



Do logging concessions decrease the availability to villagers of foods from timber trees? A quantitative analysis for Moabi (*Baillonella toxisperma*), Sapelli (*Entandrophragma cylindricum*) and Tali (*Erythrophloeum suaveolens*) in Cameroon



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ABSTRACT

Many species of timber trees in Cameroon are exploited by logging companies for timber and by forest-dependent communities for non-timber forest products (NTFPs). Quantitative analyses were conducted within and near forest concessions in Cameroon to determine the density of multiple use tree species that provide both timber for industry and foods consumed by local populations (fruit and oil or edible caterpillars), and how this has been affected by logging. Individuals of the three species (Moabi, *Baillonella toxisperma*; Sapelli, *Entandrophragma cylindricum*; and Tali, *Erythrophloeum suaveolens*), including their stumps, were identified and measured on 5 ha (100 m × 500 m) sample plots around 4 villages and in 2 concessions. Around each village 21 sample plots, stratified by distance, were laid out along three transects extending 10 km towards the concession, each oriented 45° from the other. In concessions, 20 plots were established within the 2012 cutting unit after timber harvesting, using a stratified random system. Moabi trees occurred at the lowest densities: around villages, $22.8 \pm 3.3/100$ ha of precommercial individuals and $5.0 \pm 1.4/100$ ha of individuals of harvestable size (≥ 80 cm dbh); on concessions, 7.5 ± 2.4 precommercial trees/100 ha, and $0-2.0 \pm 1.4/100$ ha harvestable individuals. Densities of Sapelli trees were not significantly different between villages and concessions, averaging $32.6 \pm 3.8/100$ ha and $37.5 \pm 5.5/100$ ha, respectively, for precommercial sizes and $9.5 \pm 2.2/100$ ha and $6 \pm 1.6/100$ ha, respectively, for harvestable trees (≥ 100 cm dbh). Pre-commercial Tali trees occurred at lower densities ($3.8 \pm 0.9/100$ ha) around villages, as compared to $11.5 \pm 3.1/100$ ha on concessions. Harvestable Tali trees (≥ 60 cm dbh) occurred at the same densities around villages and on concessions ($56.0 \pm 7.2/100$ ha). Half, or more, of commercial-sized trees of caterpillar-hosting species were left standing after harvest on concessions (89–94% of Tali; 50–79% of Sapelli), reflecting constraints due to timber quality, market demand and inaccessibility. No harvestable Moabi trees were logged from the 2012 cutting areas, reflecting agreements between communities and concessionaires to leave them for fruit and oil, but densities were so low it will be important that villagers conserve those around their villages. Stumps of all three species were found around villages, revealing that mechanisms for negotiation are also needed among villagers with interests in either timber or non-timber resources obtained from the same tree species.

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1. Introduction

The humid forests of Africa cover about 236 million ha, of which 203 million ha are located in the Congo Basin of Central Africa, a region important for its extent, natural resources, biodiversity and endemism (Mayaux et al., 2004). Cameroon has more than

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18.6 million ha of lowland moist forest, of which 6.4 million ha were under concession in 2009. Timber production is an important sector of the Cameroonian economy. The formal timber sector, oriented towards the export market, employs more than 13,000 people and contributes 6% of the nation's GDP, worth 47 billion FCFA in 2004 (about 90.24 million USD; Bayol et al., 2012), mostly from sales of lumber to Europe (Eba'a Atyi, 2009 in Eba'a Etyi et al., 2013). The population of Cameroon is estimated at 20 million, with a growth rate of 2.5% in 2015 (The World Bank, 2016a). Forty-six percent of Cameroonians live in rural areas, many within or near forests (The World Bank, 2016b; Tieguhong et al., 2012). Studies have revealed that some rural people in Cameroon obtain 50% or more of their household income (cash and subsistence) from forest products (Van Dijk, 1999; Sunderland et al., 2003) although a more recent study estimated this ratio as less than 30%, as compared to approximately 50% obtained from farming (Levang et al., 2015). Many of these wild-gathered forest species are nutritionally important complements to their agricultural staples (Fungo et al., 2015).

The Cameroonian forests include almost 300 species of commercial timbers of which about 60 are extracted on a regular basis. More than 61% of the commercial timber species also produce non-timber forest products (NTFPs) that are important for communities that live within or close to the concessions, as sources of food, building materials, traditional medicines and other products (Ndoye and Tieguhong, 2004; Tieguhong and Ndoye, 2007; Guariguata et al., 2010; Laird, 1999).

Since 1994 the management of concession forests in Cameroon has been governed by Forest Law No. 94-01, which mandates that logging companies prepare detailed forest management plans (FMPs) to ensure the ecological, economic, and socially sustainable management of their forests (Cerutti et al., 2008). This law also provides for communities to obtain licenses to harvest timber in community concessions of up to 5000 ha, an innovation that was implemented in 1998 (FAO, 2005). Article 8 of the law recognizes the rights of local people to exploit NTFPs within the concessions for their personal use, as long as they are not protected species (Republic of Cameroon, 1994). However, the implementation of this Article does not give communities the right to harvest forest resources in large quantities or for sale.

The importance of timber and non-timber forest resources to both concessionaires and communities means that forest management needs to consider the value of and access to products from these species for both sets of stakeholders. Forest exploitation can have a positive impact, a negative impact, or no impact on the availability of or access to NTFPs, depending on the species, the resource, and management practices (Rist et al., 2012). Timber concessions can reduce the availability of NTFPs through three mechanisms: restriction of access to forest resources, logging of timber species that are also important sources of NTFPs and indirect impacts of logging activities on other forest resources (Newing, 2007). In most cases information about the use, value and ecology of these species is insufficient to provide a foundation for forest management guidelines and practices (Guariguata et al., 2010; but see Vermeulen and Doucet, 2004); and it has been noted that few quantitative studies have been carried out to evaluate the impact of selective logging on the ability of local populations to obtain non-timber forest products (Rist et al., 2012). This study was carried out to help fill these gaps.

The study focuses on three species that have both timber and non-timber values, specifically as food sources. The objective was to quantify these species within an accessible radius of nearby villages and within the neighboring concession and to evaluate the impact of logging on their abundance, to determine whether or not villagers were being deprived of access to these resources as a result of timber harvesting on industrial concessions.

