Improved management of species of the African *Entandrophragma* genus, now listed as vulnerable

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Photo 1.
Entandrophragma cylindricum log in a processing plant (CFT) in Kisangani (DRC).
Photo N. Bourland.

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RÉSUMÉ

Enjeux et amélioration de la gestion des espèces du genre *Entandrophragma*, arbres africains devenus vulnérables

Par la qualité de leur bois et leurs nombreux usages traditionnels, les espèces du genre *Entandrophragma* font l'objet d'une intense exploitation, susceptible de compromettre leur pérennité en l'absence de gestion durable. La présente étude dresse un état de la situation de cinq espèces commerciales principales de ce genre : *Entandrophragma angolense*, *E. congoense* (souvent assimilée par erreur à *E. angolense*), *E. candollei*, *E. cylindricum* et *E. utile*. Elle propose des pistes de recherche pour améliorer les stratégies de gestion durable au sein de ce genre. L'étude est principalement basée sur les données scientifiques (publications), économiques (statistiques de production et d'exportation) et juridiques (lois et réglementations), mais aussi sur les plans d'aménagement et les rapports d'inventaire. Les connaissances sur leur gestion sont encore fragmentaires alors qu'elles sont considérées comme vulnérables dans la liste rouge de l'UICN. La forte exploitation industrielle et artisanale de ces espèces ne s'effectue pas toujours dans le respect d'un plan d'aménagement validé, ni de la durée minimum des rotations qui permettraient l'un et l'autre un taux de reconstitution pérennisant cette ressource. Leur gestion durable exige notamment le développement et le respect de mesures d'aménagement pour rendre leur exploitation renouvelable à long terme. Cette exploitation doit s'appuyer sur une gestion adéquate des peuplements naturels et sur le reboisement ainsi que sur des mesures de conservation. Les recherches à développer doivent intéresser leur vitesse de croissance face aux évolutions climatiques, l'évaluation de leurs stocks (production, biomasse, carbone), l'actualisation de leur distribution spatiale, l'amélioration de leur régénération naturelle, les processus de leur reproduction, leurs propriétés anatomiques et technologiques, autant de pistes pertinentes pour garantir la pérennité des espèces exploitables du genre *Entandrophragma*.

Mots-clés : *Entandrophragma*, aménagement forestier, exploitation forestière, bois, économie, forêt dense humide, gestion durable, reboisement, Afrique.

ABSTRACT

Improved management of species of the African *Entandrophragma* genus, now listed as vulnerable

Because of the quality of their wood and their many traditional uses, species of the *Entandrophragma* genus are being intensively logged, and this is likely to compromise their survival unless sustainable management is introduced. This study reviews the current status of the five main commercial *Entandrophragma* species: *Entandrophragma angolense*, *E. congolense* (often confused with *E. angolense*), *E. candollei*, *E. cylindricum* and *E. utile*. We suggest directions for research to improve sustainable management strategies for this genus. The study draws mainly on published scientific data, economic data (production and export statistics) and on relevant laws and regulations, but also on existing management plans and inventory reports. Although these species are reported as vulnerable on the IUCN Red List, knowledge on their management is still patchy. Industrial and artisanal logging is intensive and does not always follow a validated management plan or abide by the minimum rotation period, both of which would help to ensure the renewal of these resources. Managing them to ensure that logging is sustainable in the long term requires management measures to be developed and complied with. Sustainable use has to be based on appropriate management of natural stands and on reforestation and conservation measures. Research studies to be developed should encompass the growth rates of the species in the light of the changing climate, assessments of stocks (timber, biomass and carbon), updates of their spatial distribution, improvements to natural regeneration, reproduction processes and the anatomical and technical properties of each species. All these research topics are necessary to ensure the permanence of these *Entandrophragma* species.

Keywords: *Entandrophragma*, forestry, logging, wood, economy, dense humid forest, sustainable management, reforestation, Africa.

RESUMEN

Retos y mejoras para la gestión de las especies del género *Entandrophragma*, árboles africanos que han pasado a ser vulnerables

Por la calidad de su madera y sus numerosos usos tradicionales, las especies del género *Entandrophragma* son objeto de una intensa explotación, que puede comprometer su durabilidad sin una gestión sostenible. Este estudio describe la situación de las cinco especies comerciales principales de este género: *Entandrophragma angolense*, *E. congoense* (a menudo asimilada por error a *E. angolense*), *E. candollei*, *E. cylindricum* y *E. utile*. Y propone líneas de investigación para mejorar las estrategias de gestión sostenible aplicadas a este género. El estudio se basa principalmente en los datos científicos (publicaciones), económicos (estadísticas de producción y de exportación) y jurídicos (leyes y reglamentaciones), pero también en la ordenación forestal y los informes de los inventarios. Los conocimientos sobre la gestión de estas especies todavía son parciales, mientras que se consideran vulnerables en la lista roja de la UICN. La fuerte explotación industrial y artesanal de estas especies no se realiza siempre respetando un plan de ordenación validado, ni la duración mínima de las rotaciones que permitirían una tasa de repoblación que perpetuase este recurso. Su gestión sostenible exige principalmente el desarrollo y el respeto de medidas de ordenación para que la explotación sea renovable a largo plazo. Esta explotación debe basarse en una gestión adecuada de las poblaciones naturales y en la repoblación, así como en las medidas de conservación. Las investigaciones que se desarrollen deben tener en consideración la velocidad de crecimiento ante las evoluciones climáticas, la evaluación de los stocks (producción, biomasa, carbono), la actualización de la distribución espacial, la mejora de la regeneración natural, los procesos de reproducción, las propiedades anatómicas y tecnológicas, todas ellas pistas pertinentes para garantizar la perpetuidad de las especies explotables del género *Entandrophragma*.

Palabras clave: *Entandrophragma*, ordenación forestal, explotación forestal, leña, economía, bosque denso húmedo, gestión sostenible, repoblación, África.

Introduction

Timber extraction is one of the direct causes of tropical deforestation (Geist *et al.*, 2002; Gillet *et al.*, 2016). However, Karsenty and Ongolo (2012) note that, apart from cases of very intensive timber extraction in South-East Asia and Latin America, logging in the humid tropics is generally selective and rarely leads directly to sufficient felling and damage to be considered as deforestation. In the Congo Basin, Doucet and Kouadio (2007) point out that the timber market is also highly selective and that, as a result, extraction is limited to the largest and finest trees of a few species of high market value. In this context, the extraction of high-quality stems of a small number of species can actually result in genetic skimming of these species (Nanson, 2004). This high risk of genetic erosion concerns many African tree species of economic interest, including *Entandrophragma*.

The genus *Entandrophragma* C. DC. includes, depending on sources, 10 to 12 tree species distributed exclusively in tropical Africa (Kasongo Yakusu *et al.*, 2018). Within the Meliaceae family, this genus is the richest in precious species that have been logged for decades for industrial timber (Tailfer, 1989; Kasongo Yakusu *et al.*, 2018; Lebacq *et al.*, 1950) because of the excellent quality of their wood, which is suited to a variety of uses including cabinet making. Lescuyer *et al.* (2012) show that these species are also extracted by artisan loggers. The technological quality of the wood, and therefore its commercial value, varies from one species to another. Populations of *Entandrophragma* in dense humid forests include *E. angolense* (Welw.) C. DC. (trade name: white tiama), *E. candollei* Harms (kosipo), *E. congolense* (Pierre ex De Wild.) A. Chev. (black tiama), *E. cylindricum* (Dawe & Sprague) Sprague (sapelli), and *E. utile* (Dawe & Sprague) Sprague (sipo). They are distributed across a wide band north and south of the equator from the Atlantic coast through the Congo Basin to the western slope of the Kivu Ridge in the east (White, 1986; Kasongo Yakusu *et al.*, 2018). These species provide some of the most valuable timber (Hall, 2008; IITO, 2017). In the Central African Republic (CAR), they account for more than 70% of the total volume of timber exported (Hall, 2008). They have been heavily exploited in West Africa: Côte d'Ivoire, for example, exported more than 3.7 million m³ of *Entandrophragma* logs and more than 400,000 m³ of sawn timber between 1970 and 1974. As a result, logging of these species has dried up in West Africa while gradually shifting to Central Africa (Bayol *et al.*, 2012).

