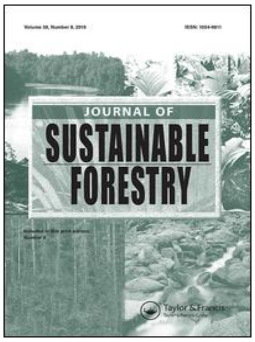

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Conservation Outcomes of Collaborative Forest Management in a Medium Altitude Semideciduous Forest in Mid-western Uganda

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ABSTRACT

Globally, community involvement in forest management has been hailed as an effective strategy to achieve both conservation and livelihoods improvement goals. In Uganda, Collaborative Forest Management (CFM) has been promoted to enable registered local community groups to co-manage specified areas of state forests with state agencies. However, there is paucity of empirical research evidence on conservation outcomes that are attributable to CFM. To fill this gap, this study used forest inventory data collected in compartments under different forest management regimes (CFM, inactive-CFM, and non-CFM) in 2003 and 2016 to assess spatial and temporal changes in forest structural attributes in a semideciduous forest in mid-western Uganda. Our ordination results show significant changes in tree communities in the non-CFM compartment. The CFM compartment registered a net increase in basal area. We attribute these changes to the high rate of illegal timber extraction and charcoal processing, with signs of the latter only recorded in the inactive- and non-CFM compartments. Illegal timber extraction was perpetuated by powerful outsiders while charcoal processing was dominated by local area residents for cash income. Deliberate management interventions should be instituted to curb illegal human activities and enhance regeneration and recruitment of target tree species in the forest.

KEYWORDS

Collaborative Forest Management; forest conservation outcomes; human activity; Uganda

Introduction

Forests provide vital goods and services that support livelihoods of more than one billion people globally (Newton et al., 2016). Many rural communities in developing countries use forest resources as a supplementary livelihood option (Shackleton et al., 2001) or alternatively, as a gap filler following inadequacies in preferred options, but also frequently as a safety net during emergencies such as prolonged drought or famine periods (Takasaki et al., 2001). High human population growth rates and extensive farming systems in most of these countries increase pressure on the forestry resources. Consequently, there has been renewed interest among the conservation

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community to craft strategies to achieve a *"win-win"*outcome, where forests are conserved while simultaneously improving rural livelihoods.

Until the 1970s, most national governments relied on the protectionist conservation approach to manage forest resources. This entailed centralized regulatory control that banned the extraction of resources from protected forested areas, basically excluding local people from the forests and its resources (Benjaminsen & Svarstad, 2010). However, local people became hostile to conservation agencies, effectively jeopardizing the hegemony, legitimacy, and popularity that the protectionist approach had garnered. Eventually, external pressures for policy reform ensued. Consequently, during 1980–1985, the global conservation community advocated for more participatory conservation approaches that recognized and promoted active involvement of local communities in conservation (Anderson and Grove, 1987; Barrow et al., 2002; Levis, 1996). Over the last four decades, most countries in Africa have promoted more participatory natural resource management approaches – albeit with different labels in different countries (Turyahabwe et al., 2015).

In Uganda, two key participatory approaches have been promoted in the forest sector: Community Forestry (CF) and Collaborative Forest Management (CFM) (GoU, 2003). The underlying principle of these approaches is that local communities living in proximity to forests are in the best position to manage and protect them as long as they perceive it to be beneficial (Larson et al., 2010). CFM is a co-management arrangement in which local forest-adjacent communities form and register Community-Based Organizations (CBOs) that then sign CFM agreements with the state agency to share rights, responsibilities, and returns in a specified state-owned forest. The community benefits envisaged in the agreements include devolved rights to exclude unauthorized users from accessing forest resources, extraction of agreed-upon forest resources from the forest by CFM members, tree planting on degraded parts of the forest reserve, involvement in alternative livelihood activities such as beekeeping and establishment of commercial tree nurseries. CFM has been institutionalized through the 2001 Forest Policy (MWLE, 2001) and the 2003 National Forestry and Tree Planting Act (GoU, 2003) and has been implemented in over 27% of the government-owned forest reserves under the National Forestry Authority (Kazoora et al., 2019; MWE, 2016).

Since the one main objective of CFM is to enhance forest conservation, compartments where local communities are involved in forest management are expected to have a lower count of illegal human activities and higher basal area (BA) and stem densities of preferred tree species. However, the existing literature presents mixed results on the effect of CFM on forest conservation in Uganda. For example, Banana et al. (2004) reported continued illegal extraction of timber in five out of eight forests where pilot CFM initiatives were being implemented in central Uganda. Other studies have reported partial success in Mabira, Mt. Elgon National Park and Budongo Forest Reserves (Jagger, 2010; Jiren, 2013; Nakakaawa et al., 2015; Turyahabwe et al., 2013). However, most of these studies have used perception-based assessments rather than inventory data or remote-sensing data which could be more reliable (Lund et al., 2010). Moreover, those that used inventory data do not adequately address the question of influence of forest edge-interior distance on the incidence of human activities, even though studies such as Olupot and Chapman (2003) demonstrate its importance.

