

Original Research Article

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Phytoecological Characterization of the Spontaneous Oleaginous of the Congolese Forest

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ABSTRACT

The study of the potential of Congo's spontaneous flora in biofuel resources is based on the parameters of ecological structure. 11 species (22.9%) are present on the 48 main retained by PROTA 14. The spatial distribution of the species shows that only the Bétou UFA gathers all the species. The best represented in the different forest areas are *Ongokea gore*, *Pentaclethra eetveldeana*, *Pentaclethra macrophylla* and *Pycnanthus angolensis*. Except for the Conkouati-Douli National Park, the Lossi Sanctuary and the Aubeville Forest, where there are some peculiarities, these species are characterized by low densities ranging from 0.001 to 5 individuals.ha⁻¹ and basal areas generally less than 1 m².ha⁻¹. The diametric structure is on the whole erratic type, marker of insufficient regeneration. Phytoecological data reveal that this forest cannot support sustained industrial exploitation in the production of second-generation biofuels. These species, which constitute an energy source for the disseminating agents, are 73% nutritive and 82% phytotherapeutic to humans. These multi-purpose species are at the same time of interest to the wood and craft industries, while being non-timber forest products of prime choice.

Keywords

Congo, Floristic diversity, Biofuel, Congolese forest, NWFP, Phytoecology.

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Introduction

Located in central Africa, the Congo is covered by 60-65% rainforest and 35-40% savannah (Vennetier, 1977; Hecketsweiler, 1990). Forest cover accounts for about 12% of the Congo Basin forests; equivalent to about 10% of tropical forests (IUCN, 1996; Hecketsweiler, 1990; FAO, 2005). The Congolese forest is divided into three discontinuous blocks of unequal size, both in size and floristic diversity (IUCN, 1996; Kimpouni *et al.*, 2013a). The northern Congo block, by far the most luxuriant and diversified, covers a dry facies (31%) and a

flooded (20%). Those of the south-Congo developed on the mainland and were distributed as follows: the Mayombe (3%) and the Chaillu (11%). Congolese forests, particularly in southern Congo, have been exploited since the 1920s for: (i) dam construction, (ii) bridges, and (iii) locomotive boiler feed until 1957, when Fuel oil replaces solid fuels (Cusset, 1989). Until 1972, logging was the first support of the Congolese economy before being supplanted by oil. Studies show that Congolese populations derive substantial benefits by exploiting

floristic diversity. The most profitable aspects are ethnobotany linked to the traditional pharmacopoeia, food, crafts and phytochemistry. The issue associated with biofuels is new and almost unknown.

The surge in oil prices and the problems of pollution caused by the use of fossil and non-renewable energies, the exploitation of biofuels is a global deal with multiple benefits. Biofuels are defined as fuels produced from non-fossil organic materials derived from biomass that complement or substitute fossil fuels. Depending on the origin of the biomass used and the processing processes, biofuels are classified in three generations [(i) biofuels produced exclusively from crops (first generation); (ii) biofuels resulting from oilseeds (second generation) and (iii) biofuels of algal origin known as algae fuels (third generation)] and two sectors (alcohol and oil and derivatives).

Currently, only the first generation of biofuels has reached the industrial stage. In comparison to fossil fuels, biofuels have the advantage of being less polluting, renewable and inexhaustible if they are managed sustainably (Raven *et al.*, 2010). However, their disadvantages include: (i) the allocation of the best agricultural land, and (ii) the conversion of several hectares of forest for settlement. The dreaded consequences are: (i) occupation of arable land, (ii) food insecurity and famine, and (iii) population migration. Despite the negative aspects, the biofuel sectors are developing more and more everywhere in the world. This is the case in Europe, where consumption of biofuels increased by more than 3% between 2010 and 2011. From 13.2 million tons of oil equivalent in 2010 to 13.6 million tons of oil equivalent in 2011, an increase of 3%.

In tropical Africa, more than 250 species of oilseeds are identified and used for their oil,

but only 65 (26%) are suitable for this purpose. The tests of a second-generation biofuel operation selected 48 (19%) species with proven potential (Grace *et al.*, 2009). In the Congo, if the biofuel sector is not yet developed, Ouamba *et al.*, (1985) report that Congolese flora has a non-negligible wealth of oil-bearing species capable of producing biofuels. However, there are no studies to determine the behaviour of the biofuel resources species within the Congolese flora. The characterization of the phytoecological parameters of the said taxa is the basis of this study.

The objectives of this study focus on improving the knowledge of Congo flora by: (i) inventorying the second generation biofuel resources species of the Congolese flora; (ii) characterization of phytoecological data for each taxa; (iii) estimating the potential of the Congolese forest for a sustained and rational industrial exploitation of second-generation biofuels

Materials and Methods

Presentation of the study site

Stretching between latitudes 4 ° North and 5 ° South and longitudes 11 ° and 19 ° East (Figure 1), the Congo straddles the equator and covers 342000 km² (Venetier, 1977; Sy *et al.*, 2008). Located in Central Africa, it is bordered by the Central African Republic to the north, Cameroon to the northwest, Gabon and the Atlantic Ocean to the west, the Democratic Republic of Congo to the east and south-east, Angolan enclave of Cabinda in the South (Venetier, 1977).