2. Methods

2.1. Sample species

Focus groups and socioeconomic and nutritional surveys carried out in a parallel study (Levang et al., 2015; Fungo et al., 2016) were used to guide the choice of three priority tree species that met the following criteria: they are harvested for timber by the concessionaires and they produce or host important NTFPs that are of nutritional value to local populations. The tree species selected were Moabi (*Baillonella toxisperma* Pierre), Sapelli (*Entandrophragma cylindricum* Sprague), and Tali (*Erythrophleum suaveolens* Guill. and Perri). Moabi, limited to the lowland rainforest of West and Central Africa, is tenth in ranking on the list of timber species exported from Cameroon (Ndoye and Tieguhong, 2004). It reaches very large sizes, up to 70 in height, and has a fine-grained, hard and durable wood (Vivien and Faure, 1985). Sapelli is one of the most valuable and important timber species in Cameroon, accounting for 377,254 m³ of exports/year, the most of any species. Tali is the third most exploited timber species in Cameroon, exported to European and Asian markets (Cerutti et al., 2008). The minimum cutting diameter varies among species. For Moabi it is 80 cm, for Sapelli 100 cm and for Tali 60 cm (Medinof, 2004).

Moabi is very important to local communities for multiple purposes (Schneemann, 1995; Plenderleith and Brown, 2004) and was quantified as accounting for the most plant biomass (47%) collected from the forest (Vermeulen and Doucet, 2004). It produces edible fruits as well as oil-rich seeds. Local women carry out a time-consuming, multistage process to extract from Moabi seeds a high-value and nutritious oil which is consumed, bartered and sold (Ngueguim et al., 2011; Fungo et al., 2016). For generations this has been the only source of edible oil for local populations, its importance reflected in the fact that individuals acquire lifetime rights to gather fruits from particular Moabi trees by marking them and clearing around them (Schneemann, 1995). In the early 20th century, these seeds were imported into Europe for their fats and oils, which can also be used for making soap (Plenderleith and Brown, 2004). Moabi bark is used in traditional medicine and traditional rites (Schneemann, 1995; Veuthey and Julien-François, 2009; Ngueguim et al., 2011). Moabi, in the Sapotaceae family, is a monoecious species that commonly produces abundant fruit every three years, during the short dry season. Its seeds are dispersed by elephants.

Both Sapelli and Tali host edible caterpillars (*Imbrasia oyemensis* and *Cirina forda*, respectively) that are an important food for local populations (Ndoye and Tieguhong, 2004; Tieguhong and Ndoye, 2007). *I. forda* caterpillars contain 62% protein and 25% fat and *C. forda* 74% protein and 14% fat (Rumpold and Schluter, 2013), higher proportions than beef. In addition to producing a durable wood, Tali bark and roots are high in alkaloids and are used in traditional medicine. Its roots are also used as a fish poison (Okeyo, 2006).

2.2. Study sites

Cameroon's forest is humid semi-evergreen in the south and semi deciduous in the east. It is characterized by low densities of Caesalpinaceae (including Tali) and relatively high proportions of Euphorbiaceae and Oleaceae. Meliaceae (including Sapelli), Sterculiaceae and Ulmaceae are well represented among the largest trees (Letouzey, 1968). The studies were carried out within and near two forest concessions in Cameroon, Fabrique Camerounaise de Parquet (FIPCAM) in the south (referred to as concessionaire S), which has held the concession since 2000, and Société Camerounaise de Transformation du Bois (SCTB) in the east, referred to as concessionaire E. FIPCAM, concessionaire S, is funded by external capital

while SCTB, concessionaire E, is owned by Cameroonians. Neither one is certified. SBCT harvests 24 species and FIPCAM 38 species. The concessions were chosen based on multiple criteria: the presence of the selected species; easy access; willingness of the concessionaires to collaborate with the research project; an approved management plan or a plan in process of being approved; the presence of villages within or near the concession, preferably representing different ethnic groups; the existence of inventory and harvest data from the annual cutting area; and social responsibility contracts between the villages and the concession ('cahiers de charges'). Data was collected in early 2013 in the 5000 ha annual cutting area of 2012 in each concession and also in and around two villages located near each concession.

In 2004 the population around the SCTB concession in the East Region numbered about 25,783 people who lived in 41 villages and hamlets and were mainly of the Kako, Pol, and Maka (Bantu) and Baka (pygmy) ethnic groups (Medinof, 2004). The population around the FIPCAM concession in the South Region in 2009 was estimated at 79,353, living in 29 villages and hamlets (Enviro Consulting, 2009 in Levang et al., 2015), nearly all of the Bulu (Bantu) ethnic group. Population density around the concessions is low, with 7.1 inhabitants/km² in the East and 13.4 inhabitants/km² in the South (Levang et al., 2015).

Sample villages were chosen based on several criteria: compact layout, proximity to the concession and their selection for parallel socioeconomic studies. Around concession E, village Nkolbikon ('Nn') is inhabited by Baka, who depend to a very high degree on forest resources, as they have not traditionally practiced agriculture (Tieguhong and Ndoye, 2007; but see Levang et al., 2015). The village is located inside a formally established community forest that is located less than 5 km from the concession's annual cutting area of 2012. Community forests in Cameroon are managed

under an arrangement whereby the community – or groups within the community – have the rights to harvest and sell the timber and the revenues are supposed to be distributed to the whole community (WRI, 2005). Another sample village, Ndembo, ('No'), inhabited by Kako and Pol people (Bantu), is located 15 km from the concession (Fig. 1). The two sample villages near concession S, Ngone ('Ne') and Meyos ('Ms'), are inhabited by Bulu people (Bantu). Their principal activities are agriculture, hunting and informal timber production. These two villages are very near the concession; many of their fields and plantations of cocoa and plantain are actually located within the current concession boundaries (Noumbissi, 2012) (Fig. 1).

2.3. Field sampling

To determine whether local communities had access, on foot, to the three species of interest in the vicinity of their villages, we evaluated the density of trees within walking distance of the center of each village (Maukonen et al., in press) along three transects towards the concession, oriented 45° apart. Each transect extended 10 km from the village, subdivided into 4 strata: A, from the village center to 1.99 km distance; B, from 2 km to 3.99 km distance; C, from 4 km to 6.99 km and D, from 7 km to 10 km (Fig. 2). Sample plots of 5 ha (100 m × 500 m) were laid out alternately on one side of the transect or the other. The number of sample plots was distributed among strata to maintain a constant sampling intensity of 0.5%. A total of 21 five-hectare plots were established around each of the 4 sample villages, as illustrated in Table 1 and Fig. 2.