There is as such still dearth of recent empirical information on whether CFM is actually inhibiting illegal human activities or it is, in effect, only altering the pattern of these activities. To fill this gap, in this study, we seek to answer the following questions: (i) What are the levels of recent illegal human activities in CFM, inactive CFM and non-CFM compartments? (ii) How do illegal human activities vary with forest edge-interior distance? (iii) How do these illegal human activities influence forest structure? Our study site (Budongo Forest Reserve – BFR) is among the few where the first pilot CFM activities in the country were initiated in the early 2000s and provides a unique scenario for capturing local experiences with CFM on the ground. Inactive CFM compartments refer to compartments where CFM activities were initiated but had stalled at the time of the study. Non-CFM compartments are those that are under the management of the National Forestry Authority (NFA) (the state agency) and have never had CFM activities piloted there.

Materials and methods

Study area

Budongo Forest Reserve is a medium altitude, moist semideciduous forest located in mid-western Uganda (31° 22′ – 31° 46′ E and 1° 37′ – 2° 03′ N). The tropical-forested area occupies 53% of the 853 km^2 reserve area while the rest is comprised of grassland (Howard, 1991). The area experiences a bimodal rainfall pattern, which peaks from March to May and September to November, with a mean annual range between 1397 and 1524 mm. The minimum annual temperature is 23–29°C, while the maximum is 29–32°C (NFA, 2011). The Northern, North-eastern and North-western parts of the reserve border protected areas whereas the southern, southwestern and eastern boundaries of the reserve border villages whose inhabitants are predominantly small-scale subsistence farmers and sugarcane out-growers that supply Kinyara Sugar Factory located about 5 km on the southern part of the forest. The forest is also an important source of resources for subsistence (e.g., construction poles, medicinal plants, and firewood) and income (e.g., timber and charcoal) (Tumusiime et al., 2010) some of which are obtained illegally (Gombya-Ssembajwe et al., 2007). In terms of management, the Forest Department initially managed BFR primarily for extraction of commercial rubber and later mahogany timber (Eggeling, 1947). At present, the state agency managing the reserve – the National Forestry Authority (NFA) has embraced multiple uses in its management plan (NFA, 2011). The current plan generally favors sustainable utilization of non-timber forest products and conservation through strengthened partnerships with local communities for improved livelihoods (Babweteera et al., 2018).

In order to ease management, BFR is divided into eight forest blocks (NFA, 2011) which have been further divided into compartments that fall under three main management regimes: production, buffer/recreation, and strict nature reserve areas (Howard, 1991). In the production zone, controlled extractive forest resource harvesting is permitted by NFA which issues licenses to individuals, companies, or groups of people for selective timber extraction in accordance with the forest management plan. In the recreation/buffer zone, low-impact extractive uses such as non-wood forest products are permitted while the strict nature reserve is set aside for non-extractive uses.

In BFR, CFM was piloted in compartments bordering villages on the Southern, Eastern, and Southwestern parts of the reserve in the early 2000s. About 10% of the forest reserve area was allocated for CFM (Supplementary Figure S1). Non-Governmental Organizations played key roles in community sensitization and the formation of Local CBOs during that time (Babweteera et al., 2018). Six CBOs (locally referred to as CFM groups) were formed to co-manage parts of the reserve with NFA. These were: Kapeka Integrated Community Development Association (KICODA), North Budongo Forest Community Association (NOBUFOCA), Karujubu Forest Adjacent Community Association (KAFACA), Budongo Good Neighbor Community Association (BUNCA), Nyantonzi-Kamusenene Environment Conservation and Development Association (NECODA) and Siiba Conservation Environment and Development Association (SEDA). However, at the time of data collection in 2016, only NOBUFOCA and KICODA were still actively engaged in CFM activities. Thus, the rest of the other compartments where CFM activities were piloted but were not being implemented were considered to be inactive CFM compartments.