The climate is a wet equatorial type with three variants: (i) equatorial climate in the northern part, characterized by abundant rainfall throughout the year, with peaks oscillating from 1600 to 2000 mm / year; (ii) subtropical

in the center, the characteristics of which are (i) a dry season of 1 to 3 months, (ii) precipitation between 1600 and 1800 mm (Vennetier, 1977); (iii) low-Congolese climate in the south-west, characterized by moderate rainfall and a very marked dry season (June to September) framed by two rainy periods, the most abundant from February to May. The precipitations vary between 1200 and 1700 mm (M.E.F.E, 2012b). It is characterized by an average annual temperature of about 25 ° C. The thermal amplitudes do not exceed 5 ° C during the year. This climate is marked by (i) a dry and cool season from June to September and (ii) a warm and humid rainy season from October to June with a very pronounced slowdown in precipitation between January and February (Vennetier, 1977).

Soils

Congo soils are generally ferrallitic, poor in exchangeable bases and highly permeable due to the sandy substrate which facilitates the migration of soil solutions (Vennetier, 1977; Denis, 1970). According to Denis (1970), these soils are divided into four main classes: hydromorphic soils, podzols, poorly developed soils and ferrallitic soils.

Vegetation and flora

The forest formations have a floristic composition dominated by Fabaceae, Malvaceae, Rubiaceae and Euphorbiaceae (White, 1986; Kimpouni, 1993). Dense and clear forests on land develop in the Mayombe and Kouilou regions (150,3172 hectares, or 6.69% of Congolese forests), (ii) in Chaillu (4,386,633 hectares, or 19.52% of forest cover), (iii) Upper Sangha (7,500,000 hectares, or 33% of Congo's total forests); The flooded forests of Lower Sangha (85,000,000 hectares, or 38% of Congolese forests); Forests, galleries and forest mosaics

(589,862 hectares, or 2.63% of Congo's forests) are developing in the Plateaux, the Pool and the Bouenza. The savannahs, mainly in the south of the equator, are interspersed with forest groves and galleries. They are divided into three zones of unequal importance: the Plateau of the Cataracts, the Niari Valley and the large Batéké itself heterogeneous (Diafouka, 1997).

Congolese chorology

The territory of the Republic of Congo is included in the regional center of Guineo-Congolese endemism (White, 1986). Inspired by the subdivision of Descoings (1975), Kimpouni *et al.*, (1992) integrated this territory into the African chorological system of White (1979, 1986). Eleven phytogeographical districts grouped into six sectors; three domains and two regions are recognized. Congolese forests are mainly located in the (i) Mayombe (Mayombian forests) phytogeographical districts; (ii) Chaillu (Chaillu forest); (iii) Upper Sangha and Lower Sangha (Congo northern forest).

Materials

The base of the biofuel source species is the inventory of PROTA 14. Taxa whose samples are absent from the herbarium, their certification in the Congolese flora is based on data from the literature; this is the case of *Irvingia wombulu* Vermeesen. This activity not only confirmed the existence of biofuel source species of the Congolese spontaneous flora; But also to establish their geographical distribution.

The material is based on specimens of spontaneous oilseed plants collected in Congolese forests and deposited in the national herbarium (IEC) located at the IRSEN; of our own floristic inventories (Youbi, Lossi, Aubeville), the compilation of

forest management inventory data from forest concessions (BétouUFA, MissaUFA, Mokabi-DzangaUFA, LopolaUFA, IpendjaUFA, Loudoungou-ToukoulakaUFA, KaboUFA, PokolaUFA, NgombéUFA, Pikounda NordUFE) and protected areas (Odzala National Park, Conkouati-Douli National Park), the Makany (1976) phytosociological surveys in the plateaux Téké forest (Figure 1).

The analysis of the labels of the 39 herbarium samples representing 10 species reveals that: (i) 12 are harvested in the Mayombe forest; (ii) seven from the forests of the Mayama area; (iii) 3 from the Moutampa forest; (iv) two collected from the Gamboma forest islets; (v) 15 samples collected from the Congolese forest, one specimen per locality: Zanaga forest, forest on the Kinkala road, 17 km from Brazzaville, Frigniagbe forest (French Guinea), Bomassa forest, gallery of Banza-Ngedi (Brazzaville), forest at Mabombo, forest at N'douo ferry, forest block at Inoni cliff, forest at Divinié, forest gallery near Edou, forest on Mayéyé road, Ngo forest block, Forest north of the IEC concession, Mandombé forest (Boko), gallery at Loufoulakari falls.

Methods

The study method is based on two complementary approaches: bibliographic compilation, on the one hand, and (i) the use of forest inventory data for management plans and (ii) accessible floristic surveys.

Bibliographic compilation

The bibliographic compilation allowed the state of place of taxa source of biofuel, the spontaneous flora Congolese. It is based on the work of Makany (1976), Sita and Moutsambote (1988), Hecketsweiler and Mokoko-Ikonga (1991), Nzinga (1992), Van Asbroeck *et al.*, (1997), Kimpouni (2006), Kimpouni *et al.*, (2008), M.E.F.E (2003a,

2003b, 2004, 2006, 2007, 2008a, 2008b, 2010a, 2010b, 2011, 2012).

Using data from accessible management plans and accessible plant records

The data result from the UFAs which have been the subject of a multi-resource inventory for a management plan on the one hand, and on the other hand of all accessible plant works. For example, in the forest zone (i) in the northern Congo, the combined data come from the UFAs Betou (300,000 ha), Missa (225,500 ha), Mokabi-Dzanga (370,000 ha), Lopola (199,900 ha), Ipendja, Loudoungou-Toukoulaka (552,676 ha), Kabo (267,048 ha), Pokola (377,550 ha), Ngombé (13,500,289 ha), Pikounda North UFE (93,970 ha), Odzala-Kokoua National Park Sanctuary of Lossi (35,000 ha); (ii) Cataracts, the floristic data of the Aubeville forest (1.5 ha); (iii) the Mayombe and the Congolese littoral, the data are those of the GREFE on the *Aucoumeaklaineana* forest (4 ha), and in the Conkouati-Douli National Park (504,950 ha) the survey is about 6 ha.