To determine whether the density of these species was affected by timber harvesting, sampling was carried out in both concessions on the 5000 ha annual cutting areas of 2012 shortly after the harvest, in UFA 10060 of SCTB, East Cameroon and UFA 09017 of

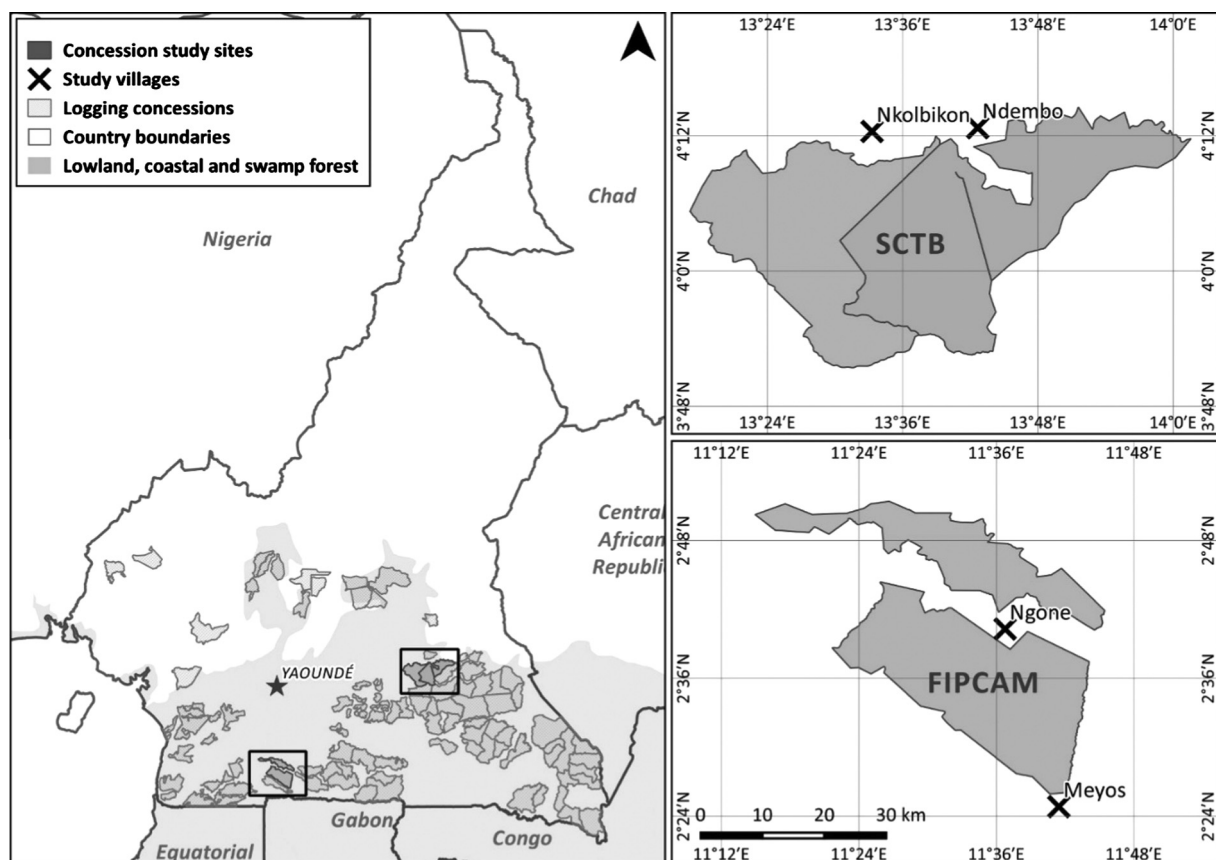


Fig. 1. Location of SCTB and FIPCAM concessions and associated sample villages in Cameroon.

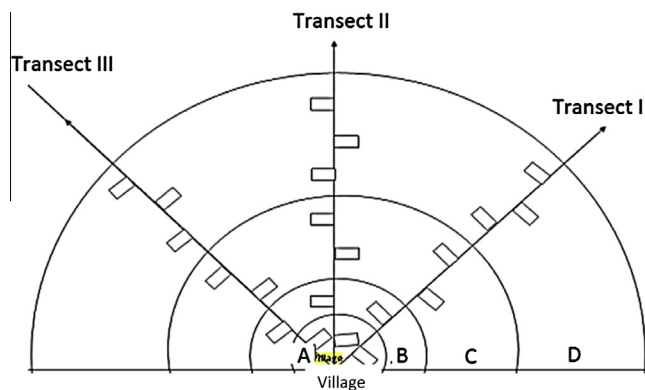


Fig. 2. Layout of sample plots between villages and concessions, indicating distance strata A, B, C, and D (not to scale).

FIPCAM, South Cameroon. Sampling was stratified using the companies' 25 ha inventory plots: five 25-ha inventory plots were selected at random within each of four quadrants. Within each selected inventory plot, five 5 ha sample plots were established at random, for a total of 20 five ha plots per concession.

2.4. Data collection and analysis

Within each 5 ha sample plot all individuals ≥ 20 cm diameter at breast height (dbh) of the three sample species were identified and their diameters measured at 1.3 m height or 10 cm above buttresses. In addition, stumps of these species, revealing the impact of the 2012 harvest in the timber concessions or of felling around the villages, were identified and noted.

Because of a high number of zeros in the results, average density values per plot were compared using nonparametric tests (Kruskal-Wallis ANOVA H-test and Wilcoxon test). Statistical analyses were carried out using 'R' (R Core Team, 2013) to compare: (1) the density of individuals of harvestable and precommercial sizes around different villages and at different distances from the villages; (2) the density of individuals remaining compared to the density of stumps on the 2012 cutting area within the concession; and (3) the density of trees around the villages compared to the density on neighboring concessions.

3. Results

Densities of individuals are expressed per 100 ha except where indicated otherwise. Individuals are described as 'harvestable' if their diameters are larger than or equal to the minimum cutting diameter for that species; 'pre-commercial' is used for individuals below those sizes.

3.1. Densities around the villages

Individuals of Moabi occurred at lower densities than the other two species. The density of individuals of precommercial and harvestable sizes was significantly different among villages ($P = 1.934e-05$ and $P = 0.014$, respectively). For both size classes,

Table 2

Average density (per 100 ha) of trees and stumps around villages, with standard errors. Minimum cutting diameter: Moabi ≥ 80 cm; Sapelli ≥ 100 cm; Tali ≥ 60 cm. Comparisons were made within rows, where different subscripts reveal statistically significant differences.