Data collection

We used two datasets: one from an Exploratory Inventory (EI) that was collected by the National Forestry Authority (NFA) in 2003 and the other collected between October 2015 and April 2016. This enabled us to compare changes in key attributes of the forest at both spatial and temporal scales. Before the actual fieldwork, we conducted a reconnaissance during which we held key informant interviews with leaders of the CFM groups and NFA officials in the area. During the interviews, we sought to understand the challenges, opportunities, and emerging local realities in collaborative forest management. From these interviews, a list of preferred (herein referred to as 'target') timber, pole (mainly 5–15 cm DBH) and charcoal tree species in the reserve were also generated. The target timber tree species were *Khaya anthotheca* (Welw.), *Entandrophragma* spp., *Guarea cedrata* (A. Chev.) Pellegrin, *Cordia millenii* Baker, *Maesopsis eminii* Engl., *Milicia excelsa* (Welw.) C.C.Berg, while *Cynometra alexandri* C.H.Wright was the main target charcoal tree species obtained from the reserve. *Lasiodiscus mildbraedii* Engl., *Celtis* spp., *Combretum* spp. and *C. alexandri* were preferred for poles.

Study design

Three adjacent study compartments were selected namely: W24 (active CFM group – KIKODA), W23 (inactive CFM group – BUNCA) and W42 (no CFM group). In order to control for the effect of natural forest disturbance, past management history, tree species biology, and biophysical factors, all the selected compartments were located in the production zone, shared similar management histories and were accessible to the surrounding local communities.

For the 2016 dataset, we established parallel forest edge-interior transects varying in length from 2.7 km to 3.1 km to assess how extraction levels and vegetation structure changed from the forest edge to the interior. Within each compartment, three transects were established equidistantly (400 m apart), running from South to North. We sampled between 13 and 16 geo-referenced plots along each transect, depending on the compartment boundary. The first plot on each transect was established 100 m inside the forest boundary to minimize edge effects and subsequent plots were established at 200 m intervals.

For the 2003 Exploratory Inventory (EI) dataset, 1 km x 1 km georeferenced inventory blocks were laid out. Two Transects running in East-West orientation were then established at any two of the following random points: 200, 400, 600, 800, and 1 000 m where the starting point (zero-meter point) is the southwestern corner of the block (Supplementary Figure S2). Ten circular plots of 12.6 m radius were then laid along each selected transect at 100 m intervals with the first plot 50 m from the western end of the transect. This sampling strategy yielded a 1% sampling intensity.

Illegal human activity

Since most of the extractive human activities in the forest are illegal, it is difficult to find people overtly engaging in them. Therefore, following Mackenzie and Hartter (2013), Mugume et al. (2015), Olupot and Chapman (2003), Sassen and Sheil (2013), and Turyahabwe and Geldenhuys (2008), we conducted a survey of illegal human activity based on indirect signs. Since NFA had not issued charcoal and timber harvesting licenses in the selected compartments in the 5 years preceding data collection (2016), we considered any observed recent signs as illegal. We also recorded human trails that were encountered in the study plots and used their densities to predict count of the extractive illegal activities.

Tree enumeration and measurement

For the 2003 dataset, in each circular plot, trees with diameter at breast height (DBH) ≥ 20 cm were identified to species level and their diameters recorded. Each circular plot was divided into quadrants that served as subplots to enumerate trees with DBH between 10 cm and 19.9 cm. For consistency, these smaller diameter trees were enumerated in only the North East quadrant.

For the 2016 dataset, nested plots of 50 m x 20 m were established every 200 m along each 3.1 km forest edge-interior transect. All trees with DBH ≥ 10 cm were identified to species level by a forest botanist. This information was cross-referenced with available references (Hamilton, 1984; Katende et al., 1995). DBH was measured following standard forest mensuration guidelines by Malimbwi (1997). Within each plot, two 10 m x 10 m subplots were established (Supplementary Figure S3) to record the species and DBH of small-diameter trees (5 cm to 9.9 cm DBH).

Data analysis

Determinants of signs of extractive human activity

We fitted generalized linear models with Poisson response and log link in R version 3.5.3 for Windows (R Core Team, 2019). The count of signs of pitsawing and charcoal processing sites per hectare were used as the response variables. The compartment, distance from the forest edge (in meters) and the number of human trails per hectare were used as predictor variables. Since the Poisson regression model restricts the conditional variance to equal the conditional mean, a property known as equi-dispersion, we checked for over-dispersion using the *dispersiontest* function in *AER* package (Kleiber & Zeileis, 2008) prior to fitting the models.

We compared differences in the count of human activities among the compartments in the 0–1 Km, 1–2 Km and 2–3 Km segments of the forest edge-interior transects in the different compartments using Kruskal-Wallis test (Kruskal & Wallis, 1952) and a post-hoc Dunn's test for multiple comparisons with Bonferroni correction (Dunn, 1964) using the *dunn.test* function in *dunn.test* package (Dinno, 2017).

