RESEARCH PAPER

Effects of logging regimes on woody species diversity and stand structure in community forests adjacent to the Dja biosphere reserve, Cameroon

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ABSTRACT

This study assessed the effects of different logging regimes on woody species diversity and stand structure in three community forests (Adjane, Kompia and Nemeyong II) located in the peripheral zone of the Dja Biosphere Reserve, southeastern Cameroon. Floristic inventories and dendrometric measurements were conducted in 24 temporary plots (250 × 20 m) established under contrasting logging practices, including artisanal and industrial logging, applied either intermittently or continuously. All woody individuals with a diameter at breast height (DBH)≥ 5 cm were recorded and diversity and structural parameters were compared among logging regimes. A total of 8.089 trees belonging to 289 species, 199 genera and 58 families were inventoried. Forests subjected to intermittent artisanal logging exhibited higher species richness, diversity indices, tree density and basal area compared to forests exposed to continuous or industrial logging. Diameter-class distributions were dominated by small-sized individuals, indicating active natural regeneration across all sites. In contrast, forests affected by permanent industrial logging showed reduced canopy cover and a higher dominance of pioneer and heliophilous species. Overall, logging regime strongly influences woody vegetation diversity and forest structure. Intermittent artisanal logging appears to enhance forest resilience and represents a viable option for sustainable community forest management in the buffer zones surrounding protected areas in the Congo Basin.

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INTRODUCTION

The Dja Biosphere Reserve, designated as a UNESCO World Heritage Site in 1987, is one of the most biologically diverse forest ecosystems in the Congo Basin (Sonké, 1998; Bruce *et al.*, 2018). Although its core area is legally protected, the surrounding community forests are increasingly subjected to anthropogenic pressures, particularly logging activities, which may alter forest structure and threaten biodiversity conservation within the buffer zone (IUCN, 2020; Tegno Nguekam *et al.*, 2020). In Cameroon, community forestry was introduced to promote sustainable forest management while improving local livelihoods (MINFOF, 2024). However, community forests are often exposed to diverse logging regimes, including artisanal and industrial logging, practiced either intermittently or continuously. These regimes differ in terms of intensity, frequency and spatial extent of disturbance, resulting in contrasting ecological impacts on forest ecosystems. Logging is a major driver of change in tropical forests, influencing woody species diversity, stand structure and regeneration dynamics (Fonteyn, 2017).

Continuous and industrial logging are generally associated with canopy opening, reductions in basal area and the proliferation of pioneer species, whereas intermittent artisanal logging may better preserve forest heterogeneity and resilience (Kengne *et al.*, 2018). Despite this, comparative studies evaluating the ecological effects of these logging regimes in community forests adjacent to protected areas remain scarce.

This study aims to assess the effects of different logging regimes on woody species diversity and stand structure in three community forests (Adjane, Kompia and Nemeyong II) located in the peripheral zone of the Dja Biosphere Reserve. Specifically, it examines how artisanal and industrial logging practices influence forest composition, structure attributes and regeneration patterns, and discusses the implications for sustainable community forest management in the Congo Basin.

MATERIALS AND METHODS

Study area

The study was conducted in the peripheral zone of the Dja Biosphere Reserve, located in south-eastern Cameroon between 2°50' - 3°30' N latitude and 12°20' - 13°40' E longitude. The northern periphery of the reserve lies within the East Region, Haut-Nyong Division, bordering the municipalities of Somalomo and Messamena.