Ecological parameters monitored

The phytoecological parameters identified for each species are density, diametric structure, basal area, relative frequency, relative density, relative abundance and mean overlap, type of diaspora and ecological group.

The frequency of taxa is equal to the number of surveys where the taxon is present;

The relative frequency is equal to the number of surveys where the taxon is present relative to the total number of surveys;

The relative density is equal to the density of the taxon by the total density of the taxa;

Index of diversity is equal to the number of species of the family by the total of the species of the survey;

The density expresses the number of individuals of a species per unit area. It allows not only to assess the contribution of each species in the forest sectors, but also to compare them whatever the size of the areas inventoried (Puig, 2001);

Basal area is the area of trunks projected on the ground. It allows us to better appreciate the spatial areas occupied by the trunks of a species in a given ecosystem, but also to estimate the production capacity of a species (White and Edwards, 2001; Mbou, 2009);

The diametric structure makes it possible to assess the regeneration capacity of these species within the forest (Peters, 1997; Puig, 2001);

Relative abundance is the number of individuals of a species relative to the total number of individuals in a given ecosystem. It makes it possible to form an idea of the rank occupied by each species in relation to the others, in the different forests;

The average coverage is the projection on the ground of the air cover of an individual. It allows appreciating the surface of all the aerial part of the individual, in order to have an idea of the productive capacity of the latter.

Results and Discussion

Floristic diversity

From 48 main spontaneous oilseeds of the tropical flora, 11 are present in forest formations in the Congo, 23% (Table 1 and Appendix 1).

They are distributed in 7 families of which Irvingiaceae is the most diversified with 3 species.

Phytoecological data

Frequency and densities

The frequency of the present taxa varies from 17.65 to 94.12%; the relative frequency oscillates from 2.56 to 13.68%; the relative density is between 9.09 and 27.27%. The best represented species are *Pentaclethra macrophylla*, *Pycnanthus angolensis* and *Ongokea gore*. The most prominent families are Irvingiaceae (27.27%), Fabaceae and Clusiaceae with 8.18% each.

Among all the taxa, *Pentadesma butyracea* and *Irvingia wombulu* would be the least present in the Congolese forest. These taxa combine the weakest phytoecological data (frequency, relative frequency and relative density).

Relative abundance

The biofuel resources species are less abundant in the forest formations of the Congo (Table 2). The Lopola forest, taken as an example, reveals a relative abundance ranging from 0.84 to 2.82%. Total recovery in the UFA is 7.59%. *Panda oleosa* is the most abundant species and one that supports the recovery of species resources in biofuel.

Density data for taxa

From one forest type to another, the density of the different taxa is very variable without being high. For all forest formations, they range from 5.5 to 0.17 trees.ha⁻¹.

Kouilou district

In the Youbi forest the densities vary from 1 to 1.7 tree.ha⁻¹, for an average of 1.08 ± 0.35 tree.ha⁻¹. Conkouati-Douli national park, the density of biofuel source species varies from 4 to 35 trees.ha⁻¹, an average of 21 ± 4.09

trees ha⁻¹. This density is associated with *Pentaclethra eetveldeana* with an average of 16.6 ± 5.44 trees.ha⁻¹.

Niari District

In the Aubeville forest, densities range from 0.7 to 13.3 trees.ha⁻¹, or 5.5 ± 1.95 trees.ha⁻¹ on average.

Upper Sangha District

Likouala forest

Ipendja UFA, the densities of species biofuel resources vary according to forest types. (i) in the dense hardwood forest, the density varies from 0.01 to 0.37 trees.ha⁻¹ and an average of 0.30 ± 0.11 trees.ha⁻¹; (ii) in light forest, it oscillates from 0.01 to 0.39 trees.ha⁻¹, that is to say an average of 0.32 ± 0.08 tree.ha⁻¹; (iii) in the flooded forest, the density is between 0.001 and 0.71, with an average of 0.24 ± 0.07 tree.ha⁻¹.

Loundougou-ToukoulakaUFA, the stem density $10 \leq dbh < 70$ cm, is as follows: (i) in the southern mixed forest the densities vary from 0.001 to 2.32 trees.ha⁻¹, or 1.14 ± 0.35 trees.ha⁻¹ on average; (ii) in the forest at *Gilbertiodendron dewevrei* (Limballi) they range from 0.03 to 1.13 trees.ha⁻¹ and 0.42 ± 0.18 trees.ha⁻¹ on average; (iii) they range from 0.5 to 1.94 trees.ha⁻¹, with an average of 1.05 ± 0.20 trees.ha⁻¹ in the northern mixed forest.

The data for the Betou, Missa, Mokabi-Dzanga and Lopola UFAs are collected according to two classes of dbh. The class of $20 \leq dbh < 50$ cm: (i) in the Betou UFA the densities are between 0.01 and 0.65 for an average of 0.25 ± 0.05 tree.ha⁻¹; (ii) in the Missa UFA, they are between 0.01 and 0.48 tree.ha⁻¹ and the mean is 0.17 ± 0.05 tree.ha⁻¹; (iii) in the Mokabi-Dzanga forest, densities

oscillate from 0.01 to 0.55 tree.ha⁻¹ for an average of 0.44 ± 0.13 tree.ha⁻¹; (iv) and at Lopola, densities range from 0.001 to 0.74 tree.ha⁻¹ and an average of 0.31 ± 0.06 tree.ha⁻¹. As for the trees $dbh \geq 50$ cm, (i) the density in the Betou forest is from 0.05 to 2.08 tree.ha⁻¹ for an average of 0.7 ± 0.14 tree.ha⁻¹; (ii) they are between 0.02 and 1.49 tree.ha⁻¹, an average of 0.44 ± 0.12 tree.ha⁻¹, in the Missa forest; (iii) in Mokabi-Dzanga, densities range from 0.01 to 1.62 tree.ha⁻¹ and an average of 0.71 ± 0.22 tree.ha⁻¹; (iv) and in the Lopola forest, they range from 0.001 to 1.53 tree.ha⁻¹, or 0.45 ± 0.16 tree.ha⁻¹ on average.