Differences in forest structure and composition

We computed standardized measures of forest structural characteristics that are influenced by extractive human activities: recruitment (pole density), tree density and Basal Area (BA). These were then compared among the selected compartments using one-way ANOVA with Tukey's multiple comparisons of means to test for mean difference. Where assumption of normality was violated, we used Kruskal–Wallis and a post-hoc Dunn's test for multiple comparisons. Further, we computed Importance Value Index (IVI) (Curtis & McIntosh, 1951) for all the tree species recorded in the two datasets. We computed the IVI as the average value of a species' Relative Dominance (i.e. the relative size of individuals), Relative Density (i.e., species abundance), and Relative Frequency (how often a species is encountered throughout the forest) (see Mawa et al., 2020). We used non-metric multidimensional scaling (NMDS using Bray–Curtis similarity index based on abundance data) to assess differences in the tree composition among the three compartments in 2003 and 2016. We used the "vegan" package (Oksanen et al., 2019) for the NMDS ordination.

Inventory data for preferred timber and charcoal tree species were tallied into progressively increasing diameter size class widths to balance the samples across size classes because the number of individuals declined with increasing DBH (Lykke, 1998). Size class distributions (SCDs) were drawn by plotting the number of individuals per hectare for each stem diameter class against the respective size class.

We performed a least-squares linear regression with the size class mid-point (d_i) as the predictor variable and the mean number of individuals in that size class ($\ln(N_i+1)$) as the response variable. N_i was derived by dividing the number of individuals by the width of that size class. We used N_i+1 instead of N_i because some size classes had no individuals (Obiri et al., 2002). The SCD slopes were computed as indicators of the population structure (Condit et al., 1998; Lykke, 1998; Mwavu & Witkowski, 2009; Obiri et al., 2002). SCD slopes were also computed for the target timber and charcoal tree species for the 2016 dataset since the 2003 dataset did not have records of target timber tree species.

Results

Tree species composition

We recorded 126 tree species with an average density of 386 stems per hectare in 2016. In the 2003 dataset, 129 tree species with an average of 350 trees per hectare were recorded in the sample compartments. In the non-CFM compartment, *L. mildbraedii* and *C. alexandri*, were among the five most important tree species recorded in 2003 and 2016. In the CFM and inactive CFM compartments, *Celtis* spp. and *C. alexandri* were among the five species with the highest IVI in both datasets (Figure 1).

The NMDS ordination plots (Figure 2) show that the community composition of trees in the three compartments were similar in 2003 since there was considerable overlap. However, the mean NMDS scores in the non-CFM compartment in 2016 had shifted to the right along the first axis, thus its composition was becoming different from the rest of the compartments.