The five main *Entandrophragma* species extracted grow in evergreen and semi-deciduous dense humid forests (Meunier *et al.*, 2015; Kasongo Yakusu *et al.*, 2018) where they have been logged to such an extent that natural regeneration has not been able to restore populations to their initial states, all the more so as natural regeneration is sometimes defective in these species (Lemmens, 2008). This state of affairs is raising serious concerns about the conservation risks weighing on these species, which are now listed as "vulnerable" on the IUCN Red List (IUCN, 2012). Listing in this category is not intended to prohibit their extraction, but rather to draw the attention of forest managers (e.g. States and logging companies) to the need to create the necessary conditions to manage forest resources, and these species more specifically, for sustainability. The conservation status of *Entandrophragma* species will certainly evolve according to the conditions of their extraction and regeneration and their population dynamics. It is therefore advisable to draw up a status report on these species, taking into account not only their economic importance but also the legislation and regulations in force concerning resource management. Relevant information should therefore be collected on their growth dynamics, their environmental requirements and their economic value based on the anatomical and technological properties of their wood and on their social importance.

The aim of this review is to gather and analyze published knowledge on the most heavily exploited *Entandrophragma* species in Africa (sapelli, sipo, kosipo, black and white tiamas) in order to:

- characterize their growth and the quality of their wood;
- evaluate the scale of their extraction;
- describe their economic, industrial and commercial status;
- analyze the impact of legal and regulatory measures concerning forest development and management;
- discuss the relevance of their conservation status in the light of anthropogenic pressures on their populations; and
- identify research themes aimed at good management of their populations in order to ensure that their extraction is sustainable.

Photo 2.
Sawn timber of *Entandrophragma cylindricum* ready for export.
Photo N. Bourland.

Growth dynamics

Tree-ring analysis and growth rates

Tree-ring analysis

Distinct growth rings are marked by a sudden structural change at the boundaries between them, usually involving a change in fibre wall thickness and/or radial fibre diameter, whereas indistinct or absent growth rings are unclear and marked by more or less progressive structural changes at their ill-defined or non-visible boundaries (IAWA, 1989). Tree ring analysis makes it possible to measure a tree's past growth rate and its variations (e.g. due to climatic changes through analysis of the ring width/rainfall relationship) and to estimate its age. The presence and legibility of rings thus allow dendrochronological analysis, provided that each ring can be associated with a given year and measured accurately (Fétéké *et al.*, 2016). The first observations made on *Entandrophragma*, notably *E. cylindricum* and *E. utile*, show rings bordered by a thin continuous line and likely to be annual (Détienne and Mariaux, 1977; Porter *et al.*, 2004). However, Banak *et al.* (2008) note that the ring boundaries of *E. angolense*, *E. cylindricum* and *E. utile* are sometimes indistinct or absent and those of *E. candollei* are generally indistinct or absent. Although reading the rings in species of the genus *Entandrophragma* can be difficult, doing so would bring a better understanding of their diametric growth rate, at least for some of the species.

The study of stable oxygen isotopes (δ18O) in the growth rings of tropical trees is another promising tool for high-resolution (annual) climate reconstructions. Because of the easily measurable and datable growth rings in *E. utile*, the presence of a strong common δ18O signal and its relationship with regional rainfall, Van der Sleen *et al.* (2015) argue that δ18O analysis of these rings is a promising tool for reconstructing climate variability over the past few centuries in Africa. This new research applied to other commercial *Entandrophragma* species would allow climate reconstructions from distinct growth rings.

Photo 3.
Sampling straw used to record data from a core extracted from a stem of *Entandrophragma* sp. in the buffer zone of the Yangambi Biosphere Reserve.
Photo M. Devriendt.

Growth rate

According to Couralet *et al.* (2010), the growth rate of trees, and thus the formation of growth rings, depends mainly on climatic variations. The optimal seasons for diametric growth and ring formation in *Entandrophragma* in Côte d'Ivoire, Cameroon and CAR are the two rainy seasons. A brief cessation of diametric growth in some stems is observed during the short dry season in July-August, while the long dry season corresponds to a period of slow or no growth (Détienne *et al.*, 1977; Fétéké *et al.*, 2016). In general, the resumption of growth activity in *Entandrophragma* occurs during the first rainy month and is not modified by variations in the rainfall regime during the growing season from April to November (Détienne *et al.*, 1977).

Measuring increase in diameter

In Central and West Africa, management rules for commercial species are based on the recovery rate of the number and standing volume of target species (Durrieu de Madron and Forni, 1997). The calculation of the recovery rate is based in particular on the rate of diametric growth (Fétéké *et al.*, 2016). Tree-ring analysis and diameter measurements repeated over time (table I) have been carried out in Cameroon, Côte d'Ivoire, Ghana, CAR and the Republic of

Table I.
Average annual diametric increase of *Entandrophragma* species.
Cam: Cameroun; CAR: Central African Republic; CI: Côte d'Ivoire; RC: Republic of the Congo.

Species	Methods used					
	Tree-ring analysis (mm/year)				Measurement of circumference (mm/year)	
	Détienne *et al.*, 1998			Owona Ndongo *et al.*, 2009	Détienne *et al.*, 1998	Gillet *et al.*, 2008
	Cam and CI	RCA (FAC 192)	RCA (Sangha M'Baéré)	Cam	Ghana	RC
Entandrophragma angolense	5.8	4.6	4.9	–	4-5	4
Entandrophragma candollei	5.8	5.1	4.6	4.4	4-5	6
Entandrophragma cylindricum	3.4	4.8	3.9-4.7	3	4-5	8
Entandrophragma utile	3.7	5.8	6.5	–	4-5	8.5

–: no information.

the Congo (Congo) to study the growth of certain commercial *Entandrophragma* species (Détienne and Mariaux, 1977; Adler, 1989; Détienne *et al.*, 1998; Durrieu de Madron *et al.*, 2000; Gillet *et al.*, 2008; Owona Ndongo *et al.*, 2009; Fétéké *et al.*, 2015, 2016).

The increases observed with these two methods are comparable. For a given species, they give fairly precise ranges of diametric growth rates and make it possible to calculate the recovery rate between two rotations. In order to refine the knowledge of their growth in diameter, further research would be needed on the basis of larger numbers distributed over the entire range of *Entandrophragma* (Durrieu de Madron *et al.*, 2000). As growth rates also strongly depend on the social hierarchy of a tree in relation to neighbouring stems (Gillet *et al.*, 2008), the diametric growth of the tree should be measured in relation to its social status (dominated, co-dominant and dominant). According to Durrieu de Madron *et al.* (2000), the average annual diametric growth of *E. cylindricum* varies from 2.8 to 7.7 mm/year, but Gillet *et al.* (2008) showed that part of this variability can be explained by the social status of the tree. These authors thus determined that the average growth in diameter of a dominated tree was 5 mm/year, 8 mm/year for a co-dominant and 11 mm/year for a dominant tree. However, the growth rate also depends on other factors such as soil quality, inter-annual climate variability, especially rainfall, and the intensity and history of logging operations, which in particular modify competition between trees. As a result of all these factors, the growth of a sapelli (as well as other *Entandrophragma* species) can vary by as much as a factor of two depending on the year (Fétéké *et al.*, 2016).

