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Focus on:

Ecology and management of *Pericopsis elata* (Harms) Meeuwen (Fabaceae) populations: a review

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Pericopsis elata (Fabaceae) is a valuable timber species occurring in moist semi-deciduous African forests. While it is at present substantially reduced, the tree's natural distribution previously covered several distinct areas from Côte d'Ivoire to the Democratic Republic of Congo. This species has been logged since the second half of the 20th century. Because it suffers from a lack of regeneration, *P. elata* is now included in CITES Appendix II and is recorded as "Endangered A1cd" on the IUCN Red List. As with other long-lived light-demanding species, the survival of *P. elata* may have been favored by important disturbances that occurred in the Congo Basin during the last millennia. While both international trade and industrial uses of the wood of *P. elata* are well documented, information about its ecology are very sparse or contradictory, and even absent in some cases (*e.g.*, regarding its effective flowering diameter). Furthermore, data describing the management of *P. elata* are scarce, including potential solutions to compensate for the deficit of natural regeneration. Along the same lines, genetic studies still remain at an early stage and only vague hypotheses have been offered to explain the origins of the tree's populations. We emphasize the need for new research on those topics. Further studies would be useful in deciding whether *P. elata* populations can continue to be logged without the species being threatened with extinction. Finally, such research needs to target effective and inexpensive management procedures that could secure the future of the species in a logging context.
Keywords. Tropical rain forests, wood, *Pericopsis*, forest management, genetic variation, geographical distribution, trees, logging, endangered species, Africa.

Synthèse bibliographique : écologie et gestion des populations de *Pericopsis elata* (Harms) Meeuwen (Fabaceae). *Pericopsis elata* (Fabaceae) est un arbre de haute valeur commerciale des forêts denses humides semi-sempervirentes africaines. Son aire de distribution, aujourd'hui en régression, couvrait autrefois plusieurs régions disjointes allant de la Côte d'Ivoire à la République Démocratique du Congo. Cette espèce est exploitée depuis la deuxième moitié du 20e siècle pour son bois précieux. Elle souffre aujourd'hui d'un manque de régénération. De ce fait, elle est inscrite en annexe II de la CITES et est considérée « en danger » par l'IUCN. Comme d'autres essences exigeantes en lumière et présentant un déficit de régénération, elle pourrait s'être établie à la faveur d'importantes perturbations qu'ont connues les forêts du Bassin du Congo durant les derniers millénaires. Alors que le commerce international et les utilisations industrielles de son bois sont bien documentés, les données décrivant l'écologie de cette espèce sont, selon la région, partielles, contradictoires, voire inexistantes (*e.g.*, son diamètre de fructification régulière). En outre, seules des bribes d'information sont connues quant à sa sylviculture et aucune solution crédible n'est actuellement apportée pour pallier la carence en régénération naturelle. Enfin, les connaissances sur sa génétique n'en sont encore qu'à leurs balbutiements, tandis que seules de vagues hypothèses ont été émises quant à l'historique de ses populations. Ces derniers constats mettent en lumière la nécessité de nouvelles recherches scientifiques dans ces domaines. Ces études devraient être à même d'apporter les informations manquantes qui permettraient de statuer sans ambigüité sur les menaces qui pèsent potentiellement sur l'espèce. Enfin, ces recherches devraient aboutir à des mesures de gestion efficaces, pragmatiques et peu couteuses, conditions pour garantir la survie de l'espèce sur le long terme dans un contexte d'exploitation forestière.
Mots-clés. Forêts tropicales humides, bois, *Pericopsis*, aménagement forestier, variation génétique, distribution géographique, arbres, espèce en danger, Afrique.

1. INTRODUCTION

Formerly considered as pristine, Central African rainforests have undergone important changes during the last millennia. Indeed, recent studies (*e.g.*, Bayon et al., 2012) have come to the conclusion that this development could have been caused by climatic variations as well as past anthropogenic activities. Nowadays, these forests are logged to provide the international timber trade with valuable wood. In the Congo Basin, national regulations impose the implementation of management plans based on relatively strict standards. Among other management tasks, logging companies are obliged to conduct specific botanical inventories. Covering large forested areas, such inventories also provide relevant information regarding the population dynamics of timber species. Several timber species are suffering from a lack of regeneration within their natural distribution areas. How these aging timber populations originated is still in question (see for instance van Gemerden et al., 2003; Willis et al., 2004). Nomadic human populations, mainly through slash and burn practices, may have played an important role in the establishment of these species (Brncic et al., 2007; Bayon et al., 2012). *Pericopsis elata* (Harms) Meeuwen (Fabaceae), a tall tree occurring in the semi-deciduous African forest, is an example of a long-lived light-demanding commercial species, together with *Terminalia superba* Engl. & Diels and *Triplochiton scleroxylon* K.Schum. The main goal of this paper is to draw up an inventory of existing information in relation to *P. elata*, which is a potentially threatened species (IUCN, 2001; Abensperg-Traun, 2009). Particular attention is paid to the study of the tree's autecology and to the understanding of its population history, important information for everyone interested in securing its future.

2. GENERAL AND BOTANICAL DESCRIPTIONS

2.1. General description of *Pericopsis elata*

Pericopsis elata is a medium-sized to large tree of up to 130 cm in diameter and 40-50(60) m in height. The tree is mainly known under the local names of *afrormosia* (DRC, Congo, trade name most commonly used), *assamela* (Cameroon, Côte d'Ivoire) and *kokrodua* (Ghana). Howland (1979) and Dahms (1999) have cited other local names including *ole* and *oleo pardo* (Congo), *bohalala* and *ole* (DRC), *ejen* and *obang* (Cameroon), *mohole* (Ghana), and *ayin*, *aneran* and *elo uta* (Nigeria). Also commercialized as African teak or gold teak (because of the color of its dry heartwood), this high commercial value timber species is restricted to moist semi-deciduous African forests (West and Central Africa). *Pericopsis elata* is valued for the high quality of its wood, and its exploitation started more than 50 years ago, mainly in Ghana and Côte d'Ivoire (Dickson et al., 2005).