Villages Species/size	Ms	Ne	No	Nn
Moabi-harvestable	13.4 \pm 4.4 _a	2.0 \pm 1.4 _b	1.0 \pm 1.0 _b	3.8 \pm 2.2 _b
Moabi-stumps	0.0 \pm 0.0 _a	0.0 \pm 0.0 _a	0.9 \pm 0.4 _a	1.1 \pm 0.5 _a
Moabi-precommercial	51.4 \pm 7.8 _a	18.0 \pm 5.0 _b	5.8 \pm 1.6 _b	16.2 \pm 5.6 _b
Sapelli-harvestable	13.4 \pm 5.8 _a	2.8 \pm 1.6 _a	6.6 \pm 2.6 _a	15.2 \pm 2.2 _a
Sapelli-stumps	0.9 \pm 0.4 _a	0.9 \pm 0.4 _a	0.0 \pm 0.0 _a	0.0 \pm 0.0 _a
Sapelli-precommercial	8.6 \pm 3.6 _a	14.2 \pm 3.8 _a	62.8 \pm 8.0 _b	15.2 \pm 7.6 _a
Tali-harvestable	54.2 \pm 10.8 _a	55.2 \pm 7.8 _a	29.6 \pm 6.8 _b	84.8 \pm 11.4 _a
Tali-stumps	2.8 \pm 0.7 _a	0.9 \pm 0.4 _a	0.0 \pm 0.0 _a	0.9 \pm 0.4 _a
Tali-precommercial	0.0 \pm 0.0 _a	4.8 \pm 2.0 _a	5.8 \pm 2.4 _a	4.8 \pm 2.0 _a

the densities were higher around 'Ms' reaching 13.4 \pm 4.4/100 ha for harvestable sizes and 51.4 \pm 7.8/100 ha for precommercial sizes. The precommercial sizes were more abundant around the villages than the harvestable sizes: (22.8 \pm 3.3/100 ha and 5.0 \pm 1.4/100 ha, respectively) (Table 2). The density of precommercial individuals of Sapelli varied significantly among villages ($P = 2.6e-08$), but the density of harvestable Sapelli trees did not, averaging 9.5 \pm 2.2/100 ha ($P = 0.33$). The density of precommercial Sapelli was higher than the density of those of harvestable size (32.6 \pm 3.8/100 ha and up to 62.8 \pm 8.0/100 ha around 'No'; and 9.6 \pm 2.3/100 ha, respectively). Precommercial-sized Tali trees were poorly represented, and their density did not vary significantly among villages ($P = 0.111$). However, the density of individuals of harvestable size did vary significantly among villages ($P = 0.001$); densities around 'No' were significantly lower than around the other 3 villages. Around the villages, the density of harvestable Tali trees (56.0 \pm 5.1/100 ha) was higher than the density of individuals of pre-commercial size (3.8 \pm 0.9/100 ha). Stumps of Moabi, Sapelli and Tali were also found in plots around the villages. The density of stumps was not significantly different among villages (for Moabi, $P = 0.2889$; Sapelli, $P = 0.5674$; Tali, $P = 0.2623$), but the highest density of stumps was found near the village 'Ms': (2.8 \pm 0.7/100 ha of Tali; Table 2). This represents only a small fraction of the number of harvestable Tali trees on the same area (54.2 \pm 10.8/100 ha). Differences in density of trees at different distances from the villages were not statistically significant (Moabi, $P = 0.8039$; Sapelli, $P = 0.4776$; and Tali, $P = 0.2514$; Tables 3–5). The density of stumps varied with distance only for Sapelli ($P = 0.024447$) (Tables 6–8). All Sapelli stumps were found within 2 km of two of the villages.

3.2. Densities in the concessions and the effect of logging

Differences between concessions in the density of precommercial Moabi trees (E, 6.0 \pm 2.3/100 ha; S, 9.0 \pm 2.6/100 ha) were not statistically significant ($P = 0.463$), nor was the difference in harvestable Moabi trees, which occurred at very low densities (E, 2.0 \pm 1.4/100 ha; S, 0 \pm 0/100 ha; $P = 0.317$). The density of Sapelli varied between the two concessions, both for precommercial individuals (E, 54.0 \pm 6.0/100 ha; S, 21.0 \pm 3.4/100 ha; $P = 0.002$) and

Table 1
Sampling scheme across distance strata.

Distance/stratum	A: 0–1.99 km	B: 2–3.99 km	C: 4–6.99 km	D: 7–10 km
Stratum area	6 km ² (600 ha)	18 km ² (1800 ha)	51 km ² (5100 ha)	82 km ² (8200 ha)
Sample plot area (0.5%)	3 ha	9 ha	26 ha	41 ha
Number of 5 ha plots	3 ^a	3 ^a	6 ^a	9

^a Plot numbers have been increased somewhat to ensure representation.

Table 3

Density of Moabi trees/100 ha by distance stratum in the different villages.

Villages/distance (km)	Ms	Ne	No	Nn	Average
0.0–1.99	20.0 ± 11.5	20.0 ± 0.0	13.4 ± 13.2	13.4 ± 6.7	16.6 ± 8.3
2.0–3.99	60.0 ± 19.9	20.0 ± 11.5	6.6 ± 6.7	33.4 ± 17.6	30.0 ± 17.4
4.0–6.99	60.0 ± 13.6	20.0 ± 9.3	13.4 ± 6.7	26.6 ± 16.0	29.6 ± 13.3
7.0–10.0	84.4 ± 19.4	20.0 ± 9.4	0.0 ± 0.0	13.4 ± 6.6	29.8 ± 15.3

Table 4

Density of Sapelli trees/100 ha by stratum in the different villages.

Villages/distance (km)	Ms	Ne	No	Nn	Average
0.0–1.99	20.0 ± 11.6	13.4 ± 13.3	46.6 ± 24.0	33.4 ± 17.7	28.4 ± 16.6
2.0–3.99	6.6 ± 6.9	26.6 ± 17.7	40.0 ± 0.0	86.6 ± 33.4	40.0 ± 24.1
4.0–6.99	10.0 ± 6.9	22.8 ± 5.6	80.0 ± 16.3	33.4 ± 6.7	36.0 ± 14.1
7.0–10.0	35.6 ± 17.3	10.0 ± 12.2	80.0 ± 10.0	77.8 ± 15.1	52.0 ± 15.2

Table 5

Density of Tali trees/100 ha by stratum in the different villages.

Villages/distance (km)	Ms	Ne	No	Nn	Average
0.0–1.99	46.6 ± 20.1	46.6 ± 17.6	6.6 ± 20.1	33.4 ± 20.1	33.4 ± 17.7
2.0–3.99	73.4 ± 46.6	60.0 ± 11.5	40.0 ± 19.9	106.6 ± 20.1	70.0 ± 26.6
4.0–6.99	56.6 ± 22.7	57.2 ± 15.9	40.0 ± 13.6	103.4 ± 24.9	64.0 ± 20.8
7.0–10.0	48.8 ± 16.4	67.5 ± 13.8	40.0 ± 12.4	93.4 ± 18.8	62.2 ± 16.4

Table 6

Density of stumps of Moabi/100 ha by stratum in the different villages.

Villages/strata	Ms	Ne	No	Nn	Average
0.0–1.99	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
2.0–3.99	0 ± 0	0 ± 0	0 ± 0	6.6 ± 1.2	1.6 ± 0.6
4.0–6.99	0 ± 0	0 ± 0	3.3 ± 0.8	3.3 ± 0.8	1.6 ± 0.6
7.0–10.0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0

Table 7

Density of stumps of Sapelli/100 ha by stratum in the different villages.