Three community forests were selected : Adjane, Kompia and Nemeyong II (Fig. 1). The Adjane community forest covers an area of 3.136 ha and has been mainly subjected to artisanal logging since 2019, with the introduction of industrial logging in 2022. The Kompia community forest covers 1.433 ha and has experienced artisanal logging since 2002, alongside industrial logging activities initiated in 2022. The Nemeyong II community forest covers 1.325 ha and has been exclusively exploited through small-scale artisanal logging since 2013.
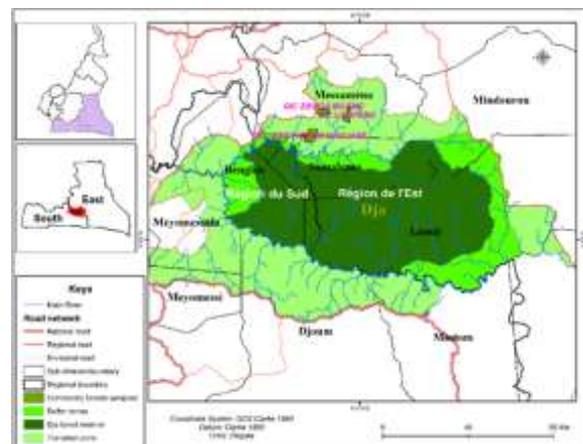

Fig. 1. Geographical location of the Adjane, Kompia and Nemeyong II community forests surrounding the Dja Biosphere Reserve, Cameroon (Wild Earth, 2023, modified)

Artisanal logging is characterised by the use of simple equipment and the absence of heavy machinery within the forest. It is generally conducted by small independent loggers, with or without formal permits. In contrast, industrial logging involves large-scale timber extraction, road construction for access and

log transport, and is associated with greater environmental disturbance.

The climate of the study area is characterised by a bimodal rainfall regime, with two rainy seasons ("March-June" and "August-November") alternating with two dry seasons (Tsalefac e*t al.*, 2015). Altitude ranges between 500 and 700 m above sea level. The relief consists mainly of shallow valleys and gently undulating terrain (Sonké, 1998). The hydrographic network is dominated by the Dja River.

Soils are mainly derived from schists, quartzitic sandstones, gneisses and limestones (MINFOF, 2004). Vegetation is dominated by semi-deciduous lowland tropical rainforest, including mature forests, secondary forests and swamp forests (Nguenang *et al.*, 2010). The fauna is particularly rich, with emblematic mammal species such as *Loxodonta cyclotis* and *Pan troglodytes*, as well as diverse bird, reptile and amphibian species (Bruce *et al.*, 2018).

Experimental design and data collection
Floristic inventories were carried out in 24 temporary rectangular plots measuring 250 × 20 m (0.5 ha), a sampling design commonly used for forest structure and diversity studies in tropical ecosystems (Tabue Mbobda *et al.*, 2018). Plots were systematically established along a south-north orientation and spaced at least 500 m apart to ensure spatial independence (Mounmemi, 2021).

Sampling intensity was 0.13 % for Adjane, 0.28 % for Kompia and 0.30 % for Nemeyong II. The plots encompassed different forest facies, including mature forest, young forest, degraded forest and swamp forest, in order to capture the structural and compositional heterogeneity of the study area.

Floristic inventory
All woody individuals with a diameter at breast height (DBH) ≥ 5 cm were inventoried within each plot following the standard methodology described by Staub (2019). Fieldwork was conducted in November 2023.

Trees were identified in situ using local or commercial names when scientific identification was not immediately possible. Voucher specimens were collected for unidentified or ambiguous individuals, pressed and preserved, and subsequently identified by comparison with reference collections at the National Herbarium of Cameroon (Yaoundé). Scientific nomenclature followed the Angiosperm Phylogeny Group IV (APG IV) classification system.

Dendrometric measurements
Diameter was the only dendrometric parameter measured. For individuals with DBH ≥ 10 cm, measurements were taken at 1.30 m above ground level for trees without buttresses, or 30 cm above the buttress for buttressed trees (Angoni *et al.*, 2018; Bosanza *et al.*, 2021).

For individuals with diameters between 5 cm and 10 cm, measurements were taken at 50 cm above ground level. Diameters were measured using a diameter tape and recorded to the nearest millimetre (Mounmeni, 2021).