Main characteristics of the wood and most common uses. *Pericopsis elata* heartwood combines very good technical properties such as dimensional stability and good natural durability. The tree also offers good resistance against termites and its wood density is quite high. Heartwood is resistant to pressure impregnation (**Table 1**). Growth rings are present and the species has a straight but often interlocked grain. Its wood is considered to be an excellent substitute for teak (*Tectona grandis* L.f.) in all respects (Kukachka, 1960). Calcium deposits have been reported by some authors, with minor or no consequences for technical applications (*e.g.*, Dahms, 1999). On average, the sapwood is rather narrow (3 cm; Toussaint et al., 1953). Because of its relative ease of working, traditional uses of wood derived from *P. elata* include boards (coffins, furniture) and tool handles. The principal industrial uses are flooring, furniture, window/door frames, decorative veneer and shipbuilding (Kukachka, 1960).

Finally, with regard to agroforestry systems, Anglaaere (2005) identified *P. elata* as being among the shade tree species preferred by farmers in cocoa plantations in Ghana (species declared as "good for cocoa"). Nevertheless, when some *P. elata* seedlings were utilized during on-farm trials, they showed a very poor ability to survive and those that did survive demonstrated low initial growth rates (Anglaaere, 2005).

International timber trade. The earliest shipments of *P. elata* timber are thought to have started in 1947-1948 from Ghana to England, as the main wood characteristics of the species were still unknown before World War II (Howland, 1979; Dahms, 1999). Since the beginning of the 1990s, Cameroon and DRC have been the main exporters of *P. elata* (ATIBT, 2012). The drop in the quantity of the timber exported by DRC in 2009 (**Figure 1**) may be explained by difficulties encountered in the implementation of sustainable management procedures. In 2009, Belgium and France imported ca. 60 and 30% of the total volume of sawn wood produced in Cameroon, respectively. After ca. 60 years of lumbering, the price paid for the wood of *P. elata* became one of the highest on the world tropical timber market (800-1,000 €·m^{-3} FOB in January 2012).

Table 1. Main industrial and physical-mechanical properties of *Pericopsis elata* mature wood — *Principales propriétés industrielles et physico-mécaniques du bois de* Pericopsis elata *à maturité*.

Properties		Results	Comments
Specific gravity	- Oven-dried weight/green volume - Radial	540-630 kg·m^{-3} 3.2%	/ 1.5%(*)
Shrinkage (green to OD conditions)	- Tangential - Volumetric	5.8-6.0% 9.5-10.0%	2.5%(*) /
Wood-bending	/	Moderate in bending	/
Working	- Hand or machine tools	Readily workable, finishes well, turns satisfactorily, good gluing	Sawdust may be irritating
Monnin hardness	/	7(*)	/
Preservation	- Preservative treatments	Heartwood extremely resistant	French saturation class 4 (NF EN 350-2)
Decay resistance	- Soil-block tests	Very resistant to brown rot and resistant to white rot	French durability class 1-2 (NF EN 350-1)
Marine durability	/	Intermediate	French durability group 5 (1: best; 9: worst)
Resistance to subterranean termites	/	Resistant	French durability class D (NF EN 350-1)

Source: Kukachka (1960); Gerard et al. (1998). (*) = values at a moisture content of 12% — *valeurs données à un taux d'humidité de 12 %*.

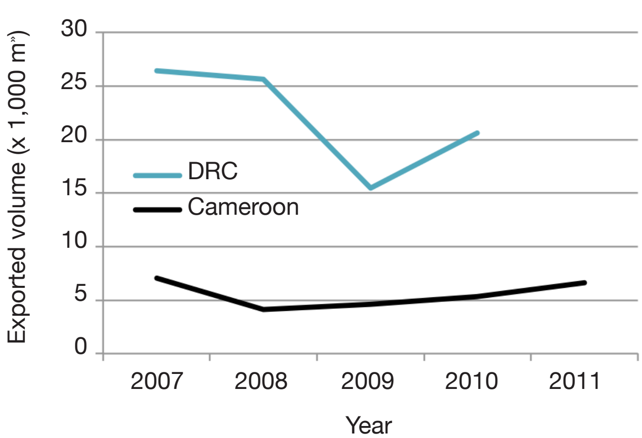

Figure 1. Changes in export volume of wood of *Pericopsis elata*'s (x 1,000 m^3) by the two main producing countries between 2007 and 2011 (2010 for DRC) — *Évolution des exportations de bois de* Pericopsis elata *(x 1 000 m^3) par les deux plus gros pays producteurs entre 2007 et 2011 (2010 pour la RDC)* (ATIBT, 2012).

Values include logs, sawn timber and flooring — *les valeurs incluent les grumes, les sciages et les contreplaqués*.

2.2. Main botanical aspects of *Pericopsis elata*

The information given in this section are derived from a selection of reference documents (Louis et al., 1943; Toussaint et al., 1953; Bonnier, 1957; Taylor, 1960; de la Mensbruge, 1966; Allen et al., 1981; Hawthorne et al., 2006; Anglaaere, 2008; Kouadio, 2009; Vivien et al., 2011).