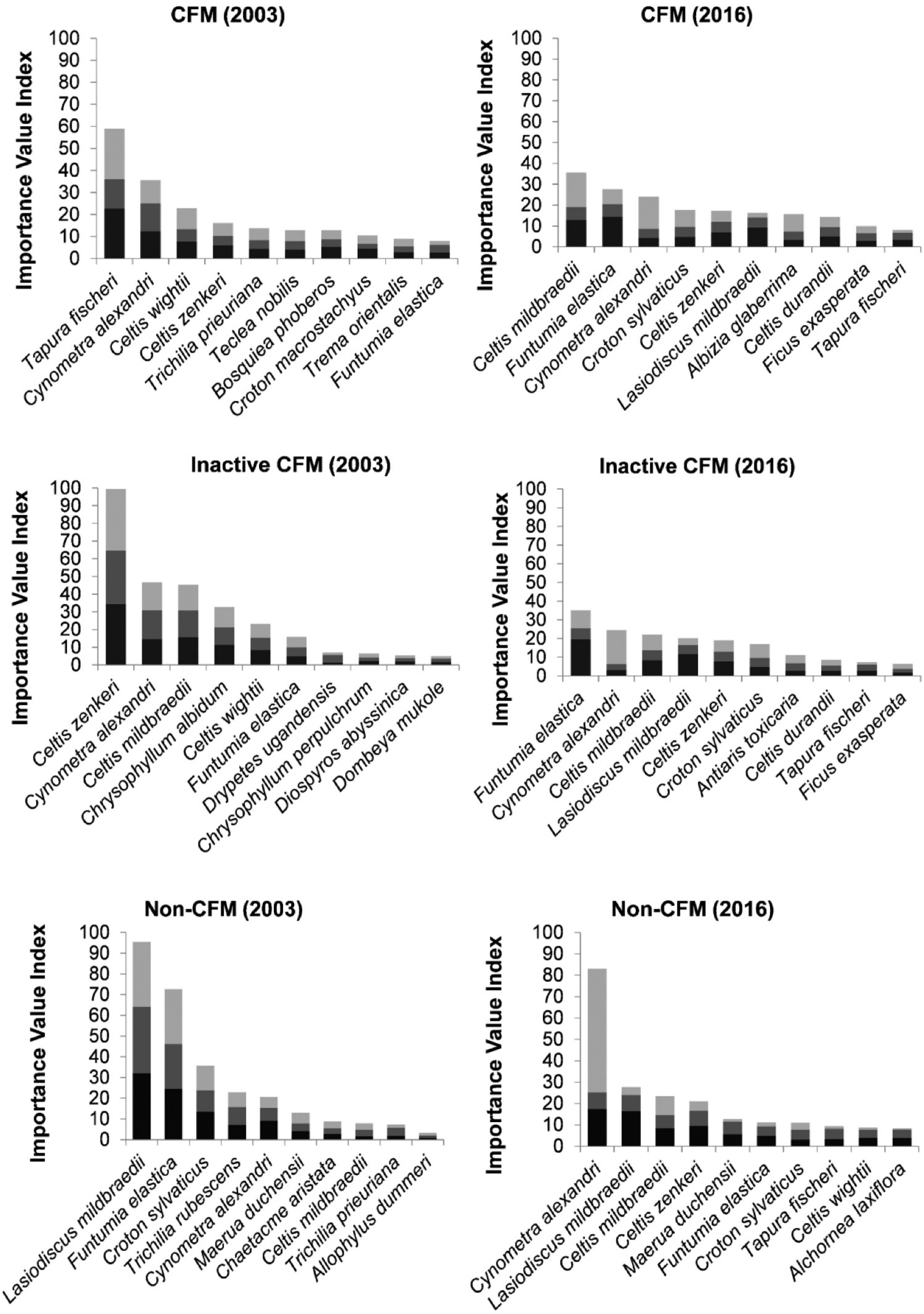

Figure 1. Importance Value Index (IVI) for the ten most important tree species in the CFM, inactive CFM and non-CFM compartments in 2003 and 2016.

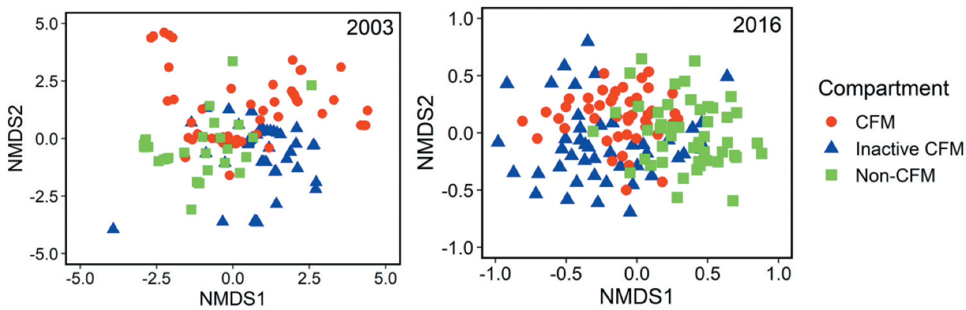

Figure 2. Non-metric multidimensional scaling ordination plot showing community composition of trees ≥10 cm DBH in 2003 and 2016 in compartments under different management regimes in Budongo forest.

Illegal human activities

The main illegal human activities recorded were charcoal processing and timber extraction. We did not record any signs of grazing but recorded five cases of vegetable gardening in recent charcoal processing points. The highest average count of recent pit sawing and charcoal processing sites were recorded in the inactive CFM compartment and the lowest recorded in the CFM compartment (Figure 3). The count of charcoal processing sites in the inactive and non-CFM compartments were significantly higher than those in the CFM compartment (Kruskal–Wallis test: $\chi^2(2) = 6.967$, $p = .031$). However, the average count of pit sawing sites did not significantly differ among the compartments (Kruskal–Wallis test: $\chi^2(2) = 0.511$, $p = .775$) as shown in Figure 3.

Timber extraction along forest edge-interior distance

The forest edge-interior distance and number of trails per hectare significantly predicted the count of signs of timber extraction in Budongo Forest Reserve (Table 1). Every one-