Villages/strata	Ms	Ne	No	Nn	Average
0.0–1.99	6.6 ± 1.2	6.6 ± 1.2	0 ± 0	0 ± 0	3.3 ± 0.8
2.0–3.99	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
4.0–6.99	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
7.0–10.0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0

Table 8

Density of stumps of Tali/100 ha by stratum in the different villages.

Villages/strata	Ms	Ne	No	Nn	Average
0.0–1.99	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
2.0–3.99	13.3 ± 1.2	6.6 ± 1.2	0 ± 0	0 ± 0	5.0 ± 0.9
4.0–6.99	3.3 ± 0.8	0 ± 0	0 ± 0	0 ± 0	0.8 ± 0.4
7.0–10.0	0 ± 0	0 ± 0	0 ± 0	2.2 ± 0.7	0.5 ± 0.3

for those of harvestable size (E, 11.0 ± 1.9/100 ha; S, 1.0 ± 0.7/100 ha; P = 0.001). Among the three sampled species, Tali occurred at the highest densities. The density of precommercial Tali trees varied significantly between concessions

(E, 21.0 ± 3.7/100 ha; S, 2.0 ± 0.9/100 ha; P = 0.0007), but the densities of harvestable Tali trees did not (E, 64.0 ± 8.9/100 ha; S, 48.0 ± 4.9/100 ha; P = 0.63). On concessions, harvestable individuals occurred at higher densities than precommercial individuals (averaging 56.0 ± 7.2/100 ha and 11.5 ± 3.1/100 ha, P = 0.0007, respectively) (Table 9).

Stump densities did not differ significantly between concessions: for Sapelli, 3.0 ± 1.5/100 ha on E and 1.0 ± 0.7/100 ha on S (P = 0.534) and for Tali 8.0 ± 2.5/100 ha on E and 3.0 ± 1.1/100 ha on S (P = 0.371). The proportion of harvestable trees extracted did not differ for Tali (11% on E and 6% on S, P = 0.63), but it did for Sapelli, where on concession E 21% of harvestable trees were extracted as compared to 50% on concession S (P = 0.001). No Moabi stumps were found on sample plots in the 2012 cutting area of either of the two concessions (Table 9).

3.3. The density of species around villages compared to their density in concessions

The relative density of individuals on concessions and around villages varied between concessions and among species (Table 10). The density of Moabi trees was significantly lower on concession S as compared to its neighboring villages for both harvestable trees (0.0 ± 0.0/100 ha and 7.6 ± 1.7/100 ha, respectively; P = 0.018) and precommercial sizes (9.0 ± 2.6/100 ha and 34.7 ± 3.7/100 ha, respectively, P = 0.002). There were no significant differences in densities of Moabi between concession E and its neighboring villages: 2.0 ± 1.4/100 ha and 2.3 ± 0.8/100 ha respectively, of harvestable trees (P = 0.576); and 6.0 ± 2.3/100 ha and 10.9 ± 2.2/100 ha, respectively, for precommercial sizes (P = 0.273; Table 10).

Table 9

Average density of stumps and of harvestable trees per 100 ha (cutting diameters: Moabi ≥ 80 cm, Sapelli ≥ 100 cm, Tali ≥ 60 cm) on concessions and percentage extracted. Different subscripts indicate statistically significant differences between concessions.

Concessions/species	E			S		
	Trees	Stumps	% Harvested	Trees	Stumps	% Harvested
Moabi	2.04 ± 1.4 _a	0.0 ± 0.0 _b	0	0.0 ± 0.0 _a	0.0 ± 0.0 _b	0
Sapelli	11.0 ± 1.9 _a	3.0 ± 1.5 _a	21 _a	1.0 ± 0.7 _b	1.0 ± 0.7 _a	50 _b
Tali	64.0 ± 8.9 _a	8.0 ± 2.5 _b	11 _a	48.0 ± 4.9 _a	3.0 ± 1.5 _b	6 _a

Table 10

Tree densities/100 ha (harvestable and precommercial) on concessions and the averages between their neighboring villages. Different subscripts indicate statistically significant differences between villages and their neighboring concessions (a, b, c, d) or between concessions (w, x, y, z).

Species	Villages E		Concession E		Concession S		Villages S	
	Precommercial	Harvestable	Precommercial	Harvestable	Precommercial	Harvestable	Precommercial	Harvestable
Moabi	10.9 ± 2.2 _a	2.3 ± 0.8 _b	6.0 ± 2.3 _{a,x}	2.0 ± 1.4 _{b,y}	9.0 ± 2.6 _{c,x}	0.0 ± 0.0 _{e,y}	34.7 ± 3.7 _d	7.6 ± 1.7 _f
Sapelli	53.8 ± 3.9 _a	10.9 ± 2.3 _b	54.0 ± 6.0 _{a,x}	11.0 ± 1.9 _{b,z}	21.0 ± 3.4 _{c,y}	1.0 ± 0.7 _{d,w}	11.4 ± 1.6 _e	8.0 ± 2.2 _f
Tali	5.2 ± 1.0 _a	57.1 ± 5.5 _c	21.0 ± 3.7 _{b,x}	64.0 ± 8.9 _{c,z}	2.0 ± 0.9 _{d,y}	48.0 ± 0.9 _{e,z}	2.3 ± 0.7 _d	54.7 ± 4.6 _e