Sangha forest

In PokolaUFA, global densities range from 0.27 to 1.22 tree.ha⁻¹ and the mean is 0.60 ± 0.12 tree.ha⁻¹. However, they are expressed according to the forest types and according to two classes of diameter of dbh, for the dense and clear forests. The trees of $20 \leq dbh < 50$ cm, (i) in dense forest the densities oscillate from 0.05 to 1.07 tree.ha⁻¹ for an average of 0.59 ± 0.15 tree.ha⁻¹; (ii) in clear forests, they range from 0.22 to 1.02 tree.ha⁻¹ with an average of 0.62 ± 0.11 . As for dbh trees ≥ 50 cm, densities range from 0.27 to 1.51 tree.ha⁻¹ for an average of 0.59 ± 0.17 tree.ha⁻¹, in dense forest; in the clear forest, they oscillate from 0.21 to 1.21 tree.ha⁻¹ and the mean is 0.58 ± 0.12 tree.ha⁻¹; (iii) in the forest at *Gilbertiodendron dewevrei* (Limballi) the densities range from 0.28 to 1.42 tree.ha⁻¹ for an average of 0.82 ± 0.13 tree.ha⁻¹; (iv) in the Marantaceae forest, densities range from 0.04 to 0.34 tree.ha⁻¹, the mean is 0.20 ± 0.04 tree.ha⁻¹; (v) and in the flooded forest, they range from 0.29 to 1.97 tree.ha⁻¹, or 0.97 ± 0.21 tree.ha⁻¹ on average.

In KaboUFA, densities range from 0.01 to 0.76 trees.ha⁻¹ and the mean is 0.39 ± 0.13 tree.ha⁻¹.

In the NgombéUFA: for the trees of $20 \leq \text{dbh} < 50$ cm, the densities are between 0.24 and 1.37 tree.ha⁻¹ and an average of 0.58 ± 0.14 tree.ha⁻¹; For trees of $\text{dbh} \geq 50$ cm, densities range from 0.11 to 0.63 tree.ha⁻¹, or 0.27 ± 0.05 tree.ha⁻¹ on average.

In the Pikounda north UFE, densities oscillate from 0.1 to 1.54 tree.ha⁻¹ for an average of 0.83 ± 0.27 tree.ha⁻¹.

West Cuvette Forest

In the Lossi forest, trees of $10 \leq \text{dbh} < 70$ cm have densities between 0.4 and 6.8 trees.ha⁻¹ for an average of 2.18 ± 0.99 trees.ha⁻¹; for trees of $\text{dbh} \geq 70$ cm, they oscillate from 0.4 to 0.8 tree.ha⁻¹, or 1.4 ± 1.04 tree.ha⁻¹ on average.

Basal area

The projection of the trunk surface of the biofuel resource species shows that all have low forest area occupancy. For all forest formations, the basal area varies from 0.27 to 1.83 m².ha⁻¹. Individually, the basal area of taxa does not reach 1 m².ha⁻¹.

Within the different UFA forests and elsewhere, the maximum basal area covered by biofuel resources is 1.83 m².ha⁻¹, at best.

In the Likouala forest area, the projected area of trunks on the ground, of biofuel resources, ranges from 1.04 to 1.78 m².ha⁻¹. *Pentaclethra macrophylla* is the species that bears this basal area.

The basal area of the species, (1) in the BetouUFA, ranges from 0.001 to 0.39 m².ha⁻¹, for a total of 1.78 m².ha⁻¹; (2) in the MissaUFA, basal area varies from 0.001 to 0.30 m².ha⁻¹ against a total of 1.04 m².ha⁻¹; (3) it ranges from 0.001 to 0.31 m².ha⁻¹ in the Mokabi-Dzanga UFA, compared with a total basal area of 1.24 m².ha⁻¹; (4) the basal area in

the Lopola UFA forest varies from 0.001 to 0.36 m².ha⁻¹ whereas it is 1.33 m².ha⁻¹ for all taxa; (5) in the Ipendja UFA, the basal area varies from 0.001 to 0.5 m².ha⁻¹ for a total of 0.86 m².ha⁻¹ overall. (i) It ranges from 0.001 to 0.22 m².ha⁻¹ in the dense forest and is 0.65 m².ha⁻¹ for all taxa; (ii) from 0.001 to 0.1 m².ha⁻¹ for a total basal area of 0.54 m².ha⁻¹ in the swamp forest; (iii) from 0.001 to 0.18 m².ha⁻¹ for a total basal area of 0.51 m².ha⁻¹ in the light forest; (6) in Loundoungou-Toukoulaka UFA, the basal area varies from 0.81 to 1.02 m².ha⁻¹ for a total of 1.83 m².ha⁻¹, in mixed mixed-land forest; It is between 0.06 and 0.21 m².ha⁻¹ and the total basal area is 0.27 m².ha⁻¹ in the Limbali forest. The taxon carrying this basal area is *Irvingia grandifolia*.

In the Sangha forest, (i) the basal area is between 0.06 and 0.30 m².ha⁻¹ against 1 m².ha⁻¹ for all species of the Ngombé UFA; (ii) it is between 0.37 and 0.56 m².ha⁻¹ and 0.93 m².ha⁻¹ overall, in the Pikounda north UFE. The most prominent species is *Panda oleosa*.