Anatomical and technological properties

The origin and growing conditions of a tree influence the physical and mechanical properties of its wood (Guibal *et al.*, 2016). Applied anatomy helps to understand the properties of wood materials and to explain variations in the quality of wood and processed products (Louppe, 2015). Gérard (1999) therefore recommends that these properties, which make it possible to qualify wood according to its intended use, should be systematically studied and analyzed in order to optimize the use of African species and respond in a relevant way to the demands of industrialists and end users. Anatomy, through the identification of logs and processed wood, makes it possible to control the timber trade, and particularly illegal trade. It can therefore contribute to the sustainable management of certain tree species whose excessive extraction and trade can result in the disappearance of their habitat, or even their extinction (Louppe, 2015). This knowledge is necessary to justify priority measures to ensure that species threatened by intensive extraction, in this case *Entandrophragma,* are managed sustainably (e.g. orientation towards forestry and integration into a reforestation programme).

Anatomical properties

Anatomical descriptions of *Entandrophragma* wood according to IAWA standards have been made by several authors under PROTA (Louppe *et al.*, 2008). These descriptions have been integrated into the *InsideWood* website (http://insidewood.lib.ncsu.edu). Anatomically, the wood of these species differs little except for a few distinctive features (Brazier and Franklin, 1961; Banak *et al.*, 2008;

Table II.
Distinctive anatomical features of the wood of *Entandrophragma* species (adapted from Banak *et al.*, 2008).
Anatomical feature: totally distinctive (unique to the species concerned); moderately distinctive (also observed in a species other than the species concerned) and marginally distinctive (also observed in two species other than the species concerned).

Species	Anatomical characteristics		
	Totally distinctive	**Moderately distinctive**	**Marginally distinctive**
Entandrophragma angolense	12: solitary vessel outline angular; 107: Body ray cells procumbent with mostly 2 to 4 rows of upright and/or square marginal cells.	94: over eight cells per parenchyma strand.	1: Growth ring boundaries distinct; 98: Larger rays commonly 4- to 10- seriate; 115: Rays per millimetre (4-12/mm); 136: Prismatic crystals present; 141: Prismatic crystals in non-chambered axial parenchyma cells; 142: Prismatic crystals in chambered axial parenchyma cells.
Entandrophragma candollei	43: Mean tangential diameter of vessel lumina ≥ 200 µm; 84: Axial parenchyma unilateral paratracheal; 159: Silica bodies present in axial rays; 161: Silica bodies in axial parenchyma cells.	46: Vessels per square millimetre (≤ 5 vessels per square millimetre); 94: Over eight cells per parenchyma strand.	82: Axial parenchyma winged-aliform; 85: Axial parenchyma bands more than three cells wide; 86: Axial parenchyma in narrow bands or lines up to three cells wide; 98: Larger rays commonly 4- to 10-seriate; 115: Rays per millimetre (4-12/ mm).
Entandrophragma cylindricum	25: Intervessel pits small (4-7 µm); 81: Axial parenchyma lozenge-aliform.	97: Ray width 1 to 3 cells; 104: All ray cells procumbent; 118: All rays storied; 131: Intercellular canals of traumatic origin; 137: Prismatic crystals in upright and/or square ray cells.	1: Growth ring boundaries distinct; 82: Axial parenchyma winged-aliform; 85: Axial parenchyma bands more than three cells wide; 86: Axial parenchyma in narrow bands or lines up to three cells wide; 98: Larger rays commonly 4- to 10-seriate; 115: Rays per millimetre (4-12/mm); 141: Prismatic crystals in non-chambered axial parenchyma cells; 142: Prismatic crystals in chambered axial parenchyma cells.
Entandrophragma utile		46: Vessels per square millimetre (≤ 5 vessels per square millimetre); 97: Ray width 1 to 3 cells; 104: All ray cells procumbent; 118: All rays storied; 131: Intercellular canals of traumatic origin; 137: Prismatic crystals in upright and /or square ray cells.	1: Growth ring boundaries distinct; 82: Axial parenchyma winged-aliform; 85: Axial parenchyma bands more than three cells wide; 86: Axial parenchyma in narrow bands or lines up to three cells wide; 136: Prismatic crystals present; 141: Prismatic crystals in non-chambered axial parenchyma cells; 142: Prismatic crystals in chambered axial parenchyma cells.

table II). The anatomical identification key for the four main *Entandrophragma* species proposed by Brazier and Franklin (1961) was established from a small number of specimens (4-7 per species). It has therefore been completed (table II) thanks to the anatomical descriptions made by Banak *et al.* (2008).

Five features fully characterize *E. candollei* (43, 84, 159, 160 and 161); two distinguish *E. angolense* (12 and 107) and *E. cylindricum* (25 and 81). Five moderately distinctive anatomical features (97, 104, 118, 131 and 137) bring *E. cylindricum* and *E. utile* closer together, which are otherwise separated by two anatomical features (25 and 81); the marginally distinctive feature (98) is observed in *E. cylindricum*, and the (46) in *E. utile*. In addition, the wood of *E. cylindricum* often has a more pleasing colour and is more attractively patterned (Lemmens *et al.*, 2008). The same moderately distinctive anatomical feature (94) is common to the wood of *E. candollei* and *E. angolense*. *E. candollei* differs from the other three species by the presence of silica in the rays, the axial parenchyma and in the fibres (159, 160 and 161).

The wood anatomy of these species should be studied in greater depth to better distinguish the growth ring boundaries by analyzing the diameter of the vessels. Measuring the width of growth rings from the pith to the bark at different heights of the trunk would thus improve knowledge of the growth in diameter and height of *Entandrophragma* (Beeckman, 2016).

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Table III.
The main physical and mechanical features of commercial *Entandrophragma* species.

Feature	*Entandrophragma angolense*	*Entandrophragma candollei*	*Entandrophragma cylindricum*	*Entandrophragma utile*
1. Physical				
Density when green (kg/m^3)	850-950	850-950	850-950	800-900
Density when dry* (kg/m^3)	500-735	570-810	560-780	550-680
Monnin hardness*	2.4	3.2	4.2	3
Fibre saturation point (%)	33	32	29	30
Total volumetric shrinkage (%)	12	13.1	13.1	12.4
Total tangential retraction (%)	5.8 - 9.6	5.7-7.6	4.3-9.8	6.4
Total radial / axial shrinkage (%)	3.8-6.6	4.4-5.1	3.5-7.6	4.6
Stability to air humidity variations	Medium	Low	Low to medium	Low to medium
Stable on average	Moderately stable to stable	Stable	Moderately stable	Moderately stable to stable
2. Mechanical				
Stress rupture in parallel compression* (N/mm^2)	37-67	47-53	40-75	45-72
Static bending breaking stress* (N/mm^2)	92-127	97-122	114-142	101-114
Longitudinal and flexural modulus of elasticity* (N/mm^2)	7,900-14,700	7,940-11,800	11,200-11,300	8,830-13,830
References	Cirad, 2015; Dahms, 1999; Tchinda, 2008; Gérard *et al.*, 1998; ATIBT, 1986	Cirad, 2015; Nyunaï, 2008; Dahms, 1999; Gérard *et al.*, 1998; ATIBT, 1986	Cirad, 2015; Kémeuzé, 2008; Dahms, 1999; Gérard *et al.*, 1998; ATIBT, 1986	Cirad, 2015; Dahms, 1999; Kémeuzé, 2008; Gérard *et al.*, 1998; ATIBT, 1986

* at 12% humidity.