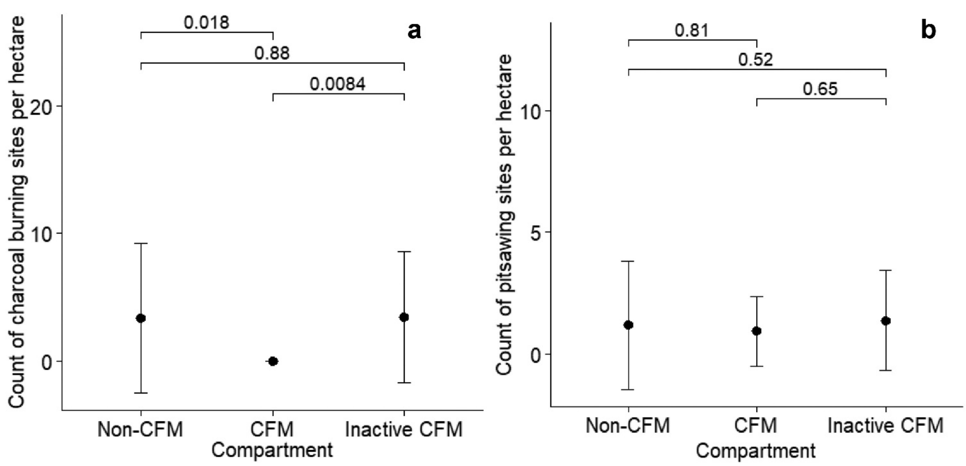

Figure 3. Comparison of charcoal processing (A) and pit sawing (B) sites per hectare among Collaborative Forest Management (CFM), inactive CFM and non-CFM compartments in BFR in 2016. *P*-values for multiple comparisons are shown.

Table 1. Summary of Poisson regression model predictors of count of signs of timber extraction in BFR.

Predictor	Estimate (β)	Robust SE	Exp (β)	Z	p-value
Intercept	−3.3610***	1.0279	0.0347	−3.270	0.0011
Distance (m)	0.0009***	0.0003	1.0009	3.081	0.0021
Trail	0.4887***	0.1344	1.6302	3.637	0.0003
Non-CFM	−0.4914^{ns}	0.6475	0.6118	−0.759	0.4480
Inactive CFM	0.1802^{ns}	0.4681	1.1975	0.385	0.7002

*** = significant at $p < 0.01$ and ^{ns} = Not significant
SE = Standard Error
Wald χ^2 (4) = 18.59 ($p < 0.001$)
Log pseudolikelihood = −33.7298
Pseudo R^2 = 0.1156
AIC = 77.46

kilometer increase in forest edge-interior distance increased the count of signs of timber extraction by 1%. Additionally, on average, every active human trail encountered increased the count of signs of illegal timber extraction by 63%. The management regime did not have a statistically significant effect on the count of signs of timber extraction.

Charcoal processing along forest edge-interior distance

In our model, the forest edge-interior distance and the management regime significantly predicted the count of charcoal processing points (Table 2). The number of charcoal processing points decreased with increasing forest edge-interior distance ($p < .001$). Both the non-CFM and inactive CFM compartments had significantly higher count of charcoal processing points compared to the CFM compartment ($p < .001$).

Forest structure

General tree size-class distribution profile

We did not record a significant difference in tree stem density between 2003 and 2016 in all compartments (Figure 4–5) (Wilcoxon rank-sum test: Z = 0.329, 0.132, 0.592, and $p = .742$, 0.895, 0.554 for CFM, inactive CFM and non-CFM compartments, respectively). There were also no significant differences in stem densities among the compartments in 2003 (Kruskal-Wallis test: $\chi^2(2) = 0.060$, $p = .970$) and 2016 (Kruskal–Wallis test: $\chi^2(2) = 0.033$, $p = .984$). The general outlook of the three compartments, from the SCD (Figure 4) follows

Table 2. Summary of Poisson regression model Predictors of count of signs of charcoal processing in BFR.

Predictor	Estimate (β)	Robust SE	Exp (β)	z	p-value
Intercept	−16.1551***	0.5747	9.6×10^{-8}	−28.110	0.0000
Distance (m)	−0.0015***	0.0005	0.9985	−3.368	0.0008
Trail	0.1478*	0.0852	1.1593	1.735	0.0828
Non-CFM	16.9914***	0.5379	2.39×10^{7}	31.589	0.0000
Inactive CFM	17.3990***	0.5117	3.60×10^{7}	34.002	0.0000

*** = significant at $p < 0.01$, ** = significant at $p < 0.05$, * = significant at $p < 0.1$, and ^{ns} = Not significant
SE = Standard Error
Wald χ^2 (4) = 1680.52 ($p < 0.001$)
Log pseudolikelihood = −26.857
Pseudo R^2 = 0.5853
AIC = 63.714

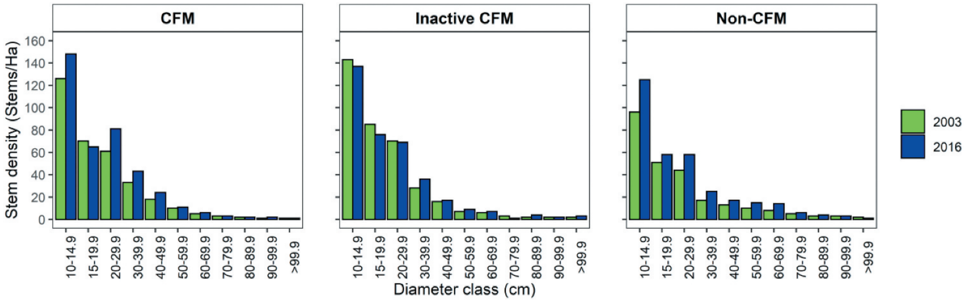

Figure 4. General stem diameter distribution profile for trees (≥10 cm DBH) recorded from Collaborative Forest Management (CFM), inactive CFM and non-CFM compartments in Budongo forest in 2003 and 2016.

the inverse J-shaped curve, where there are relatively higher numbers of small-diameter trees.