In the Lossi forest, the basal area varies from 0.03 to 0.51 m².ha⁻¹ and, on the whole, is 1 m².ha⁻¹ for trees of $10 \leq \text{dbh} < 70$ cm. They range from 0.03 to 0.56 m².ha⁻¹, or 1.2 m².ha⁻¹ for all trees of $\text{dbh} \geq 70$ cm.

In the Youbi forest, the basal area varies from 0.07 to 0.2 m².ha⁻¹ per taxon and 0.4 m².ha⁻¹ for the whole.

In the Conkouati-Douli National Park, the basal area is between 0.54 and 5.17 m².ha⁻¹, an average of 3.57 ± 2.63 m².ha⁻¹. *Pentaclethra eetveldeana* is the species that occupies space better (3.06 ± 0.54 m².ha⁻¹).

Diameter structure

The diametric structure of the biofuel resources species in the Congolese forest illustrates poor recruitment within diameter

classes (Figure 2). In the forests of Betou, Mokabi-Dzanga and Lopola, the diametric structure reveals a regenerative cohort, almost

nonexistent. With some exceptions, the diametric structure denotes an erratic distribution.

Table.1 Distribution of taxa in different forest inventory areas

Taxa	Forest areas																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Clusiaceae																	
<i>Allanblackia floribunda</i> Oliv.	+	+	+	-	-	+	+	-	-	+	-	-	+	+	-	+	+
<i>Pentadesma butyracea</i> (Sab.)Sabine	+	+	+	+	-	-	-	-	-	-	-	-	+	-	-	+	-
Euphorbiaceae																	
<i>Ricinodendron heudelotii</i> (Baill.) Pierre ex Heckel	+	+	+	+	+	+	+	+	+	+	-	+	+	-	+	-	-
Fabaceae																	
<i>Pentaclethra eetveldeana</i> De Wild. & Th. Dur.	+	+	-	-	-	-	-	+	+	+	+	+	+	-	+	+	-
<i>Pentaclethra macrophylla</i> Benth.	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+
Irvingiaceae																	
<i>Irvingia gabonensis</i> (Aubry-Lecomte ex O’Rorke)	+	+	+	+	+	+	+	-	+	+	+	-	+	+	+	-	+
<i>Irvingia grandifolia</i> (Engl.) Engl.	+	+	+	+	-	+	+	+	+	-	-	-	+	-	+	-	+
<i>Irvingia wombulu</i> Vermoesen	+	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-
Myristicaceae																	
<i>Pycnanthus angolensis</i> (Welw.) Exell.	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+
Olacaceae																	
<i>Ongokea gore</i> (Hua) Pierre	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+
Pandaceae																	
<i>Panda oleosa</i> Pierre	+	+	+	+	+	+	+	+	+	+	-	-	-	+	+	-	-

Legend: Presence (+); Absence (-); Bétou UFA (1); Missa UFA (2); Mokabi-Dzanga UFA (3); Lopola UFA (4); Ipendja UFA (5); Loundougou-Toukoulaka UFA (6); Kabo UFA (7); Pokola UFA (8); Ngombé UFA (9); Pikounda North UFA (10); Plateau Teke Forest (11); Aubeville Forest (12); Lossi forest (13); Youbi Forest (14); Odzala-Kokoua National Park (15); Conkouati-Douli National Park (16); Okoumé Forest of Mayombe (17).

Table.2 Relative abundance of biofuel resources species in PokolaUFA

Species	Relative abundance (%) by types forest					
	Dense forest	Clear forest	Marantaceae forest	Limballi forest	Flooded forest	All UFA forest
<i>Panda oleosa</i>	5,14	4,81	1,40	3,10	3,99	2,82
<i>Pentaclethra eetveldeana</i>	1,01	2,19	1,24	1,98	2,24	1,44
<i>Pentaclethra macrophylla</i>	1,22	1,46	0,16	1,55	1,25	0,84
<i>Pycnanthus angolensis</i>	2,10	2,1	0,47	1,68	1,72	1,18
<i>Ricinodendron heudelotii</i>	2,71	2,71	0,78	0,61	0,59	1,31
Total recovery	12,18	13,27	4,05	8,92	9,79	7,59