Technological properties

The timber properties of the main commercially extracted *Entandrophragma* species are well documented (ATIBT, 1986; Gérard *et al.*, 1998; Dahms, 1999; Kémeuzé, 2008; Nyunaï, 2008; Tchinda, 2008; CIRAD, 2015; Gérard *et al.*, 2016). They seem to vary greatly from one species to another as well as within the same species. The main physical and mechanical characteristics (e.g. dry density, hardness and stability) of the four commercial *Entandrophragma* species are summarized in table III. They predispose these species to the timber industry, especially as their heartwood used outside wetlands is also known to resist attack by fungi, dry wood insects and termites (Staner *et al.*, 1958; Gérard *et al.*, 2016).

Socio-economic value

Economic value

Entandrophragma species as well as those of *Swietenia* Jacq. and *Khaya* A. Juss. are listed under the Anglo-Saxon name of Mahogany, which includes the best woods for cabinet-making worldwide (White and Gasson, 2008). African mahogany includes the genera *Khaya* and *Entandrophragma*, which are among the most valuable forest species and are traded in significant volumes, accounting for more than 70% of the total volume exported from CAR (Hall, 2008) for example. *Entandrophragma* is the only genus of which five species are extracted from Africa's dense tropical forests (Staner *et al.*, 1958; Bayol *et al.*, 2012). To understand the economic importance of these species and the threats to their future, it would be important to know how harvests in their range have evolved since the 1960s on a country-by-country basis, in order to follow the migration of logging areas over time.

Distribution area

Six species of *Entandrophragma* are very widely distributed across the Guinean-Congolese zone: *E. angolense*, *E. candollei*, *E. congoense*, *E. cylindricum*, *E. palustre* and *E. utile* (Kasongo Yakusu *et al.*, 2018). With the exception of *E. palustre*, which is restricted to swamp forests, mainly in DRC and the Republic of the Congo (Lemmens, 2008), the other five species grow in dense evergreen and semi-deciduous tropical forests (Meunier *et al.*, 2015; Kasongo Yakusu *et al.*, 2018). Figure 1 shows the geographical distribution of these species, adapted from the "Rainbio" database (Dauby *et al.*, 2016). *E. cylindricum* and *E. angolense* have the widest distribution and are locally more abundant than *E. candolei* and *E. utile* (Doumenge *et al.*, 2010; Kasongo Yakusu *et al.*, 2018).

Concentration of production in West Africa

Statistics (from the 1960s onwards) on timber production in logs or exports by type of product (e.g. logs, sawn wood, peeled veneer and plywood) and by *Entandrophragma* species are rarely available and accessible. Moreover, they are not regular and not chronologically continuous. From data published in the *Bois et Forêts des Tropiques* journal between 1963 and 1974 under the heading "*Commerce des bois tropicaux*", it is possible to track *Entandrophragma* log exports from 1963 to 1973 from Côte d'Ivoire, Cameroon and Gabon. Although they are patchy, ATIBT statistics can be used to draw out figures for Gabon for the 1998-2003 period. Large quantities of *Entandrophragma* logs were exported during 1963-1973: ± 6 million m^3 of sipo, ± 1.5 million m^3 of sapelli and ± 5 million m^3 of white tiama from Côte d'Ivoire; ± 350,000 m^3 of sapelli, ± 150,000 m^3 of sipo and ± 40,000 m^3 of kosipo from Cameroon; ± 200,000 m^3 of sipo, ± 150,000 m^3 of sapelli and ± 75,000 m^3 of tiama from Congo and ± 25,000 m^3 of sipo, ± 15,000 m^3 of white tiama and ± 7,000 m^3 of sapelli from Gabon. Figure 2 shows these exports by year. For the 1996-2013 period, only the statistics for Gabon are available: this country exported ± 200,000 m^3 of *Entandrophragma*.

Côte d'Ivoire is the country where commercial *Entandrophragma* species have been most heavily logged (around 10 million m^3 of logs extracted between 1963 and 1973). Together with the encroachment of agricultural land into forest areas, this has greatly reduced the resource. From the mid-1970s onwards, exports began to decline (figure 2) and by the 2000s, the resource had been exhausted. Statistics on the number of logs entering sawmills then only concern *E. angolense,* with 41,700 m^3 of logs in 2004 and 10,400 m^3 in 2012 (Louppe and Ouattara, 2013), the other species of the genus being extracted only in small quantities.

Central Africa, a new reservoir for production

Currently, logging of these species has shifted to other regions. Table IV shows this shift between 2005 and 2012, during which time controlled production, production of *Entandrophragma* logs in Central Africa was as follows:

- sapelli: Congo ± 3.5 million m^3, Cameroon ± 3 million m^3, CAR ± 2 million m^3 and DRC ± 500,000 m^3;
- sipo: Congo ± 550,000 m^3, DRC ± 200,000 m^3 and CAR ± 150,000 m^3;
- kosipo: Cameroon ± 300,000 m^3, CAR ± 150,000 m^3, Congo ± 75,000 m^3 and DRC ± 50,000 m^3; and
- white tiama: CAR ± 100,000 m^3; DRC ± 100,000 m^3.

In the early 2010s, Congo and Cameroon were the main producers of *Entandrophragma* timber (Bayol *et al.*, 2012). The history of trade in sapelli clearly illustrates the scale of extraction of species of the genus. In West Africa, logging has greatly reduced populations of sapele, so that it has shifted to Central Africa, currently the main production centre (Eckebil *et al.*, 2017) where it is by far the most heavily logged mahogany species with ± 1.3 million m^3 in 2008 (Bayol *et al.*, 2012). Extraction of sipo and kosipo is low in comparison with ± 130,000 and ± 100,000 m^3, respectively, in 2008 (figure 3). In Central Africa, in 2008, only okoume (*Aucoumea klaineana*) was extracted in greater quantities than sapelli. The low volumes of sipo can be explained by its widely scattered distribution in the forest massif, which has led some forest managers to exclude it from the main target species (Bayol *et al.*, 2012).

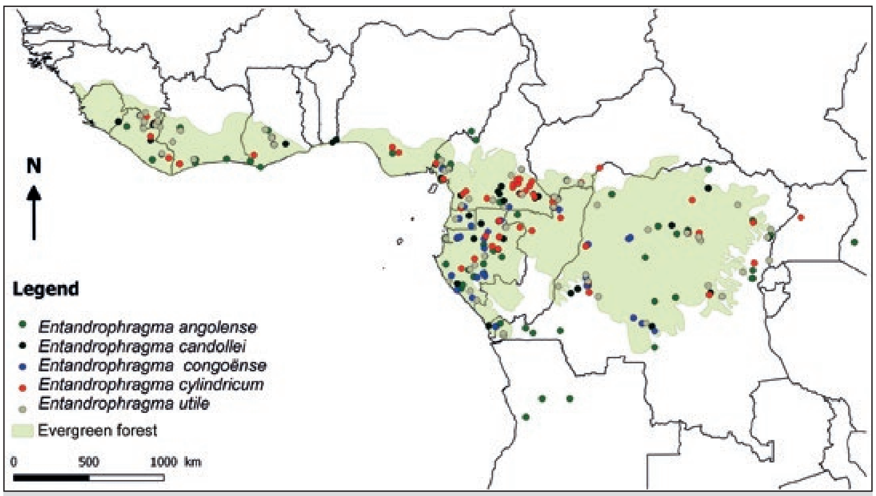

Figure 1.
Geographical distribution of the main commercial species of the genus *Entandrophragma* (map adapted from the "Rainbio" database; Dauby *et al.*, 2016).