Data analysis
Floristic richness was assessed based on the total number of species, genera and families recorded in all and each community forest. Woody species diversity was quantified using the following indices:

Shannon diversity index (H'), used to estimate species diversity and heterogeneity, is calculated as : $H' = - \Sigma (N_i/N) \ln (N_i/N)$. N_i is the number of individuals of species i and N is the total number of individuals. The maximum value of the index is given by $H'_{max} = \ln S$, where S is the total number of species (Shannon, 1948).

Pielou's evenness index (J), used to assess the evenness of species abundance, is calculated as : $J = H'/H'_{max}$. This index ranges from 0 (high dominance) to 1 (perfect evenness) (Piélou, 1966).

Simpson's diversity index (D), expressing the probability that two randomly selected individuals

belong to different species, calculated as: D= 1 - Σ $(Ni/N)^2$. The values range from 0 (low diversity) to 1 (high diversity) (Simpson, 1949).

Floristic similarity was evaluated using Sørensen's similarity coefficient (Ks) : Ks= 2C/A+B × 100. A and B represent the number of species in each forest and C the number of species common to both (Sørensen, 1948).

The ecological importance of species and families was evaluated using the Importance Value Index (IVI) and Family Importance Value (FIV), calculated as the sum of relative density (DeR), relative dominance (DoR) and relative frequency (FR) (Cottam and Curtis, 1956). DeR = number of individuals of a species or family / total number of individuals of all species or families × 100. DoR (relative dominance) calculated using the formula DoR = basal area of a species or family/sum of the basal areas of all species or families × 100. FR (relative frequency) obtained using the formula FR = number of occurrences of a species or family/sum of occurrences of all species or families × 100.

Stand structure was analysed using tree density (individuals/ha), basal area (m²/ha) and mean diameter. Basal area was calculated as: G = (Σ π ni di²/4) /Si. di is the diameter of individual i, ni is the number of individuals included in diameter i, and Si is the sampled area in hectares (Pascal, 2003).

Diameter-class distributions were established to analyse population structure and regeneration. The [5-10 cm [class was used to characterise juvenile individuals. For trees with DBH ≥ 10 cm, diameter classes of 10 cm width were applied (MINFOF, 2019).

Data were entered and processed using Microsoft Excel, and statistical analyses were performed using R software (version 4.4.3.). Data normality was tested using the Shapiro – Wilk test, and differences among community forests were assessed using Tukey's post hoc test at a 5 % significance level.

RESULTS
Woody species diversity in the three community forests
A total of 8.089 woody individuals with a DBH ≥ 5 cm were recorded across the three community forests surrounding the Dja Biosphere Reserve. These individuals belonged to 289 species, 199 genera and 58 families, reflecting the high floristic richness of the study area.

Floristic composition and richness
Floristic richness varied among the three community forests (CFs). The Nemeyong II CF exhibited the highest floristic richness, with 3.230 individuals, 219 species, 162 genera and 48 families. This was followed by the Adjane CF, which contained 2.564 individuals, 215 species, 164 genera and 51 families. The Kompia CF showed the lowest values, with 2.205 individuals, 184 species, 142 genera and 45 families.

Across all CFs, individuals with a DBH ≥ 10 cm accounted for the majority of the woody population. However, a substantial proportion of individuals belonged to the juvenile (5 cm ≤ DBH < 10 cm), particularly in Kompia and Nemeyong II, indicating active recruitment and regeneration processes.

Mean species richness per plot differed significantly among the three CFs ($p < 0.001$). Nemeyong II recorded the highest mean species richness (105 ± 10 species per plot), followed by Adjane (94 ± 9 species), while Kompia exhibited the lowest richness (69 ± 11 species) (Table 1).

Across all CFs, Fabaceae was the most represented family, accounting for 28.74 % of individuals in Adjane, 49.46 % in Kompia and 25.07 % in Nemeyong II. At the species level, *Petersianthus macrocarpus* dominated in Adjane (15.14 %) and Nemeyong II (15.20 %), whereas *Musanga cecropioides* was the most abundant species in Kompia (12.76 %).