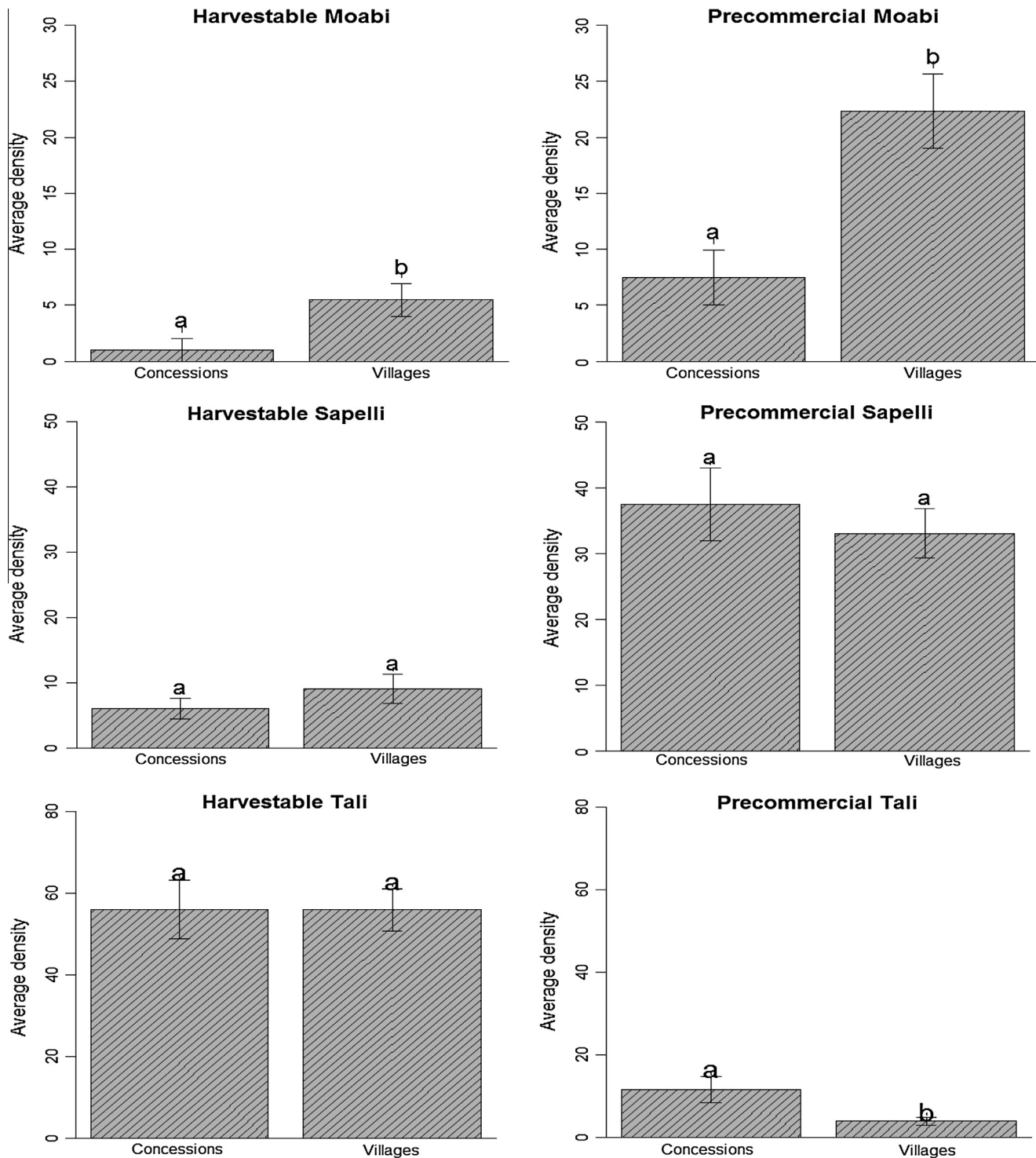


Fig. 3. Density per 100 ha of individuals of Moabi, Sapelli and Tali, harvestable and precommercial, on concessions and around villages. The minimum cutting diameter varies among species (Moabi ≥ 80 cm, Sapelli ≥ 100 cm, Tali ≥ 60 cm). Different letters indicate statistically significant differences between densities on concessions and densities around villages for each size category and species.

The density of precommercial Sapelli trees was not significantly different on concession E as compared to the surrounding villages ($54.0 \pm 6.0/100$ ha and $53.8 \pm 3.9/100$ ha, respectively, $P = 0.951$). However, the density of precommercial Sapelli was significantly higher on concession S than around the nearby villages ($21.0 \pm 3.4/100$ and $11.4 \pm 1.6/100$ ha, respectively, $P = 0.073$). Densities of harvestable Sapelli trees on concession E were not significantly different from densities around the surrounding villages ($11.0 \pm 1.9/100$ ha and $10.9 \pm 2.3/100$ ha, respectively; $P = 0.251$). However, the density of harvestable Sapelli trees on concession S ($1.0 \pm 0.7/100$ ha) was significantly lower than around its neighboring villages ($8.0 \pm 2.2/100$ ha; $P = 0.048$) (Table 10).

Densities of harvestable Tali trees on concessions S and E and their neighboring villages did not vary significantly (for concession S, $48.0 \pm 4.9/100$ ha and $54.7 \pm 4.6/100$ ha respectively, $P = 0.672$; for concession E, $64.0 \pm 8.9/100$ ha and $57.1 \pm 5.5/100$ ha, respectively $P = 0.619$). Similarly, the density of precommercial Tali trees was not significantly different between concession S and its surrounding villages ($2.0 \pm 0.9/100$ ha and $2.3 \pm 0.7/100$ ha, respectively, $P = 0.826$). However there was a significantly higher density of precommercial Tali trees on concession E as compared to surrounding villages ($21.0 \pm 3.7/100$ ha and $5.2 \pm 1.0/100$ ha, respectively, $P = 0.002$) (Table 10).

Considering all villages and both concessions together, the density of Moabi trees was higher, on average, around the villages than in the concessions: $5.0 \pm 1.3/100$ ha and $1.0 \pm 0.9/100$ ha, respectively, for harvestable trees ($P = 0.026$); and 22.5 ± 3.3 individuals/100 ha as compared to $7.5 \pm 2.4/100$ ha, respectively, for precommercial sizes ($P = 0.003$; Fig. 3). The density of harvestable and precommercial trees of Sapelli did not vary significantly between concessions and villages: $6 \pm 1.6/100$ ha and $9.5 \pm 2.2/100$ ha for harvestable trees ($P = 0.823$); and $37.5 \pm 5.5/100$ ha and $32.6 \pm 3.8/100$ ha, respectively, for precommercial sizes ($P = 0.342$). For Tali trees, there was no significant difference between densities of individuals of harvestable sizes on concessions and around villages ($56.0 \pm 7.2/100$ ha and $55.9 \pm 5.1/100$ ha, respectively, $P = 0.95$). However, for precommercial trees the average densities were higher on concessions than around villages ($11.5 \pm 3.1/100$ ha and $3.8 \pm 0.9/100$ ha, respectively, $P = 0.02$) (Fig. 3).

4. Discussion

4.1. Species density around villages

The density of tree species of interest varied among villages: some had two to three times more individuals of a species within 10 km than did others (Table 2). This could reflect the size of the village, the topography around it, past logging activities and the extent of agricultural activities, as well as variation in past ecological circumstances favoring regeneration of various species. It had been expected that density of trees would increase with distance because villagers establish fields in the vicinity of the villages. The fact that density did not change in a significant way with distance reveals either that trees have not been felled in the vicinity of villages; or that trees have been felled throughout this area, at a consistent rate. Agricultural fields and evidence of artisanal felling and sawing were found the full length of the transects.

The lower densities of Moabi trees as compared to those of Sapelli and Tali may reflect the inhibition of regeneration over the years as the result of ecological factors including the collection of fruits (Van Dijk, 1997 in Plenderleith and Brown, 2004). Low densities of both Moabi and Sapelli trees of harvestable size around villages may also reflect logging. In 'Ms', less than 2 km from the concession, and 'Ne', practically within the concession, the stumps

of Tali and Sapelli resulted from felling by the concessionaire, with permission from the local people. Stumps of Moabi and Tali were found around the villages of 'No' and 'Nn', located 8–10 km from the concession. Apparently these trees were felled by local people. In the community forest established formally around one of these villages, logging of commercial species was ongoing at the time of this study. Felling trees to sell their timber is one of the best options local people have to obtain relatively large sums of cash in case of urgent need, for example for a health emergency (Cerutti et al., 2008; Levang et al., 2015; Noubissi, 2012). The legal framework for community forestry was established within the most recent forestry law to formalize this option.