Leaves, leaflets and canopy architecture. *Pericopsis elata* has a pinnate leaf (petiole and rachis of 12-20 cm in length) with 7-11 alternate glabrous ovate leaflets (petiolule of 3-7 mm in length). Each leaflet is 3-9.5 and 2-4 cm in length and width, respectively. Leaflets increase in length along the leaf (**Figure 2**). Their venation is not very clear (the veins are very fine) and the underside is more or less glaucous. The rachis, with linear persistent filiform-subulate stipels, is more or less glabrous and is 2-5 mm in length. The foliage is light, supported by first horizontal then drooping spreading branches (**Figure 3**).

Flowers. *Pericopsis elata* has bisexual flowers held in panicles with pubescent to glabrous peduncles and a rachis of 2-6(12) cm in length. White flowers (1.5 cm long, **figure 4**) have ovate bracts, each of 1.5 mm in length, a 5-toothed pubescent calyx (9-12 mm long) with the upper 2 closely joined, ten glabrous stamens with filaments of 9-19 mm in length, and a silky-silver

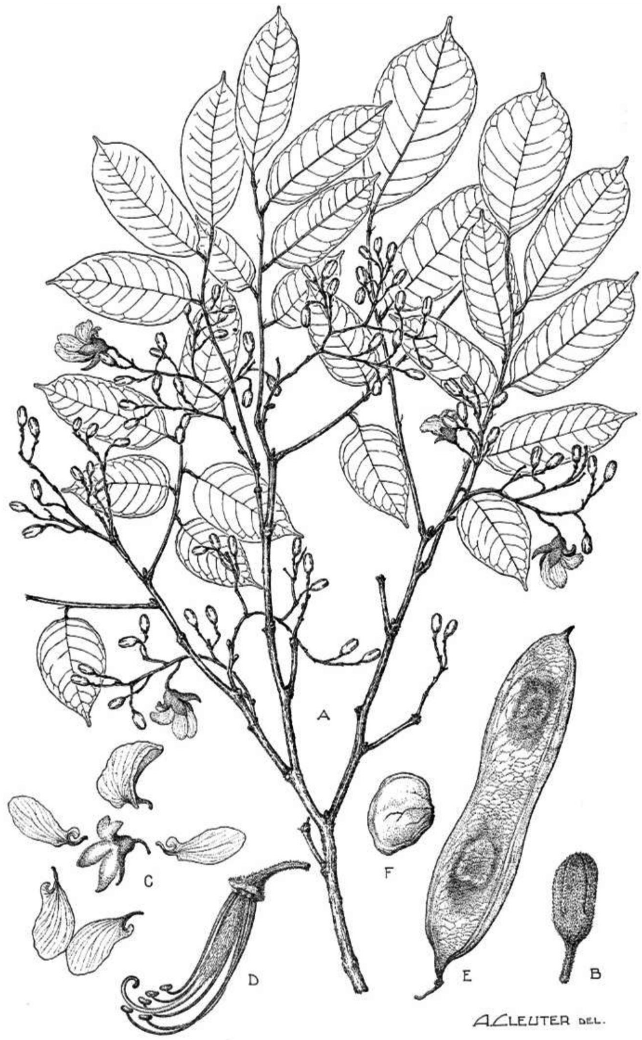

Figure 2. Foliar and floriferous organs of *Pericopsis elata* — *Détail des organes foliaires et floraux de* Pericopsis elata (Toussaint et al., 1953, with courtesy).

A: flowering branch — *branche florifère (x 0.5)*; B: flower bud — *bourgeon floral* (x 2); C: calyx and petals — *calice et pétales* (x 1); D: gynaeceum and part of the androceum — *gynécée et éléments de l'androcée* (x 2); E: pod — *gousse* (x 0.5); F: seed — *graine* (x 1).

or gold compressed ovary of 5-6 mm in length and 1.5 mm in width, containing 3-5 ovules.

Fruits. The fruit of *P. elata* is an indehiscent flat pendulous wind-dispersed pod with a reticulate ornamentation and two faint longitudinal ridges. Length and width range from 7 to 17 and from 2.5 to 3 cm, respectively. Bourland et al. (2010) have computed an average weight of 131.6 ± 10.1 cg per pod. This oblong fruit presents pointed ends and a highly reticulate surface. The fruit holds 1-4(5) seeds, with their position being easily visible from the outside. These seeds are flat with a width varying from 1 to 1.5 cm.

Germination and seedlings. Epigeal germination generally occurs 5 to 10(15) day after sowing. If sowed within the first 10-20 days, viable seed germination rates are on average ca. 85-95%. Seedlings are characterized by (4.5)6.5(9) cm long hypocotyls and somewhat fleshy opposite oval cotyledons (12 mm long and 13 mm large; **figure 5** left and centre). The first two leaves are stipulated, unifoliate and opposite or subopposite. The third and fourth leaves alternate with 2-3 leaflets (**Figure 5** right). Young trees frequently show a bushy pattern of growth characteristic of the species.

Roots, bole and bark. *Pericopsis elata* has nitrogen-fixing nodules. The stem is often uneven and unbuttressed, although in some places it is slightly fluted. The bark has a light color. At the pole stage, the bark peels off in irregular slender scales to leave reddish patches, which make the species easy to recognize. The bark thickness ranges from 0.5 to cm. The outer layer of the slash is green, while the remaining layer is yellow, turning darker upon exposure. The diameter at breast height can reach up to 130 cm.

It is interesting to note that many authors insist on alleged similarities between *P. elata* and *Distemonanthus benthamianus* Baill., mainly because of the red color of the bark and ecological similarities between the two species. **Table 2** presents some discriminatory characteristics of both species.