Diversity indices
Diversity indices confirmed a generally high level of woody diversity across the study area. Shannon

diversity values ranged from 3.54 ± 0.26 in Kompia to 4.12 ± 0.16 in Nemeyong II. Pielou's evenness index remained high in all CFs (J > 0.80), indicating a relatively even distribution of individuals among species. Simpson's index value was close to 1, reflecting high diversity and low dominance (Table 1).

Floristic similarity between community forests was high, with Sorensen similarity coefficients exceeding 70 % for all pairwise comparisons. The highest similarity was observed between Adjane and Nemeyong II (78.62 %), while the lowest occurred between Adjane and Kompia (70.68 %).

Table 1. Mean floristic richness and diversity indices among the three community forests

Community forest	SR	NG	NF	H'	J	D	NP
Adjane	94 ± 9b	82 ± 7b	34 ± 3b	4.07 ± 0.11a	0.90 ± 0.02a	0.97 ± 0.01a	8
Kompia	69 ± 11a	61 ± 10a	29 ± 3a	3.54 ± 0.26b	0.84 ± 0.05b	0.94 ± 0.03b	8
Nemeyong II	105 ± 10b	90 ± 7b	34 ± 2b	4.12 ± 0.16a	0.88 ± 0.02a	0.97 ± 0.01a	8

SR: species richness, NG: number of genera, NF: number of families, H': Shannon diversity index, J: Pielou's evenness index, D: Simpson's diversity index, NP: number of plots. Averages followed by different letters between rows are significantly different at the 5% threshold according to the Tukey test.

Table 2. Structural parameters of woody stand in three community forests

Community forest	MD (Ind./ha)	Contribution of 5 – 10 cm class to density (%)	BA (m²/ha)	Contribution of 5 – 10 cm class to BA (%)	d (cm)	NP
Adjane	641 ± 75	33.93	29.89 ± 6.82	3.04	18.28 ± 1.35	8
Kompia	551 ± 128	43.04	22.16 ± 3.86	4.42	16.59 ± 2.19	8
Nemeyong II	830 ± 143	39.70	34.36 ± 4.66	3.73	17.18 ± 1.20	8

MD: Mean density, BA: basal area, d: mean diameter, NP: number of plots.

Structure of woody stands in community forests

Tree density and basal area

Tree density and basal area varied markedly among the three CFs (Table 2). The Nemeyong II CF exhibited the highest mean tree density (830 ± 143 individuals/ha) and basal area (34.36 ± 4.66 m²/ha), indicating a dense and well-structured stand. The Adjane CF showed intermediate values (641 ± 75 individuals/ha); 29.89 ± 6.82 m²/ha), whereas the Kompia CF had the lowest density (551 ± 128 individuals/ha) and basal area (22.16 ± 3.86 m²/ha).

Juvenile individuals (5 cm ≤ DBH < 10 cm) contributed substantially to total tree density, particularly in Kompia (43.04 %), followed by Nemeyong II 39.70 %) and Adjane (33.93 %).

However, their contribution to total basal area remained low (< 5 %) in all CFs, highlighting the dominant role of larger trees in stand biomass.

Diameter structure and regeneration patterns

Diameter-class distributions in all three CFs exhibited a decreasing exponential (inverse-J) pattern, characterised by a high proportion of small-diameter individuals and a progressive decline toward larger diameter classes (Fig. 2). This structure indicates active natural regeneration and continuous recruitment across all sites.
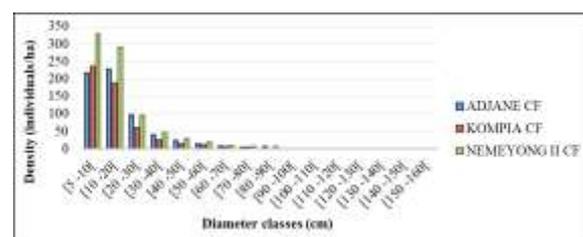

Fig. 2. Diameter-class distribution of woody individuals in the Adjane, Kompia and Nemeyong II community forests