Social value

Multiplicity of social uses

Entandrophragma has multiple uses that are well known to local people (table V). They use the different parts of the tree to satisfy needs for food (e.g. collecting caterpillars), construction, handicrafts, medicines, livelihoods, economy

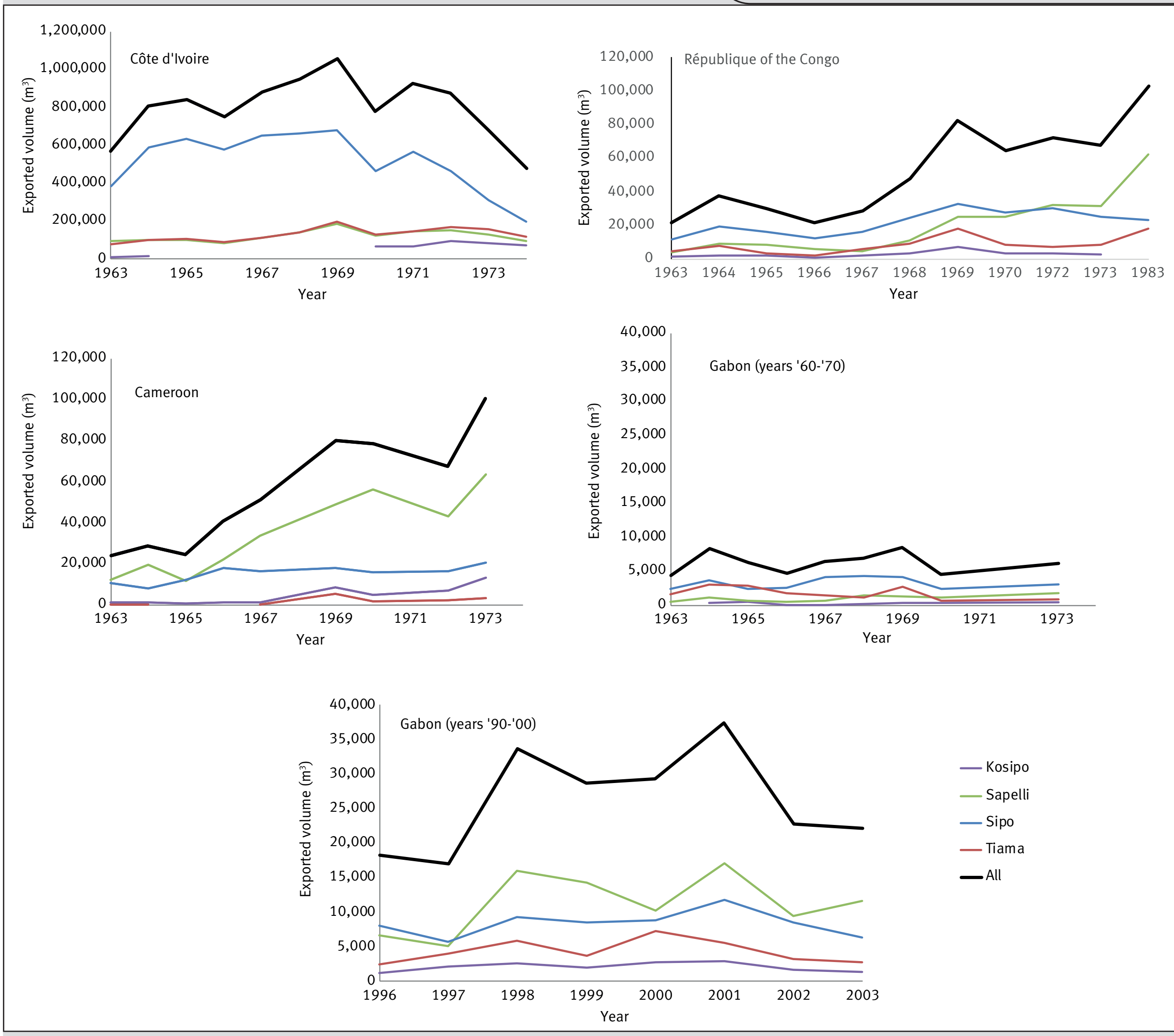

Figure 2.
Entandrophragma timber exports from Côte d'Ivoire (1963 to 1973), Cameroon (1963 to 1973), Congo (1963 to 1973) and Gabon (1963 to 1973 and 1998 to 2003).
Sources: before 1973, Bois et Forêts des Tropiques; after 1998, ATIBT newsletter.

and transport (dugout canoes), and others. (table V). The bark of all these species is used as medicine against various diseases. The roots of *E. candollei* are used as an anti-venom against snake bites. The seeds of *Entandrophragma* (e.g. *E. angolense*) are rich in oils that deserve detailed studies on their properties, including toxicity (Lemmens *et al.*, 2010). In view of their multiple medicinal uses, it would be advisable to conduct additional pharmacological studies on the bark and roots and chemical analyses to identify the active molecules.

Analysis and management of potential social conflicts

Some uses can have both positive and negative impacts on *Entandrophragma* stands and are therefore a source of conflict between local communities and logging concession managers (e.g. tree felling limits possibilities for collecting caterpillars). Edible caterpillars of the species *Imbrasia oyemensis*, which infest large sapelli, are harvested between July and August (Palla *et al.*, 2002; Eckebil *et al.*, 2017). It has sometimes been observed that collecting for food or medicinal purposes has led to trees being felled instead of conserved by users. This use of non-timber forest products by forest populations is in opposition to industrial logging (Vermeulen *et al.*, 2009) and can generate conflicts between logging operators and surrounding populations. Inclusive management of production forests in Central Africa should therefore be considered to avoid or reduce these conflicts (Karsenty and Vermeulen, 2016). This management model is observed, for example, in northern Congo, where FSC (Forest Stewardship Council) certified logging companies mark the caterpillar-infested sapelli trees with the local population to prevent them from being felled. In addition to this effective participatory approach, the CFT (*Compagnie Forestière et de Transformation*) (2015) recommends conducting an analysis of potential use conflicts village by village during the preparation of annual logging plans, so that measures can be taken to reduce the social impact, in particular by protecting trees that are important to local populations. Tieguong *et*

Table IV.
Entandrophragma timber production (volumes felled in m³) from 2005 to 2012 in Cameroon, Republic of the Congo, Central African Republic and Democratic Republic of the Congo (adapted from de Wasseige *et al.*, 2014).

Date	Cameroon				Republic of the Congo				Central African Republic				Democratic Republic of the Congo			
	Kosipo	Sapelli	Sipo	Tiama	Kosipo	Sapelli	Sipo	Tiama	Kosipo	Sapelli	Sipo	Tiama	Kosipo	Sapelli	Sipo	Tiama
2005	41,315	378,756	–	–	4,320	496,547	72,906	–	6,786	215,220	21,896	3,095	4,189	34,792	20,565	9,669
2006	45,367	377,142	–	–	12,177	316,098	75,971	–	17,174	335,604	28,909	14,399	–	65,465	31,773	11,992
2007	43,751	395,469	–	–	29,641	295,221	80,076	–	24,033	295,954	21,098	14,561	–	60,914	26,952	10,986
2008	46,151	408,068	30,901	–	13,269	343,652	35,749	–	3,0921	271,283	28,329	16,493	8,303	56,542	30,537	15,716
2009	35,267	264,771	–	–	–	412,406	128,530	–	12,548	188,206	17,359	5,176	12,768	62,079	39,356	17,312
2010	–	343,797	–	–	–	540,563	53,641	–	16,798	185,619	–	5,931	–	68,561	15,964	10,416
2011	–	365,446	–	–	–	546,440	49,035	–	22,050	215,616	13,937	17,623	–	79,811	15,902	5,714
2012	43,717	375,729	–	–	–	449,456	52,379	–	–	–	–	–	–	–	–	–
Total	255,568	2,099,178	30,901	–	59,407	3,400,383	548,287	–	130,310	1,707,502	131,528	77,278	2,726	428,164	181,049	81,805

–: no information.

al. (2017) emphasize the need for information on the availability and accessibility of multiple-use tree species in order to negotiate management agreements that satisfy both concession holders and local communities. Thus, certain populations of sapelli or other *Entandrophragma* species of high commercial value present in village lands should be classified as Type 5 High Conservation Value Zones ("forest areas providing local communities with the resources necessary to meet their basic needs [...]") (Daïnou *et al.*, 2016).

