inventory processing applied to forest management modelling; reduced harvested rates were by about half

The enrichment of disturbed forest areas using timber species was made compulsory in 2016 in Cameroon through a circular letter by the Ministry of Forests and Wildlife in the same year. However, given the volumes harvested over the past decades, it is unlikely that the current rate of reforestation can positively influence timber harvests in the medium term. Better yet, we may wonder about the future of these plantations, if there is not a rigorous follow-up. The country would benefit from actively investing in large-scale reforestation programmes and medium-term follow-up for a real sustainable logging (Ngomin 2015).

Including the protection of a fraction of seed trees in the legislation

Natural regeneration cannot take place without seed trees. In Brazil, in the absence of clear data on minimum seed tree diameters (or EFD) per species, it was decided that 10–20% of exploitable stems with DBH ≥ 45 cm should be kept off from logging (Schulze et al. 2008, Zimmerman & Kormos 2012). However, some authors consider this measure as not sufficient, because it does not take into account the reproductive biology of each harvested species. In Ghana, 50% of trees with diameter ≥ MCDL should be spared in each annual cutting area (Hawthorne et al. 2012). In Gabon, trees with a DBH > 200 cm are excluded from logging ("Order 117" of 1 March 2004, by the Ministry of Water, Forests, Sea, and the Environment). This Gabonese tree conservation strategy is appreciable, but it does not seem effective for forest regeneration because larger trees tend to have poor reproductive success, whereby fruit or seed production generally peaks in the range of intermediate diameters. Furthermore,

Table 5 Neglected principles of the sustainable forest management analysed in this review

Strength/justification	Method/ threshold used	Limit/constraint	Perspective/ recommendation
Tree population density and exclusion threshold			
Adopt for some species which are aware of the risks of exploiting rare	Exclusion threshold Less than 0.03 stem ha^{-1} in Brazil 0.10 stem ha^{-1} in Bolivia 0.02 and 0.10 stem ha^{-1} in Central African Republic and the Republic of the Congo 0.01–0.05 stem ha^{-1} by some forestry companies in Cameroon		0.05 stem ha^{-1} (Bayol & Borie 2004) 0.10 stem ha^{-1} (Schulze et al. 2008, Durrieu de Madron 2004)
Consideration of natural regeneration problems			
Many exploited tree species display lack of natural regeneration	The enrichment of disturbed forest rigorous follow-up		Large-scale reforestation programmes
Including the protection of a fraction of seed trees in the legislation			
Natural regeneration cannot take place without the seed trees	In Brazil 10–20% of exploitable stems with DBH ≥ 45 cm should be kept off from logging	Absence of clear data on minimum seed tree diameters	Seed trees should be fixed (at least 20%) with a diameter greater than the fruiting diameter
	In Ghana, 50% of trees with diameter ≥ MCDL should be spared in each annual cutting area	Specificities of the species reproductive biology are not considered	Seed trees maintained must belong to all diameter classes
	In Gabon, trees with a DBH > 200 cm are excluded from logging Seed trees must be preserved among the bonus trees (DBH ≥ MCDL + 40 cm) but no fraction is specified in Cameroon	Larger trees tend to have poor reproductive success	Seed trees must be well-shaped

large trees produce low amounts of viable seeds (Plumptre 1995, Gullison et al. 1996, Hardy et al. 2019).

In Cameroon, Order No. 0222/A/MINEF specifies that seed trees must be preserved among the bonus trees (DBH ≥ MCDL + 40 cm), but no fraction is specified (MINEF 2001). This shortcoming should be corrected on the basis of good practices identified in the literature for other regions, in particular, (1) a proportion of seed trees to be maintained per species in the concessions should be fixed (at least 20%) for trees with a diameter greater than the fruiting diameter; (2) the seed trees maintained must belong to all diameter classes; and (3) a large part of the seed trees maintained must be well-shaped without major defects or diseases. Table 5 summarises the neglected principles of the sustainable forest management analysed in this review.

CONCLUSION

The two decades of sustainable forest management practices in Central Africa in general and in Cameroon in particular, have highlighted errors or new aspects that need to be implemented in the management standards of logging forests. Although not exhaustive, this literature review presents the major problems. Areas for improvement have been proposed for a better management of exploited tree populations. They concern, among other things, the procedure for calculating the rate of reconstitution, the consideration of species tree density and the need to know the diameters of effective fruiting for defining seed trees.

Such recommendations require a better knowledge of the dynamics of tree populations, of the reproductive ecology and regeneration of these species, and faster integration of scientific results into legal forest management standards. For example, in June 2023, the Ministry of Forests and Wildlife in Cameroon launched the development of simplified management guidelines and standards for concessions of less than 100,000 ha, which include the latest scientific data on mortality and diameter growth rates obtained throughout the Congo Basin. In 2014, the ministry set up a scientific advisory committee. This innovative idea in Central Africa should quickly prove itself for a tangible evolution towards sustainable forest management. Forest management integrates many other aspects than just the management of exploited trees populations. It is feared that there are also many gaps in environmental, social, economic, and wildlife management areas.

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