Density and size-class distribution of target tree species for timber and charcoal production

The target timber tree species in the sample compartments were generally small-sized with few stems above 50 cm DBH. Out of the 5407 stems that we recorded in the three compartments, the target tree species accounted for only 0.02%. There were significant differences in their stem densities among the compartments (Kruskal–Wallis test: χ^2 (2) = 8.966, $p = .011$) with the CFM compartment having an average of one stem of a target timber tree species in 5 ha, the inactive CFM compartment having twice that number and the non-CFM compartment having one individual in 22 ha.

The target diameter size for timber extraction in the reserve were stems above 30 cm DBH. The inactive CFM compartment had the highest average density of the merchantable stems of target timber tree species compared to the CFM and the non-CFM compartments with 0.032, 0.028, and 0.011 stems/Ha, respectively.

Although all the SCD slopes of the target timber tree species were negative (Table 3), implying more individuals in smaller size classes compared to those in the bigger size classes, only *G. cedrata* (in the CFM and inactive CFM compartments) and *K. anthotheca* (in the inactive CFM compartment) had statistically significant negative SCD slopes ($p < .05$). None of the target timber tree species recorded in the non-CFM compartment had a statistically significant negative SCD slope ($p < .05$).

Only *C. alexandri* was the locally preferred tree species felled for charcoal. The SCD slopes for *C. alexandri* were significantly negative ($p < .05$) in the CFM and non-CFM Compartments (Table 3). The non-CFM compartment had the highest stem density of *C. alexandri* compared to the CFM (Dunn's test: Z = 2.710, $p = .010$) and the inactive CFM compartments (Dunn's test: Z = 3.613, $p < .001$). *C. alexandri* alone accounted for 16.4% of all the stems of the 77 tree species recorded in the non-CFM compartment compared to its 4.0% and 2.9% contribution in the CFM and inactive CFM compartments, respectively. In all the compartments, the 5–9.9 cm DBH class had the highest stem density (Figure 6). In the CFM compartment, the stem density of trees (≥ 15cm DBH) generally increased up to the 50–59.9 DBH class, eventually declining up to the largest size class. In the inactive CFM