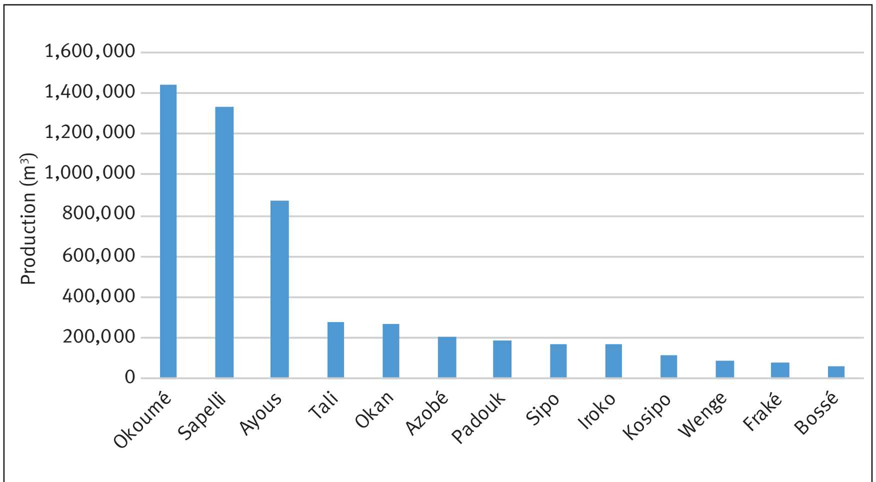

Figure 3.
Estimated 2008 production by species in the Congo Basin (m³) (Bayol *et al.*, 2012). Okoumé: *Aucoumea klaineana*; Sapelli: *Entandrophragma cylindricum*; Ayous: *Triplochiton scleroxylon*; Tali: *Erythrophleum* spp.; Okan: *Cylicodiscus gabonensis*; Azobé: *Lophira alata*; Padouk: *Pterocarpus soyauxii*; Sipo: *Entandrophragma utile*; Iroko: *Milicia excelsa*; Kosipo: *Entandrophragma candollei*; Wenge: *Millettia laurentii*; Fraké: *Terminalia superba*; Bossé: *Leplaea* spp.

Management of *Entandrophragma* populations

Conservation status

Brief overview of the classification method

The four main *Entandrophragma* species (for a long time considered similar to white tiama, very few data exist on the ecology of black tiama. Despite this, black tiama is different to white tiama morphologically and genetically; Monthe *et al.*, 2018) are classified as "Vulnerable" on the IUCN Red List (IUCN, 2012). However, none of them are listed in CITES Appendix I ("includes all species threatened with extinction [...]"; CITES, 1983) or Appendix II ("includes all species that might be threatened with extinction if trade in specimens of such species were not subject to strict regulation [...]"; CITES, 1983). A taxon is said to be "vulnerable" when the best available data (Sépulchre *et al.*, 2008) indicate that it meets, to a very precise degree, one of the following 5 criteria: reduction of the population, fragmented or declining geographical distribution (area of occurrence and area of occupancy), small and declining population (number of mature individuals), very small or restricted population, more than 50% probability of extinction within 10 years of three generations. Parts of this methodology proposed by the IUCN have been questioned by Sépulchre *et al.* (2008) because some criteria, which are difficult to quantify, are derived from estimates (of adult individuals) at the worldwide level. The IUCN has considered developing "regional" and/or "sub-regional" red lists (Sépulchre *et al.*,

Tableau V.
Social uses of the four main commercial *Entandrophragma* species.

Used parts	Uses			
	Entandrophragma angolense **(white tiama)**	***Entandrophragma candollei*** **(kosipo)**	***Entandrophragma cylindricum*** **(sapelli)**	***Entandrophragma utile*** **(sipo)**
Trees	Used in agroforestry as an alignment and shade tree.		Used in agroforestry as an alignment, ornamental and shade tree. Hosts edible caterpillars.	
Wood	Coffins, musical instruments, toys, sculptures, timbering, firewood and charcoal.	Timber, toys and novelty items.	Musical instruments, sculpture, toys, novelty items, manufacture of monocoque dugout canoes, timbering, firewood and charcoal.	Sculpture, dugout canoes, timbering, firewood and charcoal.
Bark	Its decoction is drunk to treat fever and the bark is used as an analgesic for stomach aches, peptic ulcers, earache, kidney, rheumatic or arthritic pain, eye infections, oedema and ulcers.	Yellow fever, malaria, typhoid. Used as an analgesic.	Its decoctions or macerations are used against malaria, bronchitis, lung ailments, colds, oedemas and as an analgesic; the pulp against boils and wounds. Its extracts were once used as a protective agent for stored maize.	Juice used for stomach and kidney pains, rheumatism, eye baths, inflammations, ear infections, headaches, malaria and peptic ulcers.
Leaves	–	–	Hosts the edible caterpillars of the *Imbrasia oyemensis* butterfly.	Hosts edible caterpillars.
Seeds	Rich source of oil (about 60% fat content).	–	Source of oil (approx. 45% fat content).	Source of oil (approx. 30-54% fat content) and essential oil.
Root	–	The root bark is applied to snake bites.	–	–
References	Tchinda, 2008.	Dibong *et al.*, 2011; Nyunaï, 2008	Jagoret *et al.*, 2014; Mate *et al.*, 2013; Lisingo *et al.*, 2012; Dibong *et al.*, 2011; Kémeuzé, 2008	Mate *et al.*, 2013; Lisingo *et al.*, 2012; Mujuni, 2008; Onifade, 2006

–: no information.

2008), which would allow a better assessment of the risk to species at the local level. It can thus be assumed that *Entandrophragma* from Côte d'Ivoire could be classified as "endangered" due to over-logging and drastic reduction of its habitat following land use changes.

Intensification of logging

Intensive logging of *Entandrophragma* in Central Africa could, as in West Africa, compromise the sustainability of these species. This situation varies from one species to another and from one region to another. In Central Africa, sapelli was still abundant in 2008 despite intensive logging in northern Congo, south-western CAR and DRC. At the time, this species did not show any obvious signs of vulnerability (Sépulchre, 2008), but as it provides one of the most commercially important timbers in Africa, it is still being exploited without sufficient efforts to ensure that logging is sustainable (Kémeuzé, 2008). There is therefore a risk that the scenario observed in West Africa, where exploitable trees have practically disappeared to the extent that some industrialists in Côte d'Ivoire now import sapelli from Congo (Louppe and Ouattara, 2013), will be repeated. Moreover, some industrial groups prefer to transport raw or only partially processed products from Central Africa to West Africa, where processing units with trained personnel have been established. In the absence of specific management measures for *E. utile*, Sépulchre *et al.* (2008) consider the species to be threatened despite a fairly good population

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structure showing the existence of satisfactory natural regeneration. Commercial interest in its timber has led to the extraction of the largest and most standards-compliant individual trees from the forests of Côte d'Ivoire, Ghana, Nigeria, Cameroon, CAR and Uganda. As a result, in Uganda for example, the species is on the brink of extinction (Mujuni, 2008). *E. angolense* is also threatened with genetic erosion in the near future and is considered to be under threat in Ghana and Uganda (Tchinda, 2008) and close to extinction in Kenya (Fischer *et al.*, 2010). *E. candollei*, whose timber is somewhat less valued, is nevertheless being logged in many areas on a probably unsustainable basis (Nyunaï, 2008). The data presented above are almost a decade old. Since then, due to numerous habitat modifications, increasing pressure on these species, the scale of poorly controlled artisanal logging and inadequate enforcement of regulations and sustainable management measures, the situation has probably worsened. There is therefore an urgent need to reassess the vulnerability of each *Entandrophragma* species in each country so that appropriate management measures can be recommended.