Fig.1 Distribution of Congolese forest in UFA and location of forest inventories

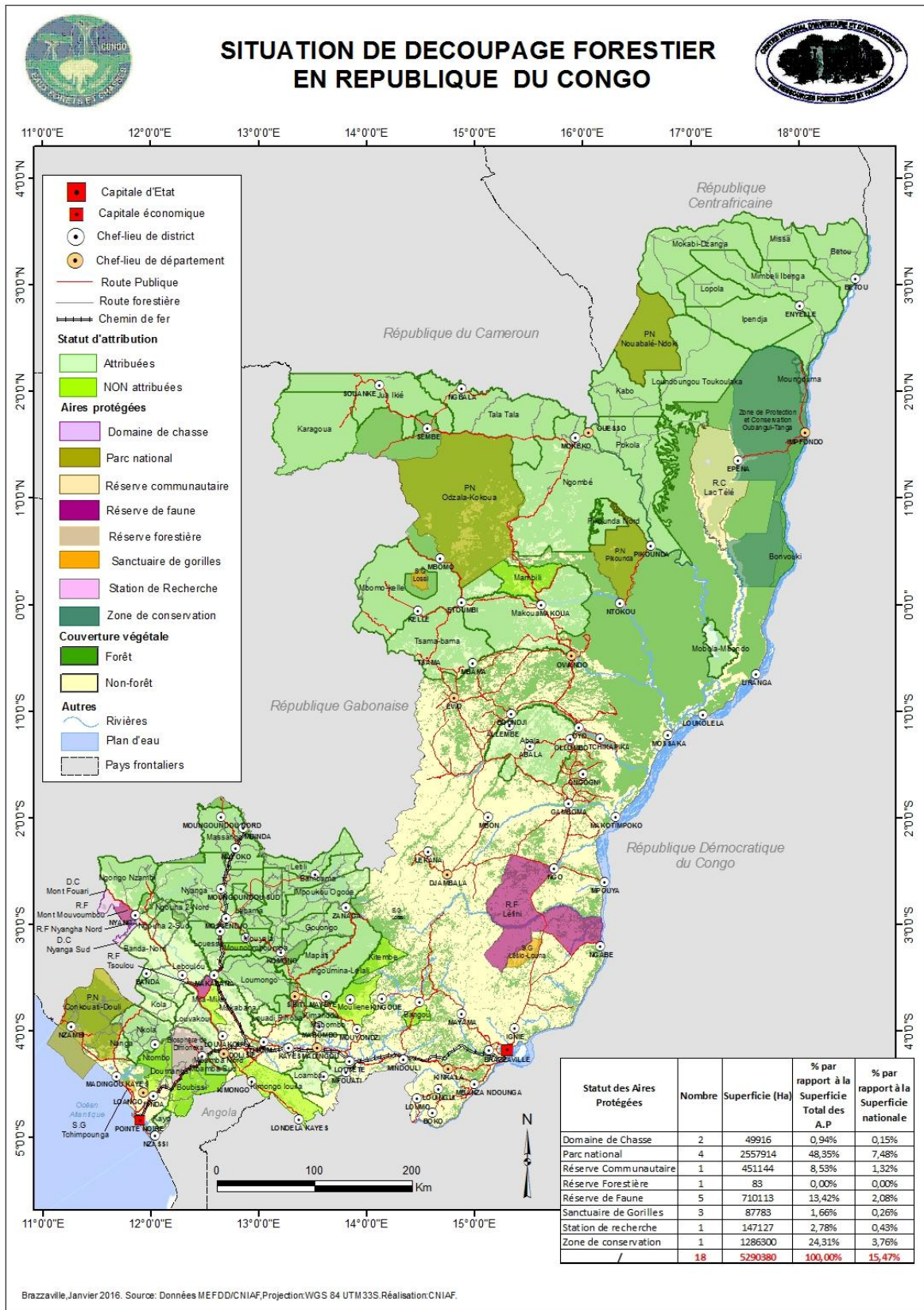
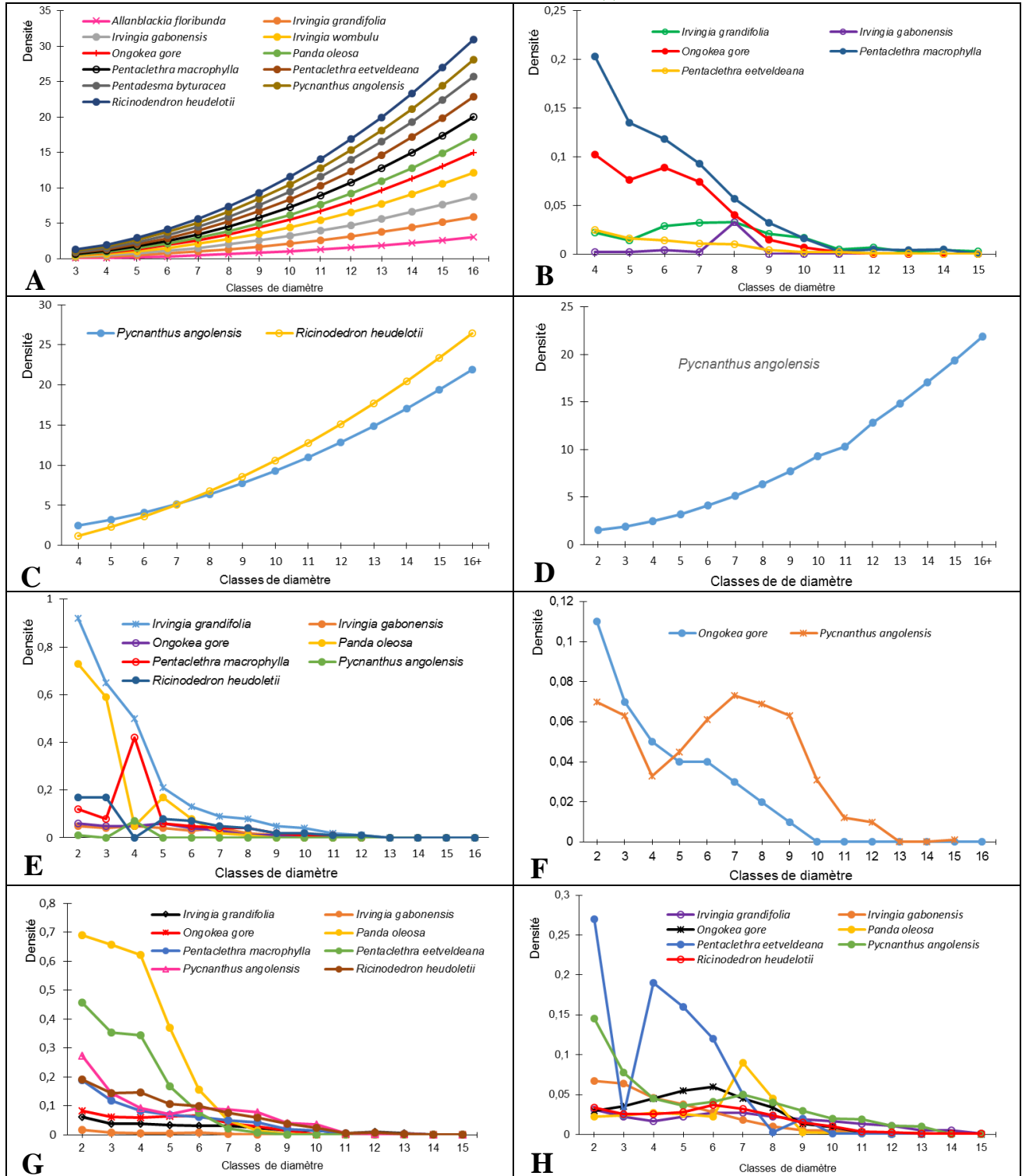
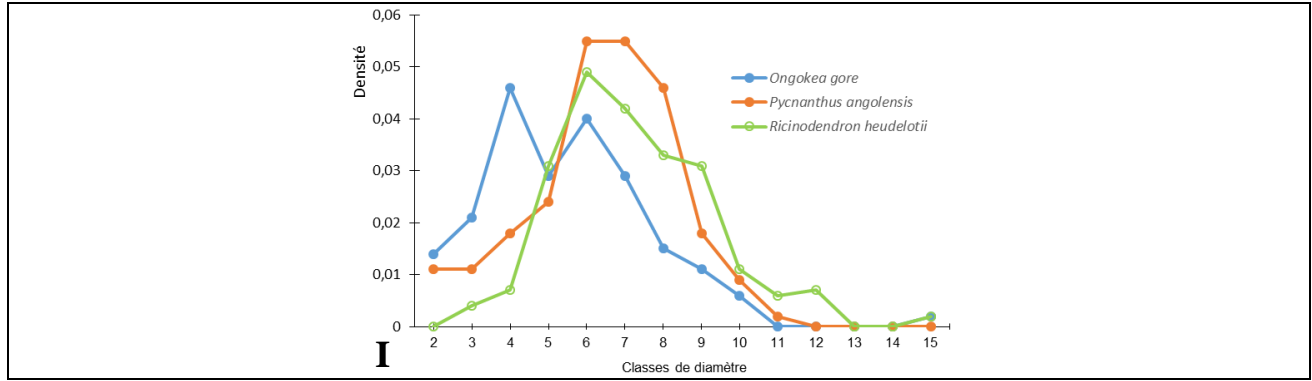