Other studies have found densities of Moabi to be even lower than the 7–64 trees ≥ 20 cm dbh per 100 ha we found around villages and the 8–9 trees ≥ 20 cm dbh per 100 ha we found on concessions. In two different areas of Cameroon, Schneemann (1995) and Nef (1997 in Plenderleith and Brown, 2004) found between 1 and 8 Moabi trees/100 ha. Vermeulen and Doucet (2004) documented 1.9 Moabi trees greater than 100 cm diameter/100 ha in the agroforestry zone around villages near the Dja forest (as compared to the 1–13 greater than 80 cm per 100 ha, depending on the village, in our study). They calculated that this density would be enough to meet the needs of the villagers in the area.

According to Debroux (1998), Moabi attains sexual maturity between 50 and 70 cm diameter, at which size it produces flowers and fruits. With densities of 1–13 Moabi trees greater than 80 cm dbh per 100 ha within 10 km of their villages on the side toward the concession, the different villages had access to 157–2045 large, fruit-producing Moabi trees within those 15,730 ha. If the density were the same on the other side of the village, they would have about 315–4090 Moabi trees ≥ 80 cm within that distance of the village, in addition to productive trees below that diameter. Based on their quantitative analysis of consumption in a village near the Dja forest in southwest Cameroon, Vermeulen and Doucet (2004) determined that the village consumed 107,000 Moabi seeds/year as oil, about 2745 seeds/household. Using Debroux's (1998) estimation that an average mature Moabi (70–240 cm diameter) produces 6000 seeds every 3 years, Vermeulen and Doucet calculated that a village of 300 people (39 households) required 50 fruit-bearing Moabi trees to meet their household needs for fruit and oil. These estimates imply that the four villages we sampled would have enough harvest-size Moabi trees within 10 km of their villages to provide for between 1890 and 24,540 people, or about 237–3067 households, depending on the village. In addition, trees between 50 cm and 80 cm, below the minimum felling diameter, also produce fruit, and occur at even higher densities around the villages. It has also been documented that villagers travel even further, as far as two days' walk (50 km) from the village to obtain Moabi fruits, camping in the forest during the fruiting period (Schneemann, 1995). However, current densities of harvestable trees within the logging concessions we studied were found to be so low that on one concession none were registered in our sample plots. It will be important that villagers sustain the trees around their villages to ensure their future access to this important resource.

The average density of 3–15 harvestable Sapelli trees per 100 ha, and 30–85 harvestable Tali trees per 100 ha, depending on the village, meant that villagers had access to approximately 472–2359 harvestable Sapelli and 4719–13,371 harvestable Tali trees in the 15,730 ha within 10 km of their villages towards the concession. If the same densities were found on the other side of the village, they would have access to double that number. Muvatsi et al. (in press) estimated that Sapelli trees ≥ 80 cm dbh yield 10.9 kg/tree each season of *I. oyemensis* caterpillars while Tali trees ≥ 60 cm dbh yield 8.2 kg of *C. forda* caterpillars/tree/season,

so these trees could be expected to provide between about 5145 kg and 25,713 kg of *I. oyemensis* and between 38,696 kg and 109,642 kg of *C. forda* caterpillars/season, just from the half circle of land within 10 km of the village, towards the concession.

Precommercial Sapelli trees (20–100 cm dbh) were found at densities of 9–63 individuals per 100 ha, depending on the village, or 1416–9910 individuals over the 15,730 ha within 10 km of the villages towards the concessions, possibly double that if the density on the other side of the village is similar. Each one could be expected to produce an average of 1.14 kg/tree of *I. oyamelensis* caterpillars/season (Muvatsi et al., in press), an additional 1614 kg to 11,297 kg from that area. However, because harvestable Sapelli trees produce more than 9 times more caterpillars per tree than do precommercial sizes, the extraction of these large trees would have a significant impact on the availability of this important food resource. In the case of Tali, it's notable that around the sample villages the density of precommercial trees (0–6 trees/100 ha) was lower than the density of trees of harvestable size. This may reflect poor regeneration under closed canopy in the past, as suggested by Doucet et al. (2009). It may also reflect felling of small trees by villagers, as revealed by the presence of stumps. Tali is appreciated for its durability and is used for local construction as well as artisanal logging. These precommercial trees could be expected to produce 5.5 kg of *C. forda* caterpillars/tree/season (Muvatsi et al., in press), a total of up to 5190 kg/season over the 15,730 ha of the area sampled (or twice that over the 31,460 ha within 10 km of the village).

4.2. Species density in the concessions and the effect of logging

On one concession no Moabi ≥ 80 cm dbh were found, and on the other, only 2/100 ha. The densities found in this study are quite similar to the 3 Moabi ≥ 70 cm dbh/100 ha recorded in the Dja district (Doucet et al., 2009). Moabi has been logged for export for decades, most of it from eastern Cameroon. It has been suggested that logging has led to a decrease and even the disappearance of Moabi in areas that have been logged over long periods. As a result, the World Conservation Monitoring Centre has classified Moabi in Cameroon as “vulnerable” (Plenderleith and Brown, 2004). A survey around four villages in the Mbang subdistrict showed that as of 1993, logging companies had extracted about 37% of the initial number of Moabi trees (as many as 86% around one village). As early as the 1990s, communities were asking logging companies to stop felling this species, in some cases attaching boards on trees indicating the name of the individual entitled to collect its fruits and in other cases arming themselves with bows and arrows to defend the trees (Schneemann, 1995). It is noteworthy that neither of the concessionaires studied harvested Moabi trees on their 2012 cutting areas, respecting an agreement with the communities who harvest the fruits for their seed oil, but the densities of commercial sized trees on concession S, were already much lower than around the neighboring villages.