Photo 4.
Stem of *Entadrophragma angolense* in the Yangambi Biosphere Reserve.
Photo M. Devriendt.

Skimming and management of tree populations

In the absence of management plans, selective commercial logging has led to over-exploitation of some valuable species (redwoods such as mahogany, sipo, sapelli or lighter woods such as okoumé) and low exploitation of (many) others (Karsenty, 2004). This selective extraction, combined with poor regeneration, low growth rates, late seed maturity and poor seed dispersal, is leading to genetic erosion in some *Entandrophragma* species which is threatening the genetic quality of populations, at least in some countries (Lemmens *et al.*, 2010). In the specific case of *E. cylindricum*, Lourmas *et al.* (2007) showed that the reduction in the number of seed trees following logging is resulting more in a regeneration deficit than in a problem of genetic diversity. This deficit of future stems compromises logging sustainability if no specific management system is applied (Sépulchre *et al.*, 2008). Felling restrictions (e.g. increasing minimum cutting diameters) in order to conserve seed trees and provide "assistance" for regeneration are among the corrective measures recommended (Owona Ndongo, 2006; Lourmas *et al.*, 2007; Sépulchre *et al.*, 2008; Doucet *et al.*, 2016). In this context, ecological studies on *Entandrophragma* regeneration should be carried out by comparing recently logged forests with unlogged or formerly logged forests in order to better understand the reproductive processes (flowering and fruiting phenology, pollen and seed dispersal in subsequent work by Lourmas *et al.* (2007) and Monthe *et al.* (2017) as well as the ecological conditions determining seedling establishment, survival and growth and the biotic and abiotic risks they present.

Sustainable management policy, legislation and regulation

Categorization and implementation of sustainable management systems

The operational implementation of sustainable management systems for tropical forests focuses on a relatively small number of categories, i.e. in the majority of cases, management systems aim to improve either industrial and artisanal forestry (forest management, low impact logging, forest certification, reforestation, etc.) or to reinforce carbon storage (Clean Development Mechanism - CDM/Forests, REDD, etc.) or, finally, to increase the involvement of local populations in forest management and use (participatory management, community-based management, etc.; Leroy *et al.*, 2011). Currently, these three categories tend to overlap. Effective implementation of these tools or regulatory instruments would make it possible to strengthen the sustainable management of forest species. Some management tools designed to improve forest management (artisanal and industrial logging methods) and to increase wood and carbon stocks (reforestation policy) of *Entandrophragma* are discussed in the following section.

Photo 5.
Entandrophragma utile stem in the Yangambi Biosphere Reserve.
Photo M. Devriendt.

Effective implementation of forest management plans

Sectoral approach extended to the valuation of wood and carbon stocks

In Central Africa, studies for the implementation of forest management plans (FMPs) were developed in the 1990s (Marien and Mallet, 2004). In theory, FMPs assess the potential of the resource, take into account the trade-offs between ecological, economic and social aspects and propose balanced solutions (Cerutti *et al.*, 2017). In practice, forest management must ensure the conservation of resources as well as the well-being of the population, and forestry must provide the technical solutions (Dupuy, 1998). In addition, implementing an FMP is also an opportunity to reduce forest carbon emissions while presenting forest enterprises with acceptable financial trade-offs (Cerutti *et al.*, 2017).

Sustained attention to a few specific rules and actions

To avoid compromising regeneration and to boost the dynamics of a logged forest, Fargeot *et al.* (2004) propose giving priority to two management instruments or tools: the duration of the rotation, which is based in particular on economic and auto-ecological considerations, and the determination of minimum diameters in exploitable areas that take into account, at least ideally, ecological and technical imperatives. In addition to low-impact extraction techniques, these two management tools must be included in the effective implementation of FMPs. According to Karsenty (2004), the absence of management rules can raise serious problems for the renewal of the resource in unmanaged concessions but also, and probably above all, in forests where informal artisanal logging takes place. The renewal of over-exploited commercial *Entandrophragma* species will therefore require the development, validation and implementation of PAFs and compliance with them. Sustainable forest management is also relevant to the certification of good forest management (FSC, African Forest Certification Programme -AFCP-, etc.) or legality (Timber Origin and Legality -OLB-, Timber Legality & Traceability Verification -TLTV-, Verification of Legal Origin/Compliance -VLO/VLC-, etc.) (Karsenty and Ferron, 2017). To achieve this, Bayol *et al.* (2010) suggest building the capacity of forest law enforcement institutions in a context of strengthened rule of law (i.e. through strict law enforcement) when forest concessions are not managed or are slow to use the management tools discussed above.

Revision of minimum logging diameters

The Minimum Logging Diameter (MLD), the legal threshold at which a tree can legally be felled, for *Entandrophragma* species varies from country to country (table V). Côte d'Ivoire, where *Entandrophragma* species have been over-exploited since the 1960s, had set the MLE at the lowest level: 60 cm. In contrast, Ghana has set the MLD for all *Entandrophragma* species at the highest level: 110 cm. Ghana, Cameroon and Liberia are the three countries that have increased the MLD for sapelli (to 110 cm, 100 cm and 90 cm respectively) in order to improve the rate of recovery of the resource. The MLD for kosipo has been set at 80 cm by all central African exporting countries.

The regular fruiting diameter (RFD), the threshold at which efficient and regular fruiting takes place, is one of the important parameters to be taken into account to ensure logging sustainability. The RFD-MLD comparison (table VI) helps to assess the risk of shortage of seed trees and their regeneration. In order to avoid too great a reduction in the number of seed trees, it is necessary to ensure that RFD-MLD are significantly larger than the regular fruiting diameters (Durrieu de Madron *et al.*, 2004; Sépulchre *et al.*, 2008; Tchinda, 2008; Mujuni, 2008; Nyunaï, 2008; Kézeumé, 2008; Daïnou and Doucet, 2010). As future harvest is a function of the size of the diameter classes below the DME and of increment, logging damage and mortality (Durrieu de Madron and Forni, 1997), it is important to revise the regulation on the *Entandrophragma* DME by formalising an increase in RFD in all African producer countries. Fargeot *et al.* (2004) show that, for the same rotation period, a simple increase in MLD demands the maintenance of larger standing trees and increases the production of exploitable wood from the forest. This regulatory requirement should apply to all forest concession holders, including those who do not yet have MFPs and should therefore not be allowed to log. As part of a commitment to sustainable management, states should cancel the contracts of concession holders who do not yet have an MFP after the 3-year interim agreement to produce one.

Photo 6.
Measuring the increase in diameter of a trunk of *Entandrophragma cylindricum*.
Photo M. Devriendt.