Fig.2 Diametric structure of the biofuel resources of the Congolese forest. Legend: Betou UFA (A), Missa UFA (B), Mokabi-Dzanga UFA (C), Lopola UFA (D), Ipendja UFA (E), Kabo) UFA, Pikounda north UFE (I)





Appendix.1 Views of some specimens of spontaneous oilseeds of Congolese flora
 (Photo credits: Victor Kimpouni, except *Irvingia gabonensis* (Y. Issembe))



Allanblackia floribunda



Allanblackia floribunda



Ongoeka gore



Pentaclethra eetveldeana



Pentaclethra macrophylla



Panda oleosa



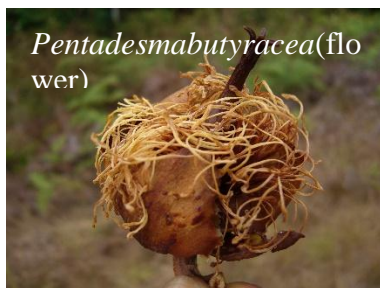
Irvingia gabonensis



Pycnanthus angolensis
(planche éclatées)



Pycnanthus angolensis
(planche éclatées)



Pentadesmabutyracea(flower)

Pentadesma butyracea
(Flower)



Pentadesma butyracea



Pentadesma butyracea



Irvingia grandiflora

Analysis of plant diversity

The spatial distribution of biofuel resource species shows that they are, to varying degrees, in all forestry facies. At the present stage of knowledge and floristic inventories, Missa and Bétou UFA have the best potential in terms of biofuel resources, respectively 91 and 100% of the species. The absence of some species in other forest areas could be explained by insufficient inventory and / or harvesting, 39 samples of herbariums listed at the IEC for 10 species of biofuel resources (Manguila, 2009; Batangouna, 2010; Mambouéni-Mbika, 2012).

The analysis of the plant data shows a paucispecific and floristic Congolese forest in biofuel resources. 11 species out of 48, let be (either) 23% of the main species retained in PROTA 14. Notwithstanding the low level of the specific diversity of biofuel resources within this forest ecosystem, these taxa have low densities. It is generally understood in all forest areas of 0.01 to 4 trees.ha⁻¹ of biofuel resources. Since the inventory analysis scale is the area covered by the UFA, taking

account of forest types, the extrapolation of data does not make it possible to detect zone with biofuel resources. This observation is supported by small-scale floristic surveys. This is the case of the Lossi Sanctuary where *Pentaclethra macrophylla* is 6.8 trees.ha⁻¹, Aubeville forest where *Pentaclethra eetveldeana* and *Pycnanthus angolensis* have 5.3 and 13.3 trees.ha⁻¹, respectively Conkouati reserve where some species have densities that reach 19 or even 27 trees.ha⁻¹. These values corroborate the data of Mitani *et al.*, (1994) in the Lopé reserve in Gabon where the densities of these species biofuel resources range from 0.2 to 9 trees.ha⁻¹. Taking into account their low representativeness in Congolese forests (0.16 to 5.14%), these species of biofuel resources can not characterize these ecosystems. The rain forests of Central Africa with densities ranging from 265 to 427 trees.ha⁻¹ show a predominance of Fabaceae, Rubiaceae, Euphorbiaceae (Kimpouni *et al.*, 2008, 2013, 2014; Puig, 2001). The basis for these low densities is the non-gregarious behavior of these taxa within Congolese forests (Nzinga, 1992).