2.3. Taxonomy

From *Ormosia* to *Pericopsis*. The species *P. elata* was originally included in the genus *Ormosia* Jacks. Harms (1913) created the genus *Afrormosia* to separate the African ("Afr", with flat indehiscent pods) species from the Asian and American ones (with inflated dehiscent pods). While Louis (1943) provided additional descriptions of the species, Knaap-van Meeuwen (1962) reduced *Afrormosia* to *Pericopsis*. Based on the anatomy of the wood of *P. elata*, Normand et al. (1976) reached conclusions similar to those of Knaap-van Meeuwen in differentiating African species from the Asian and American ones.

Pericopsis Thwaites (Fabaceae, Papilionoideae) now comprises five species, four of which naturally occur in Africa (the remaining one in Asia).

***Pericopsis laxiflora* (Benth.) Meeuwen vs. *P. elata*.** Harms (1913) stated that the main differences between *Afrormosia elata* (forest tree) and *Afrormosia laxiflora* (savanna tree/shrub) lay in the size of the leaves and of the rachi, with additional differences to be found in some traits of fertile branches (the former species presenting more pubescence). The author suggested that some specimens identified at the beginning of the

Figure 3. Trunk of an adult tree (left), details of peeling bark (centre) and foliage (right) of *Pericopsis elata — Tige adulte (à gauche), aperçu de la desquamation de l'écorce (centre) et détail du feuillage (à droite) de* Pericopsis elata.

Figure 4. *Pericopsis elata*: pedicel and flower bud (left), pedicel, calyx, gynaeceum and stamens (right) — Pericopsis elata : *pédicelle et bourgeon floral (à gauche), pédicelle, calice, gynécée et étamines (à droite)* (31 March 2009).

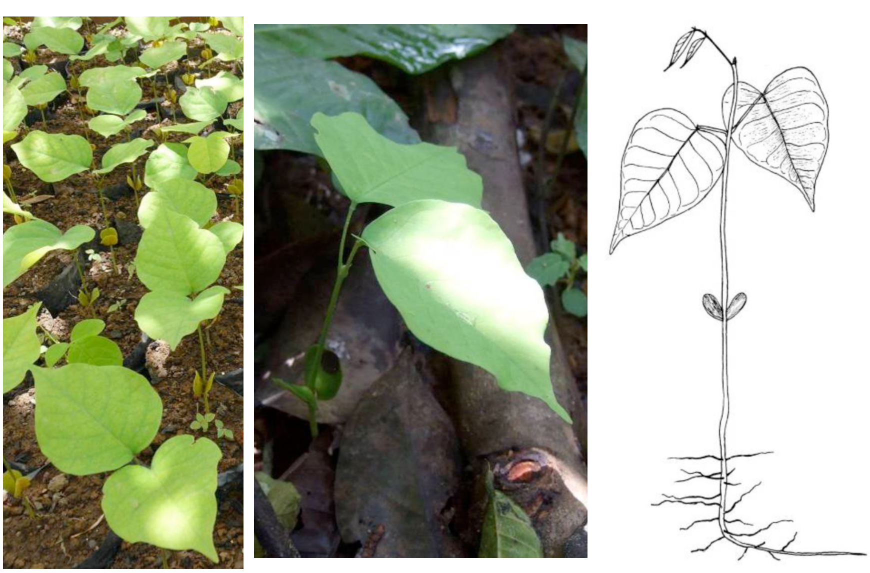

Figure 5. *Pericopsis elata* seedlings at the stage of the first two leaves (ca. 1 month after germination, cotyledons still attached) in a nursery (left) and in a natural environment (centre). Schematic view of the root system (right, modified from de la Mensbruge, 1966) — *Plantules de* Pericopsis elata *au stade des deux premières feuilles (ca. 1 mois après germination, cotylédons toujours en place) en pépinière (à gauche) et issue de la régénération naturelle (centre). Vue schématique du système racinaire (à droite, d'après de la Mensbruge, 1966).*

Table 2. A selection of discriminatory botanical characteristics distinguishing *Pericopsis elata* and *Distemonanthus benthamianus — Quelques caractères botaniques permettant de différencier aisément* Pericopsis elata *et* Distemonanthus benthamianus.

Botanical trait or physiological organ	*Pericopsis elata*	*Distemonanthus benthamianus*
Color of the bole	Light colored, peeling off to leave rusty blotches	Red, especially towards the top. Peels off on the lower part to leave light-colored marks
Stipellae of leaflets	Present	Absent
Floral diagram	S5 P5 A10 G1	S5 P5 A3 + 2 G1
Pod	With marginal ridges	Not ridged
Seed	With a notched margin	Entire

Source: Taylor (1960).

20th century as *A. laxiflora* (1) in a Ghanaian mixed deciduous forest and (2) in a Cameroonian forest should probably be considered as *A. elata*. The potential confusion between the two species is similar to the one observed in the early 20th century between *Lophira alata* Banks ex C.F.Gaertn. (forest species) and *Lophira procera* A.Chev. (savanna species, see Sabatié, 1994). Studying both *P. elata* and *P. laxiflora* in Cameroon, Sabatié (1994) noted that the natural distribution areas of both species were located at separated opposite sides of the country. This separation fits a North-South rain gradient, with *P. laxiflora* occurring in much drier environments than the taller *P. elata*. The author defined the two trees as allopatric/vicariate species, and thus suggested that they would share the same genotype. However, this is not necessarily the case.

3. DISTRIBUTION AND ORIGIN OF *PERICOPSIS ELATA* POPULATIONS

3.1. Abiotic requirements and current geographical distribution

Rainfall and soil water regime. *Pericopsis elata* is restricted to the 1,250-1,500 mm rainfall zone in Ghana (Swaine, 1996) and to 1,000 to 1,500 mm throughout its natural range. The species is tolerant to a wide range of water regimes ranging from well drained soils to seasonally waterlogged ones (Swaine, 1996; Anglaaere, 2008). No data are available regarding the potential pedological requirements of the species.