In the Adjane CF, diameter classes between 10 and 90 cm accounted for 85.06 % of the total basal area, with a peak between 20 and 30 cm class. In the Kompia CF, 85.04 % of the basal area was concentrated between 10 and 100 cm, peaking in the 10 -20 cm class. The Nemeyong II CF showed the highest concentration, with 89.39 % of basal area between 10 and 90 cm, peaking at 10 – 20 cm class (Fig. 3).
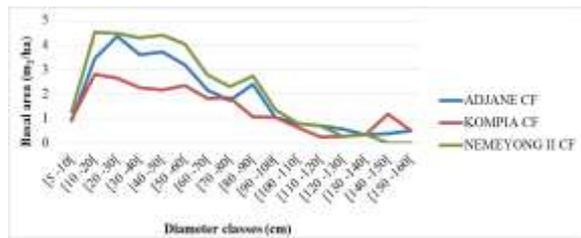
Fig. 3. Distribution of basal area across diameter classes in the three community forests

Across all CFs, Fabaceae and *petersianthus macrocarpus* contributed the largest share of basal area, confirming their structural importance within the woody stands.

Comparative analysis of vegetation characteristics

Hierarchical cluster analysis distinguished two major groups of plots (Fig. 4). The first group consisted mainly of plots from Kompia CF, associated with young, degraded and swamp forests types. The second group included plots from all three CFs and was characterised by higher species richness, tree density and basal area.
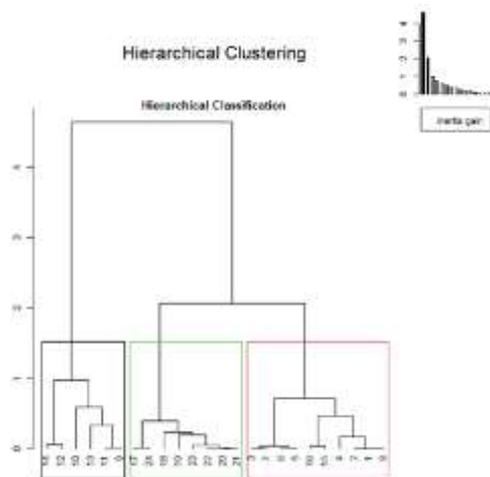

Fig. 4. Hierarchical cluster analysis of vegetation plots based on woody species composition and structural attributes

Principal Component Analysis (PCA) revealed positive correlations among species richness, tree density and basal area, whereas long-term and continuous logging duration was associated with lower diversity and structural values (Fig. 5).
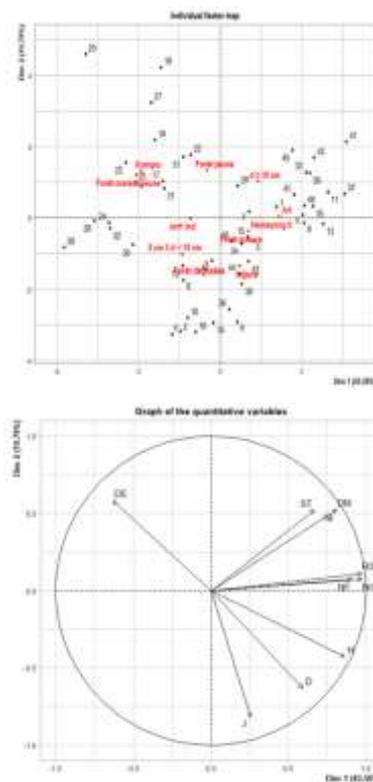

Fig. 5. Principal component analysis (PCA) showing relationship between diversity and structural variables across the three community forests

A significant positive relationship was observed between species richness and basal area ($R^2 = 0.59$; $p < 0.005$), indicating that structurally developed stands support higher woody species diversity (Fig. 6).
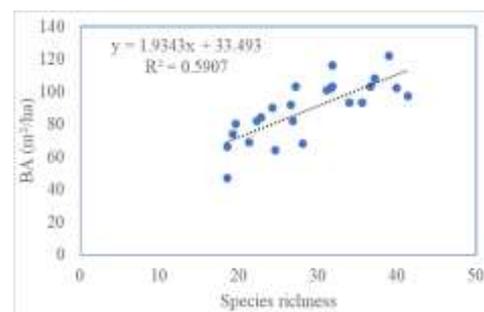