Ecological data

The analysis of the diametric structure of the biofuel resources species reveals that none shows good regeneration and/or a satisfactory occupation of the environment. Indeed, no curve has the appearance of an "inverted L or J", synonymous with satisfactory natural regeneration (Peters, 1997; Puig, 2001; White and Edwards, 2001; Mbou, 2009). According to Peters (1997), "Such a structure represents a population whose regeneration is limited for one reason or another with the difficulties of installing new seedlings". Finally, the erratic structure is explained by the fact that the planting of new seedlings is sporadic or irregular (Peters, 1997). Taking into account the ecological groups of Moutsamboté (2012), this bad regeneration could be explained by the existence of heliophiles and scia-heliophiles. They are therefore subjected to an energy competition that ensures the selection of species most often at the juvenile stage (Polunin, 1967; White, 1986; Adriens, 1993).

In spite of the structural data that are not adequate for the emergence of a biofuel sector focusing on the spontaneous flora of the Congolese forest, these taxa associate a low production of fruits. Indeed, (i) the diameter of the trunk proportionally correlated with the size of the crown, and (ii) the crown diameter affects the amount of fruit produced (Bouchon *et al.*, 1989; Bourden, 2013). This relationship reveals that the higher basal area, no tree bears branches and *ipso facto* the fruit (Bouchon *et al.*, 1989; White and Edwards, 2001; Bourden, 2013).

These biofuel resources are also an energy source for frugivorous animals. Besides *Pentaclethra eetveldeana* and *Pentaclethramacrophylla* with ballochores diaspores, the other nine taxa are sarcochores. However, the work of Van Der Pijl (1969) and Alexander (1978) showed that the Sarcochore is a food source for animals,

mainly large mammals, such as the elephant, which ensure dissemination. Today, several sources mention the threat of extinction of elephants in the Central African subregion. The corollaries of this threat weigh on the future of loxodontochore species, biofuel resources of Congolese forests.

Wood industry and endogenous knowledge

Except for *Pycnanthus angolensis* and *Ricinodendron heudelotii*, targeted by the timber industry, all species of biofuel resources are of interest to the sawmill and craft industry. Notwithstanding the timber supply chain, all species have ethnobotanical applications by local and indigenous populations (Bouquet, 1969; Adjanohoun *et al.*, 1988; Hecketsweiler and Mokoko-Ikonga, 1991; Profizi *et al.*, 1993; Raponda-Walker and Sillans, 1961; Miabangana, 1998; Tamio Matondo, 2003). Riparian populations derive substantial direct and indirect benefits by exploiting various organs, both vegetative and regenerative. They are a source of therapeutics, food, income generation, crafts, etc. (Profizi *et al.*, 1993; Raponda-Walker and Sillans, 1961). Non-timber forest products (NWFPs) in the sub-region include *Irvingia gabonensis*, *Irvingia* sp. and *Ricinodendron heudelotii*, even if the dietary use of the latter is not known. The generative organs at the center of this activity are highly sought after, which translates into high anthropogenic pressure on these species. By way of example: (i) the nutritional value of the seeds of *Ricinodendron heudelotii* is: 200 g.kg⁻¹ of protein; 450 g.kg⁻¹ of lipids; 250 g.kg⁻¹ of carbohydrates and 600 mg.kg⁻¹ of calcium; (ii) almonds of *Irvingia* sp. have generated 5,488 direct jobs in Cameroon and over 250,000 indirect jobs with an annual income of US \$ 16.34 million (Ndoye *et al.*, 2011). These NTFPs are traded locally, sub-regionally and internationally, as evidenced by the work of Tabuna (1999), Tchatat and Ndoye (2006) and Lescuyer (2010).

All these activities, which are based on the collection of generative organs, severely impact the renewal of these taxa within ecosystems. In connection with the oilseed chain, strong anthropogenic pressure was exerted on *Ongokea gore* during the colonial period (Raponda-Walker and Sillans, 1961).

Resources and industrial exploitation of second generation biofuels

Is the Congolese forest likely to support an industry focused on the sustainable and rational management of second generation biofuel species? To answer this question, the phytoecological and ethnobotanical data of the biofuel resources species contribute to maintain that the Congolese forest does not lend itself to this exploitation. In fact, we have recorded a small number of biofuel species within this flora, and these in most cases combine weak phytoecological parameters (density, basal area, crown diameter, regeneration capacity and fruit productions). Thus, the maintenance of biofuel resources species in Congolese forests is acute. However, the seeds of these taxa are the basis for the possible production of second-generation biofuels. An industrial exploitation, while being the propagation organs, would inevitably lead to the disappearance of the said taxa unless cultivated (Peters, 1997).

In conclusion, Congolese forests are scarcely provided with biofuel resources as shown by phytoecological parameters, but this study shows the existence of pockets where the gregariousness of these taxa would be proved. Notwithstanding the induced effects of the agents of dissemination, anthropogenic action is that which more seriously impacts natural regeneration. This is all the more likely given the fact that, despite their low spatial representativeness, the multi-purpose character makes them highly sought after.

Many of them are first-rate NTFPs in meeting food, phytotherapeutic and income needs for local and indigenous populations. These reasons alone explain the high degree of anthropogenic impact on these species. Analysis of the data reveals that industrial exploitation, as a primary source of production of second-generation biofuels, would surely put these plants in danger of extinction within the Congolese forest.

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