Natural distribution pattern. *Pericopsis elata* is characteristic of the semi-deciduous forest (Swaine, 1996). The tree is native to countries of Central and West Africa, occurring mainly in Ghana (West), Cameroon, Congo and DRC (Howland, 1979; Hall et al., 1981; Hawthorne, 1995; Dickson et al., 2005; Hawthorne et al., 2006; Vivien et al., 2011). The species was detected in Nigeria at the beginning of the 20th century (Howland, 1979; Dahms, 1999). It has also been observed in Côte d'Ivoire (contiguously to Ghana) and the Central African Republic (CAR), where only a few specimens have been reported (**Figure 6**).

This disrupted large-scale distribution pattern includes a series of possibly genetically isolated sub-populations. Thus, Howland (1979) suggested that further studies should be conducted in the following five major provenances (with a decreasing gradient of average annual rainfall from 1 to 5):

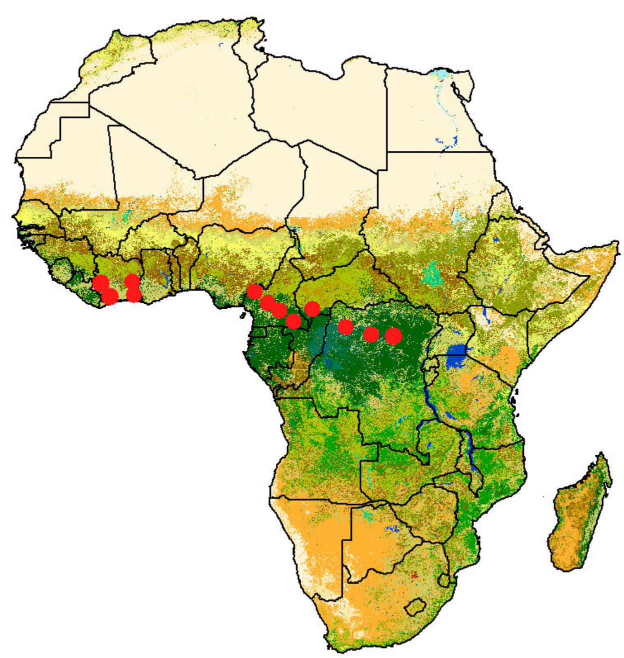

Figure 6. Natural distribution area of *Pericopsis elata* (modified from Mayaux et al., 2003 and African Plants Database, http://www.ville-ge.ch/musinfo/bd/cjb/africa/) — *Aire de distribution naturelle de* Pericopsis elata *(d'après Mayaux et al., 2003 et African Plants Database, http://www.ville-ge.ch/musinfo/bd/cjb/africa/).*

1. Côte d'Ivoire/Ghana;
2. Western Nigeria;
3. Eastern Nigeria;
4. Eastern Cameroon/Congo;
5. DRC.

Samples from each provenance (urgently 1, 2 and 3 as they are dramatically reduced) should be collected for further genetic investigations. According to Dahms (1999), the quality of the wood of *P. elata* is not homogeneous throughout its distribution pattern. The author goes on to suggest that even though the provenance of the wood of *P. elata* has not substantially affected either its price or its industrial applications so far, provenance does make a difference to the qualities of wood itself. For example, the wood of *P. elata* from Côte d'Ivoire/Ghana would differ from the wood from DRC, particularly in terms of its calcium deposit levels. This remark strengthens the need to conduct further investigations regarding the existence of such provenances as well as their origins.

Gregariousness of the species. When analyzed on a smaller scale, *P. elata* is defined as a gregarious species (Sabatié, 1994; Hawthorne, 1995; Boyemba, 2011), meaning large numbers of trees generally and naturally occur within spatially restricted areas. This ecological characteristic has also been observed for other long-lived light-demanding commercial species, such as *T. scleroxylon*. As a colonizer, the gregariousness of *T. scleroxylon* would result from its ability to invade bare areas resulting from extensive forest disturbance caused by anthropogenic activities (Hall et al., 1979). A similar reasoning could be held for *P. elata*, the two species sharing important traits (wind dispersed diaspores, tall-growing and light-demanding trees, etc.).

3.2. Assumptions regarding the origins of *Pericopsis elata* populations

Recent references (van Gemerden et al., 2003; Willis et al., 2004; Brncic et al., 2007; Bayon et al., 2012; Neumann et al., 2012) provide circumstantial evidence for the fact that Central African rainforests should no longer be considered as pristine. For some of these studies, anthracological and/or archaeological surveys have shed new light on the possible link between the dramatic changes these forests have undergone since 2500 BP (Before Present) and large-scale settlements of farming populations of Bantu origin in that area. The fact that anthropogenic activities may have strengthened the effects of already occurring climate variations is now widely accepted (Brncic et al., 2007; Dube, 2009; Greve et al., 2011). For instance, the presence of pearl millet in the excavation pits of sites where the weather is no longer suitable for its cultivation has been confirmed by pollen profiles (Neumann et al., 2012). This kind of cultivation, which still occurs today in this part of Africa, creates openings which size is estimated at between 3,300 and 7,300 m^2 (de Wachter, 2001; Nyemeck Binam et al., 2004), substantially more than the lower limit of 1,000 m^2 suggested by Boyemba (2011) for spontaneous regeneration of the species. In a forest concession under low-impact logging management where *P. elata* occurs, Kouadio et al. (2009) estimated that a logging gap area of ca. 265 m^2 is practiced. This would help to explain why low impact logging, as applied today in many parts of the distribution area of the species, does not create openings large enough to favor the natural regeneration of the species.