Regulation of artisanal and informal logging

In the Congo Basin, the domestic timber market is growing strongly in terms of quantity, but the low purchasing power of the populations and the absence of client demands in terms of resource management mean that this market is almost systematically geared to the informal and/or illegal sector (Bayol *et al.*, 2014), so much so that log production in the informal sector may even exceed production in the formal sector (Bayol *et al.*, 2012). Recent studies in Cameroon, Gabon, CAR and DRC by Lescuyer *et al.* (2012) show that the domestic market for wood from artisanal, often informal, sawmills has reached an overall annual production of about 1.25 million m^3 of processed products, higher than in the controlled industrial sector. All these studies show that artisanal operators consider *Entandrophragma*, and some other species (e.g. *Khaya anthotheca* (Welw.) C. DC., *Pericopsis elata* (Harms) Meeuwen, *Pterocarpus soyauxii* Taub., *Milicia excelsa* (Welw.) C.C. Berg.), as noble woods and target them specifically (Tshimpanga *et al.*, 2016). To improve the safety of artisanal logging, increase its contribution to the national economy and control its environmental impacts, Tiayon and Molnar (2012) recommend better control and formalization of the artisanal sawmilling sector.

Need to strengthen reforestation policy and measures

According to Marien and Mallet (2004), central African countries began to study possibilities for enriching their forest heritage in 1934, by planting arboretums in Mbuku Nsitu in the Mayombe massif (Congo), in Sibang outside Libreville (Gabon) and several other sites (Mbalmayo in Cameroon, Yangambi in DRC). State programmes were then set up to enrich these arboreta by planting commercially valuable species (sipo, sapelli, etc.) along the forest inventory strips in natural forests being logged in northern Congo, Cameroon and DRC (Yangambi). These programmes were abandoned fairly quickly and replaced by, for example, plantations of exotic species or okoumé. On a more modest scale, some peasant farmers in western Cameroon, for example, are planting kosipo in their hedgerows, which is considered as a natural forest species producing long rotation wood (Temgoua *et al.*, 2011).

In Côte d'Ivoire, when the deforestation rate reached 600,000 ha/year during the 1960-1970 decade, the country turned to reforestation, which was in full swing (Alexandre, 1982) when programmes to enrich natural forests had already been abandoned. The lack of knowledge of natural regeneration mentioned by Catinot (1965), still poorly mastered to date (Doucet *et al.*, 2016), is one of the obstacles to extensive techniques for renewing and enriching natural forest capital.

Table VI.
Minimum Fruiting Diameter (MFD), Regular Fruiting Diameter (RFD) and Minimum Logging Diameter (MLD) of *Entandrophragma* tree species.
RC: Republic of the Congo; Cam: Cameroun; DRC: Republic Democratic of the Congo; CAR: Central African Republic; CI: Côte d'Ivoire. (Source: Kasongo Yakusu *et al.*, 2018).

Species	Scientific name	MFD (cm)	RFD (cm)	MLD (cm)	Country	Reference
Kosipo	*Entandrophragma candollei*	40	–	80	CAR	Yalibanda, 1999
		–	85	70	Uganda	Plumptre, 1995
		–	–	110	Ghana	Nyunaï, 2008
				90	Liberia	
				60	CI	
				80	Gabon	
				–	RC	
					Cam	
					DRC	
Sapelli	*Entandrophragma cylindricum*	–	75	80	CAR	Durrieu de Madron and Daumeurie, 2004
		–	85	–	Uganda	Plumptre, 1995
		35	–	80	CAR	Petrucci *et al.*, 1995
		55		80	CAR	Yalibanda, 1999
		40	55	90	Gabon	Sépulchre *et al.*, 2008
		–	–	60	CI	Palla *et al.*, 2002
				110	Ghana	
				90	Liberia	
				80	RC	
				100	Cam	
				80	DRC	
Sipo	*Entandrophragma utile*	–	85	90	Gabon	Sépulchre *et al.*, 2008
		–	–	110	Ghana	Mujuni, 2008
				100	Cam	
				90	Liberia	
				60	CI	
				80	RC	
				80	DRC	
				80	CAR	
Tiama	*Entandrophragma angolense*	55	–	80	CAR	Petrucci *et al.*, 1995
		50	–	80	CAR	Yalibanda, 1999
		–	85	–	Uganda	Plumptre, 1995
		–	–	110	Ghana	Tchinda, 2008
				90	Liberia	
				60	CI	
				80	Gabon	
				80	RC	
				80	Cam	
				80	DRC	

–: no information.

In terms of forest plantations, strengthening of reforestation policies should take into account the multiple causes of failure identified by Marien and Gourlet-Fleury (2014): insufficient or faulty prior strategic analyses, approximate or unsuitable technical schemes, poor appreciation of social issues, failure to resolve land tenure issues (long-term security of land tenure, pressure for other uses, real estate or agricultural speculation), poor economic calculations, insufficiently documented environmental impacts, insufficient long-term financing, etc. To limit the depletion of over-exploited species, West and Central African countries do not have sufficient means to invest in large-scale plantations that will produce exploitable trees within a few decades. Developing agroforestry systems would make it possible to secure an annual income (e.g. from cocoa and coffee) and a one-off gain from logging over a longer period.

Photo 7.
Base of a stem of *Entandrophragma angolense*
in the Yangambi Biosphere Reserve.
Photo M. Devriendt.

Conclusion and research perspectives

This review of issues that arise for improvements in the management of the *Entandrophragma* genus in natural forests shows that this taxon is of significant economic interest, which has resulted in over-exploitation, both industrial and artisanal, initially in West Africa and now concentrated in Central Africa. Limited natural regeneration, moderate or low growth rates, failure to use low-impact logging techniques and especially the absence of MFPs or only partial and/or uncontrolled implementation, together with selective and intensive extraction are all threatening natural populations of *Entandrophragma*. These threats are also leading to genetic erosion of the genus, to a greater or lesser extent depending on regions. The multiple uses made of these species are a potential source of conflicts between stakeholders, populations and industrialists. If forest managers do not involve local populations (inclusive management) and do not respect their fundamental social rights and their rights to use the forest (e.g. for food and medicines), it is impossible to set up viable MFPs.

Furthermore, the environmental impacts caused by the skimming of *Entandrophragma* populations are poorly documented for industrial logging, and virtually ignored for artisanal logging. Because of this situation, the sustainability of these forest resources is coming more acutely into question, since the management tools that could mitigate the problem need to be analysed from an overall and interactive perspective to ensure their viability. These tools include the regulation and/or improvement of industrial and artisanal logging (e.g. regulation of MLDs and effective control of the artisanal sector), improvement of carbon storage (e.g. by reforestation) and greater involvement of local populations by promoting inclusive management to develop the traditional pharmacopoeia, caterpillar collection, reforestation policy (and measures), etc. The scientific studies that would make it possible to strengthen management guidelines and measures for commercial *Entandrophragma* species are still fragmentary and do not cover the entire range of the genus. For example, in DRC, where the greatest diversity of *Entandrophragma* species is found and where the main species are logged industrially and by small-scale operators, very few recent scientific studies have been undertaken. A number of topics need in-depth studies to improve the management of these species for sustainability and to update their conservation status (currently recognised as "vulnerable") according to their geographical distribution. To achieve this, more research is needed on the following in particular:

- Growth rings analysis to measure growth rates (e.g. as affected by climate change, by analysing the relationship between ring widths and rainfall) and studies of stable oxygen isotopes ($\delta^{18}O$) for climate reconstructions;
- analysis of diametric growth through measurements based on larger numbers of trees across their entire range;

- anatomical and technological properties to justify priority measures for sustainable management (e.g. reforestation, integration into forestry schemes and controlling the illegal timber trade);
- updating the geographical distribution of each of the main commercial species;
- the processes involved in the natural regeneration of species, particularly in logging areas;
- reproductive processes (flowering and fruiting phenology, pollen and seed dispersal);
- impacts of human activities (industrial and artisanal extraction) and the environment (e.g. climate change);
- evaluating the evolution of production stocks, biomass and carbon;
- harmonisation of forestry policies within the producer countries of valuable *Entandrophragma* timber aimed at improving their sustainable management.

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