Fig. 6. Relationship between woody species richness and basal area in the studied community forests

DISCUSSION

This study demonstrates that logging regimes strongly influence woody species diversity and stand structure in community forests surrounding the Dja Biosphere Reserve. Forests managed under intermittent artisanal logging, particularly the

Nemeyong II community forest, exhibited higher species richness, diversity indices, tree density and basal area than forests subjected to long-term continuous or industrial logging, such as the Kompia community forest. These results confirm that logging intensity and frequency are key drivers of forest structure and biodiversity in community-managed tropical forests.

The higher floristic richness observed in Nemeyong II and Adjane is consistent with previous studies conducted in community forests of southeastern Cameroon and across the Congo Basin, which report better conservation of species diversity and stand structure under intermittent exploitation regimes (Kengne *et al.*, 2018; Tabue Mbobda *et al.*, 2018; Nyeck *et al.*, 2024). In contrast, prolonged and continuous logging, as observed in Kompia, tends to reduce basal area, simplify stand structure and promote disturbance-tolerant or pioneer species, leading to progressive decline in overall diversity (Mposo Nsangua *et al.*, 2018; Mianbangana, 2020).

The dominance of Fabaceae across all community forests reflects a typical feature of semi-deciduous tropical forests in Central Africa. Species belonging to this family are often favoured under logging disturbances due to their ecological plasticity and high regeneration capacity (Lejoly, 1995; Betti, 2004). The structural importance of *petersianthus macrocarpus* further highlights its resilience and competitive advantage under moderate disturbance conditions in the peripheral zone of the Dja Biosphere Reserve.

Diameter-class distributions in all three community forests followed an inverse-J pattern, indicating active natural regeneration and continuous recruitment. However, the higher basal area recorded in Nemeyong II suggests better preservation of large-diameter trees, which play a disproportionate role in biomass storage and ecosystem functioning (Slik *et al.*, 2013).

Conversely, the lower basal area observed in Kompia reflects the cumulative effects of repeated harvesting and insufficient recovery periods.

Multivariate analyses further confirmed the influence of logging regimes on vegetation characteristics. Plots associated with Kompia were primarily linked to degraded and young forest types, whereas plots from Nemeyong II and Adjane were characterised by higher species richness, tree density and basal area. The significant positive relationship between species richness and basal area supports the widely documented link between structural complexity and biodiversity in tropical forests (Putz *et al.*, 2012; Poorter *et al.*, 2015).

Overall, the convergence of local and international evidence indicates that intermittent artisanal logging represents a more ecologically sustainable management option for community forests located in buffer zones of protected areas. By allowing sufficient recovery periods between harvesting events, this approach supports natural regeneration, maintains structural complexity and enhances long-term biodiversity conservation in the Dja Biosphere Reserve landscape.

CONCLUSION
This study demonstrates that logging regimes play a decisive role in shaping woody species diversity, stand structure and regeneration dynamics in community forests surrounding the Dja Biosphere Reserve. Forests managed under intermittent artisanal logging exhibited higher species richness, greater basal area and better preservation of large-diameter trees compared to forests subjected to continuous and long-term logging, which showed signs of structural simplification and reduced diversity.

Although all studied community forests displayed active natural regeneration, the maintenance of structural complexity and biodiversity was closely associated with lower disturbance frequency and longer recovery periods. These findings highlight the importance of promoting low-intensity and adaptive logging systems in community forests, particularly within buffer zones of protected area.

By demonstrating that artisanal and intermittent logging can be compatible with biodiversity conservation, this study provides robust scientific support for sustainable

community forest management policies in the Congo Basin and other tropical forests regions facing increasing anthropogenic pressures.

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