To complete this review of the potential positive influence of slash and burn practices on *P. elata* regeneration, it is interesting to note that the mature trees of the species are difficult to fell with traditional methods because of their high wood density. As *P. elata* adult trees have a lower than average sensitivity to fire (Dupuy, 1998), it is thus not surprising that some of them are preserved within or close to cropping areas in shifting cultivation systems (CTFT, 1956), where they may act as seed trees.

4. ECOLOGY OF NATURAL POPULATIONS

4.1. Population structure

Since juvenile and old stems are said to be rare throughout its natural distribution area, the typical population structure of *P. elata* follows a bell-shaped curve in Cameroon (Betti, 2007; Kouadio, 2009), Ghana (Swaine et al., 1988), and in some places in DRC (Boyemba, 2011). This Gaussian-type distribution suits light-demanding species, which were once favored by past large openings.

4.2. Phenology

Three documents describing the phenological traits of *P. elata* are available for the region of Yangambi (DRC; Vangu-Lutete, 1985; Pieters, 1994; Boyemba, 2011). Only a few references briefly refer to the phenology of the species in Ghana (Taylor, 1960). Apart from the preliminary results of Bourland et al. (2010), no other information are available for Cameroon. Finally, Howland (1979) gives some sparse phenological data for the species, without giving population locations.

Leaf shedding and flushing. Classified as a deciduous species by Vivien et al. (2011), leaf shedding occurs during the main dry season (January-February in the

Yangambi region). Agyeman et al. (1999) consider the tree as an evergreen species in the Ghanaian context.

Flowering. In DRC and Ghana, flowering occurs from February to (May-)June, with a maximal frequency being reached in March. In Cameroon, flowering starts in March-April (Bourland et al, 2010).

Fruiting. In the Yangambi region, the seed rain occurs either from June to September (Boyemba, 2011) or from November to March (Howland, 1979). Such a difference in the fruit maturation process, observed for the same species growing in a similar (if not identical) environment, is difficult to explain. In Ghana, the *P. elata* pods do not become ripe until August to November. According to Boyemba (2011), 70% of the fruits are disseminated within the first 50 m away from the canopy, with only 3% reaching a distance of 100 m. The author also suggests that mast fruiting would occur every 2-3 years, while Pieters (1994) suggests every 2-4 years in the same ecological conditions. Vangu-Lutete (1985) showed that dissemination of ripe fruit lasts ca. 2 weeks.

In their study of *P. elata* in Cameroon, Bourland et al. (2010) noted that minimum fertile and effective fruiting diameters were 32 and 35 cm (> 30 cm for Boyemba, 2011), respectively. They also found that the fruit ripened over 7 months.

During germination experiments conducted under the forest canopy, Pieters (1994) observed that some of the pods he had dropped on the ground had disappeared. He suggested that rodents might have fed on the pods. However, no clear evidence or other mentions of such removal/destruction by animals can be found in the literature for *P. elata*.

4.3. Germination processes, natural regeneration and light requirements

Pieters (1994) reported that *P. elata* germination occurs naturally in the Yangambi region in February and March, which suggests a seed rain from November to March, as stated by Howland (1979). In his conclusions, Pieters (1994) stated with certainty that the untouched forest microclimate (close to the ground, with a very low level of light exposure and a high moisture content) is the most favorable for the germination of these species, while the environment created after clear felling is extremely unfavorable. After germination in an untouched forest, he noted a high mortality rate among young seedlings, especially during the first weeks after germination. This mortality rate fell sharply 14 months after germination but remained higher in the darkest spots of his study site. Pieters found that the development of seedlings was strongly inhibited at that stage and that the removal of lianas and understorey trees had only a limited positive effect. The most favorable environment for height growth was achieved when all of the vegetation, apart from the possible seed trees, was removed one year after germination. Pieters' (1994) experiments confirmed the findings of Ampofo et al. (1972; seedling growth occurred best under a relative light intensity of 18%), showing that too much light inhibits height increase during the first months after germination. In the darkest spots of his study site, Pieters (1994) recorded that seedlings had a reduced number of leaves and were weak, but that they suffered little from insect attack. In contrast, in artificially opened environments, the author reported that the top shoots of seedlings were regularly nipped out by insects (leading to a bushy aspect of the young crown) and that there were high rates of defoliation by caterpillars. The assumption was that those attacks were positively linked to the importance of the silvicultural intervention in that area (but that the attacks did not necessarily induce the death of seedlings).

Taylor (1960) obtained similar results in Ghana, showing that *P. elata* is tolerant to a certain amount of shade in its early youth, but shortly afterwards becomes a light-demander. In the same Ghanaian context, *P. elata* is classified among either pioneer or non-pioneer light-demanders by various authors (Ampofo et al., 1972; Swaine et al., 1988; Hawthorne, 1995; Kyereh et al., 1999).

4.4. Growth and natural mortality

Growth. Growth monitoring of *P. elata* has been carried out in natural stands as well as plantation trials. **Table 3** summarizes the data available for planted stands in Cameroon, DRC and Ghana. The ADI ranges from 3.9 to 15.2 mm per year in enrichment plantings; the variation might be explained by differences in growth conditions. Increments obtained in line plantings in Cameroon (in similar environmental conditions) under the canopy forest and in wide open areas provide among the lowest and the highest increments, respectively. These findings emphasize high light requirements of the species at the seedling and sapling stages. Regarding growth performance at the adult stage, Schmitz (1962), Vangu-Lutete (1974) and Boyemba (2011) reported ADIs in Yangambi mixed moist forest of 6.8 (11 trees), 4.5 (101 trees) and 4.2 ± 1.4 mm per year (422 trees), respectively. In natural stands in Cameroon, Kouadio (2009) and Bourland et al. (2010) found similar results (ADI of 3.2 ± 0.4 mm per year). Except for Schmitz's finding (6.8 mm), which should be treated with caution (study restricted to 11 trees, based on tree ring analysis), ADI values range from 3.2 to 4.5 mm per year. This variability could originate in differences in soil fertility rather than other abiotic parameters (rainfall quantity

Table 3. Mean annual diameter increments (ADI) of *Pericopsis elata* recorded in plantation trials — *Valeurs moyennes de l'accroissement annuel en diamètre observé dans des essais de plantation de* Pericopsis elata.