Sapelli trees were found at lower densities (1–11/100 ha of commercial size; 22–65/100 ha ≥ 20 cm dbh) than those reported from other logged forests in Cameroon. Garcia et al. (2001) reported 146 sapelli/100 ha ≥ 20 cm dbh on a 100 ha plot in Ndama in the absence of harvesting while Lourmas et al. (2007) reported 152 sapelli ≥ 10 cm dbh before and 113/100 ha after the 2002 logging operation, on the same plot. Dubois (1998 in Garcia et al., 2001) reported 36 sapelli ≥ 20 cm dbh/100 ha on a 400 ha plot in Dimako after harvesting. The low density we found probably reflects not only the regeneration ecology of this shade-intolerant species (Hall et al., 2003; Hall, 2008) but also the high level of demand for its timber, not only now but in the past (ATIBT, 2007). Selective timber harvesting began in Cameroon in the 1880s and increased starting in the 1920s. Sapelli is one of

the species that was most appreciated from the beginning (Topa et al., 2010). The areas managed by these two concessionaires have a history of prior exploitation by other companies. In the case of Concessionaire S, timber harvests had been carried out at least since 1998 by ECAM-PLACAGE and COCAM (1998–1999) and WIJMA (2000–2001). Concession E had also been harvested by previous concession holders, since at least 1969, by EFC (1969–1989), SFID (1971–1975) and SEBC (1969–1998) (Medinof, 2004). Before the 1990s, timber harvesting was carried out under licenses that did not require management plans (ATIBT, 2007).

The more than 10-fold difference in density of harvestable Sapelli trees between the two concessions may reflect the intensity of past harvesting or the frequency and distribution of past regeneration opportunities. The proportion of harvestable trees extracted in 2012 varied between Sapelli and Tali: 21–50% of Sapelli trees compared to 6–11% of Tali trees, depending on the concession. Sapelli has practically unlimited demand while Tali is harvested only in response to orders. The low level of extraction of Tali means that timber harvesting has not, so far, had a significant impact on the densities of this species on concessions. The removal of half, or fewer, of harvest-size individuals, even of Sapelli, was explained by the concessionaires as reflecting high quality standards for logs and limited access to some portions of the concession due to flooding in lowlands or steep slopes, both of which were observed during sampling. These areas are protected from harvesting by regulation, but they are also inaccessible for logging machinery. Furthermore, regulations require that seed trees of commercial species be left standing (ATIBT, 2007). The commercial-sized trees remaining after harvesting operations represent an important resource base for edible caterpillars.

It's noteworthy that the density of precommercial Sapelli trees (20–99.9 cm dbh; $21 \pm 3.4/100$ ha on concession S and $54.0 \pm 6.0/100$ ha on concession E) was twice to almost five times higher than the density of harvestable trees. These trees can be expected to produce caterpillars each year, though at considerably lower rates than larger trees. Those that survive and grow to harvestable size might be extracted in a subsequent cutting cycle (to reoccur in 30 years), but only if they are accessible and meet quality standards. The relatively high density of Tali of harvestable size compared to its density in precommercial size classes may reflect the fact that the commercial demand for Tali is limited, and that past regeneration opportunities have also been limited.

4.3. Comparison between densities on villages and concessions

The density of Moabi trees (both harvestable and precommercial), was higher around villages than on concessions, on average, and specifically on concession S (Fig. 3). This may reflect favorable regeneration conditions in the past; however it is more likely to reflect past logging events and the protection of these trees by villagers for their fruits and oil, as revealed in their negotiations with concessionaires to prevent their felling. The higher density of precommercial sized individuals of Tali on concessions than near villages may reflect the fact that villagers who fell trees for artisanal purposes do not respect the high diameters required by the international export market. These trees are used for local construction as well as for crafts and carpentry.

5. Conclusion

This study showed that the 2012 harvesting operation on the sampled concessions had not significantly reduced the density of the commercial-sized trees of these three species as compared to their density around neighboring villages. After logging, 50–79% of commercial Sapelli trees and 89–94% of commercial Tali trees

were left standing on the cutting areas of the concessions. These trees may not meet quality standards or be extractable for timber, but they can continue to provide caterpillars at high annual rates, with no opportunity cost to timber production. At the same time, they represent important seed sources for regenerating these tree species. Nonetheless, the density of sapelli was found to be somewhat low as compared to the densities reported in the literature. This probably reflects harvesting that took place in the sampled regions before the current concessions were granted. The spatial extent of these prior operations may well have included the areas sampled within 10 km of the villages.

Caterpillars can also be obtained from trees smaller than the commercial felling diameter, which are not the target of timber harvesting in concessions that respect high diameter limits for export products. Precommercial trees of Moabi and Sapelli were more abundant on concessions than trees of commercial size. However, Moabi trees don't produce fruits or seeds until they reach 50 cm, so some of these smaller trees would not yet be productive of NTFPs. In the case of Sapelli, it would take about 9 precommercial trees to produce the number of caterpillars yielded by a tree of harvestable size.

Because local people most commonly collect NTFPs while traveling on foot through the forest, conservation of trees that produce food products should be prioritized within a reasonable walking distance of their villages. It is noteworthy that in this case villagers had successfully negotiated with neighboring timber concessions to refrain from felling commercial-sized Moabi trees because of their value to villagers for fruit and oil. This sort of negotiation between concessionaires and villagers represents a constructive initiative reflecting the country's 1994 Forestry Law, in which it is provided that timber exploitation must not hinder villagers' use of resources (Article 61, section 2). The Forest Law provides a mechanism, the 'Cahiers de Charge', for this sort of negotiation between villagers and concessionaires (Ndoye and Tieguhong, 2004). These should be promoted and supported. It is noteworthy, however, that these negotiations typically take place between industry and Bantu villagers. Pygmies are often excluded, although they are most dependent on forest resources. Approaches are needed to enhance their options for negotiating their interests, with both concessionaires and Bantu villagers (Nguiffo, 2007).

However, tree felling occurs even around villages, carried out not by concessionaires but by villagers. We learned from parallel socioeconomic studies (Levang et al., 2015; Nombissi, 2012) that individual villagers periodically sell trees for timber, even if these trees yield fruits or other non-timber products used by others. We were told by Baka people that the harvesting of timber by their neighbors in the community forest meant that they had to travel further to obtain fruits and other non-timber products. This represents a significant opportunity cost to them. Typically it is women who seek to retain access to these food resources (Nguiguim et al., 2011) while men choose to fell the tree for timber. Felling to sell the timber yields a one-time benefit from Moabi trees, but it has been calculated that their value is higher for oil production: at 7.5 years, the Net Present Value of discounted oil revenues exceeds the timber value (Schneemann, 1995). Even within villages, it is important to promote the capacity to negotiate among individuals who use different resources from the same trees.

There is considerable potential to manage these forests for the production of both timber and non-timber resources through spatial zoning, inventories, production analyses and negotiation of priorities and uses for each priority species, size class, resource and area, combined with the implementation of silvicultural practices to safeguard and sustain trees that produce both timber and non-timber resources. Our quantitative analyses reveal that the

tradeoffs and opportunity costs involved may be relatively low. To date, silviculture is not implemented even to sustain timber species, calling into question future harvests of both timber and non-timber resources from timber concessions (Hall et al., 2003; Karsenty and Gourlet-Fleury, 2006; Cerutti et al., 2008; Duminil et al., 2016). Implementing management for the full spectrum of forest resources would increase the benefits and the beneficiaries of the Congo Basin forests.

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