Location	**Source**	**ADI** (mm·year^{-1})	**Comments**
DRC	Donis (1956)	8.0	Over the first 16 years, arboretum
DRC	Donis (1956)	3.9	Over the first 13 years, plantation
Ghana	Howland (1979)	10.8	Over the first 4 years, plantation
Ghana	Howland (1979)	13.1	Over the first 7 years, plantation
Ghana	Anglaaere (2005)	11.0	Agroforestry system, planted as shade trees

and seasonality, temperature and light exposure are fairly similar between both sites).

Mortality. In the Yangambi forest, Vangu-Lutete (1974) computed over a period of 30 years annual mortality rates of 0.73 and 0.85% for stems with a dbh > 12.8 cm and for all 137 stems of his study site, respectively. In the same forest, Boyemba (2011) recorded over a much shorter period of time (but with 422 trees) an annualized mortality rate of 0.6%. No other data are currently available regarding this important forest management parameter.

5. FOREST MANAGEMENT

5.1. Main identified pests, nursery-raising, plantations and other silvicultural interventions

Identified pests. A checklist of Scolytidae (Coleoptera) pests affecting *P. elata* is given by Wood et al. (1992). Among the 26 insects listed, two are widely distributed, notably in West Africa: *Xyleborus ferrugineus* Wood & Bright (ambrosia beetle) and *Doliopygus conradti* Wood & Bright, both of which normally breed in dead/dying trees (Howland, 1979; Wagner et al., 2008).

In their study of *P. elata* in Cameroon, Bourland et al. (2010) preliminary observations of the seed rain showed that the proportion of seeds eaten by insect larvae significantly depended on the remoteness of the seed tree from other individuals of the same species (extreme rates ranging from 10 to 95% for totally isolated to clustered trees, respectively). In their study of forest insects of Ghana, Wagner et al. (2008) noted that *Laspeyresia* sp. nr. *tricentra* Meyr. may be implicated in seed feeding. Taylor (1960) suggested that instead of lack of light being a causal factor, seed damage caused by insects could cause the paucity of natural regeneration. Pieters (1994) described similar important seed losses after insect attacks in DRC populations.

Regarding pests potentially affecting seedling mortality and growth in Ghana (both in nursery and natural environments), Lemmens et al. (2010) and Wagner et al. (2008) showed that the leaf-tying moth *Lamprosema lateritialis* Hampson (Lepidoptera: Pyralidae) posed the most serious threat. According to Wagner et al. (2008), repeated defoliations by caterpillars cause up to 31% of the mortality rate of 6-month-old seedlings. The authors showed that within their average larval life span (21 days), each caterpillar consumes the equivalent of 2-3 pinnate leaves. Since an average egg batch may contain up to 200 eggs (laid on the upper surface of leaflets), caterpillars emerging from those eggs would be able to totally defoliate several 6(7)-month-old seedlings. As a pest management method for application in nurseries, the authors recommend a mechanical removal of eggs during normal morning watering. In Cameroon, other Lepidoptera may impact seedling growth and/or survival rates in plantations (see photographs in **figure 7**).

In Ghana, *Apate indistincta* Murr (Coleoptera: Bostrichidae; wood borer of living trees) has been

Figure 7. Example of two Lepidoptera (caterpillar stage, to be identified) affecting *Pericopsis elata* seedling in plantations. Photographs taken in Southeastern Cameroon in April 2008 — *Exemple de deux lépidoptères (stade chenille, à identifier) occasionnant des dégâts dans les plantations de* Pericopsis elata. *Photographies prises au Sud-Est du Cameroun en avril 2008.*

reported as attacking the seedlings of *P. elata* (Atuahene, 1976). In his conclusions, the author of that study recommends removal of infested individuals so as to control this pest in the nursery. Apart from damage caused by insects, damage has also been reported as being caused by gorillas feeding on young leaves and fruit (Tropicos.org. Missouri Botanical Garden. 11 May 2012 <http://www.tropicos.org/Specimen/78675>). This is likely to have been noted during the fruit ripening period in an environment where *P. elata* is scarce.

Handling of nursery-raised seedlings. Together with relatively high increments reached in open areas, the ease of handling *P. elata* seedlings in the nursery makes the tree a most promising plantation species (see Howland, 1979). Pieters (1994) noted a germination rate of 87% in a controlled artificial environment in Yangambi. In a nursery in Cameroon, Kouadio (2009) recorded germination rates of between 44 and 74% (reached on average after 10 days) when seeds were sowed immediately after collection. Provided basic good management procedures are applied in the nursery (including pest control) and seeds are stored for no longer than 2 months before sowing, Kouadio (2009) showed that vigorous seedlings of ca. 50-60 cm tall can be obtained after 9-12 months without fertilization.

Plantations and other silvicultural interventions. Despite the fact that *P. elata* can easily be propagated from seed, the species is not being planted on a large scale. Nevertheless, some experiments have been conducted on a smaller scale, mainly in Ghana and DRC.

Working on methods to compensate for sparse recruitment in the Yangambi area, Pieters (1994) stated that no specific initial intervention should be applied, since germination occurs best under an intact forest cover. The author recommends the cutting of lianas and saplings of undesired species for the first weeks after the tree's germination. In the meantime, a progressive release within the upper canopy cover should be promoted to avoid a massive loss of seedlings. Pieters (1994) recommends that, after this initial germination, seedlings should be freed twice during the first year and then the area weeded once a year. Although this technique led to positive results in the context of Pieters' study, its routine application is unlikely. This approach would probably be too expensive and time-demanding for most forest managers (logging companies in Central Africa). In addition, as also pointed out by Kouadio (2009), temporary storage of fruits before sowing is one of the main causes of poor regeneration success (Pieters, 1994).

In Cameroon, Kouadio (2009) investigated the possibility of rehabilitating logging gaps by applying the direct sowing method. The germination rate was found to be $44.9 \pm 7.7\%$ for ca. 1,000 sowed seeds in 11 gaps. After 30 months (with no intervention), $68.3 \pm 9.4\%$ of the seedlings had survived but growth (in height) was quite limited compared to other tested species (*e.g.*, *Baillonella toxisperma* Pierre). Such experiments conducted in logging gaps require further investigation, for instance through the planting of nursery-raised seedlings (Kouadio et al., 2009) instead of direct sowing.

5.2. Implications of national regulations for forest management

Regulations governing logging have implications for the management of *P. elata* populations. In the Congo Basin, logging companies are obliged to implement management plans based on specific inventories, a minimum logging cycle (*e.g.*, of 30 years in Cameroon) and the calculation of commercial species recovery rates (*sensu* Durrieu de Madron et al., 1998) over this period (as well as meeting other requirements). A minimum recovery rate of 50% of the initial stock (in terms of number of trees) is generally suggested. If required, the MLD may be increased. In Cameroon, exportation of *P. elata* logs is prohibited in order to promote local processing and the MLD was lowered from 100 to 90 cm in June 2010. This MLD value remains higher than the one used in other central African countries (**Table 4**).

5.3. Conservation status

Presently, stocks of *P. elata* are reported to be dramatically reduced, specifically in Ghana, Côte d'Ivoire, Nigeria and CAR (Hawthorne, 1995; Dickson et al., 2005). With the exception of Ghana, the species may even be close to disappearance in those countries

Table 4. Minimum logging diameter (MLD) applied in the three *Pericopsis elata* timber-producing countries (the Ghanaian value is given for comparison purposes only) — *MLD (diamètre minimum d'exploitation) imposés dans les trois pays producteurs de bois de* Pericopsis elata *(la valeur anciennement adoptée au Ghana est donnée à titre de comparaison)*.

	Cameroon	Congo	Democratic Republic of Congo	Ghana
MLD (cm)	90	60	60	110

Source: Dickson et al., 2005; Cameroonian Rule 0511/D/MINFOF/SG/DF/BSJ, June 2010.

(especially Côte d'Ivoire and CAR). Consequently, and because of its continuing exploitation in Cameroon, Congo and DRC, *P. elata* is now included in CITES Appendix II (Abensperg-Traun, 2009), and is recorded as "Endangered A1cd" on the IUCN Red List (IUCN, 2001). According to Abensperg-Traun (2009), national legislation in those countries is generally able to meet all (Cameroon and DRC) or parts of (Congo) the requirements for the implementation of CITES. In addition, being included in CITES Appendix II means that export and import licenses are necessary for logs and sawn wood of the species. These licenses are controlled by the scientific authorities of the CITES administration for the exporting and importing countries concerned.

6. CONCLUSION AND RESEARCH PERSPECTIVES

In most of the literature reviewed in the present study, regeneration of *P. elata* is reported as being remarkably rare, despite abundant seed production wherever it is studied in its distribution area. It is probable that the species will soon disappear from CAR, Côte d'Ivoire and Nigeria because of a combination of a lack of regeneration and the current increasing human pressure (mainly intense logging activities and agriculture). *Pericopsis elata* populations in Ghana are said to have been dramatically reduced over time (Dickson et al., 2005).

Despite being listed both in CITES Appendix II and on the IUCN Red List, important information on *P. elata* ecology are still lacking (Howland, 1979; Anglaaere, 2008). Indeed, too few data are available on phenological patterns and fertility, making it difficult, for example, to analyze the impact of logging on seed tree populations. Lemmens et al. (2010) identified growth, genetic selection for plantations and resistance to *L. lateritialis* as the main research issues still to be addressed. In addition, almost nothing is known about the history of *P. elata* populations in general and specifically why regeneration is dramatically lacking in its natural distribution area. Consequently, more research is needed before a definitive decision can be made to allow harvesting of *P. elata*, in order to ensure that this action does not threaten the species with extinction. Recent developments in genetics (Micheneau et al., 2011) should prove useful in investigating Sabatié's (1994) assumption that phenotypic differences between *P. elata* and *P. laxiflora* are induced by environmental changes. As highlighted by Daïnou et al. (2012) for another timber species, such a study would also investigate the genetic variation and spatial genetic structure of *P. elata*. These genetic studies (especially the analysis of the origin of phylogeographic patterns for the species), together with work involving archaeological and anthracological aspects, could help us to understand the origins of *P. elata* natural populations as well as their evolution. Finally, plantation trials need to be conducted to identify affordable and effective enrichment methods that could be routinely applied by logging companies (including pest identification and control techniques).

Abbreviations

ADI: mean annual diameter increment
ATIBT: Association Technique Internationale des Bois Tropicaux
CAR: the Central African Republic
CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora
CTFT: Centre Technique Forestier Tropical
DRC: Democratic Republic of Congo
FOB: free-on-board
IUCN: International Union for Conservation of Nature
MLD: minimum logging diameter (official value)

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