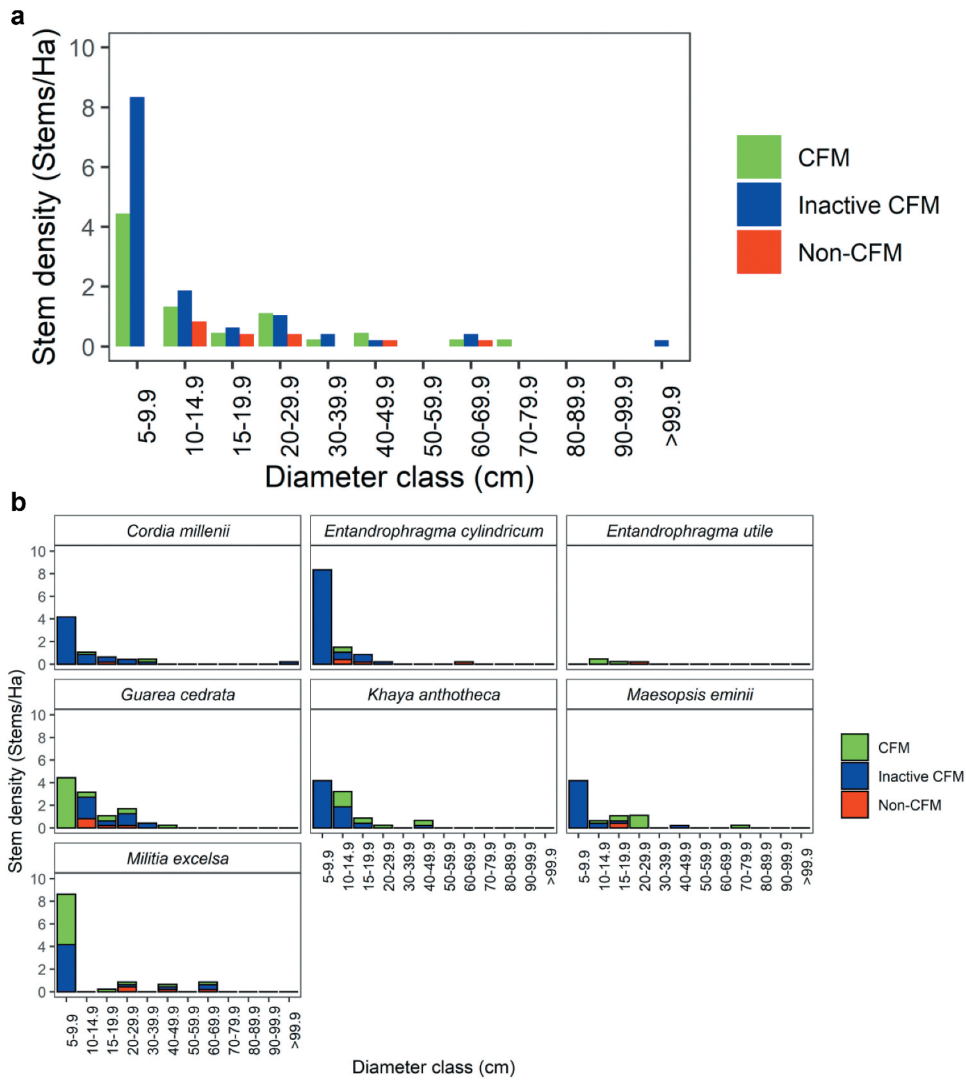

Figure 5. (a) General stem diameter distribution profile for target timber tree species (≥5 cm DBH) recorded from Collaborative Forest Management (CFM), inactive CFM and non-CFM compartments in Budongo forest in 2016. (b) Individual stem diameter distribution profile for target timber species (≥5 cm DBH) recorded from Collaborative Forest Management (CFM), inactive CFM and non-CFM compartments in Budongo forest in 2016.

compartment, we registered relatively higher density of trees above 80 cm. In the non-CFM compartment, stem density steadily increased from 5 stems/hectare in the15-19.9 cm diameter-size class up to 10 stems per hectare in the 60–60.9 cm diameter-size class, followed by a steady drop until the largest size class.

Pole density along forest edge-interior distance

The lowest pole densities were recorded in plots within the 0–1 km segment of the forest edge-interior transects in all the compartments. The pole densities increased with the forest

Table 3. Size class distribution least-squares regression slopes for target tree species recorded in CFM, inactive CFM and non-CFM compartments in Budongo forest in 2016.

Species	CFM				Inactive CFM				Non-CFM			
	Slope	t	*Adj.* r^2(%)	p-value	Slope	t	*Adj.* r^2(%)	p-value	Slope	t	*Adj.* r^2(%)	p-value
Cordia millenii	−0.0014^{ns}	−1.41	8.19	0.190	−0.0016**	−2.41	30.33	0.037	−0.0001	−1.05	0.84	0.320
Entandrophragma cylindricum	−0.0002 ^{ns}	−1.21	4.09	0.253	−0.0021*	−2.20	25.91	0.052	−0.0003 ^{ns}	−1.41	8.27	0.188
Entandrophragma utile	−0.0003 ^{ns}	−1.75	15.71	0.111	-	-	-	-	−0.0001 ^{ns}	−0.81	3.24	0.437
Guarea cedrata	−0.0016**	−2.28	27.73	0.045	−0.0012**	−2.32	28.41	0.043	−0.0005*	−1.91	19.41	0.085
Khaya anthotheca	−0.0007*	−1.92	19.64	0.084	−0.0019**	−2.58	33.90	0.028	-	-	-	-
Maesopsis eminii	−0.0004*	−1.90	19.17	0.087	−0.0014*	−1.96	20.63	0.078	−0.0002 ^{ns}	−1.05	0.84	0.320
Milicia excelsa	−0.0012 ^{ns}	−1.64	13.28	0.132	−0.0001 ^{ns}	−1.56	10.61	0.148	−0.0001 ^{ns}	−0.39	9.29	0.708
Cynometra alexandri	−0.0023**	−2.46	31.43	0.034	−0.0010 ^{ns}	−1.48	9.77	0.170	−0.0022**	−2.65	35.41	0.024
All target timber species	−0.0007***	−3.94	14.90	<0.001	−0.0012***	−5.23	23.89	<0.001	−0.0002***	−2.81	7.73	0.006
All tree species	−0.0484***	−10.31	90.54	<0.001	−0.0451***	−6.45	78.69	<0.001	−0.0420***	−10.37	90.65	<0.001

*** = significant at $p < 0.01$, ** = significant at $p < 0.05$, * = significant at $p < 0.1$, and ^{ns} = Not significant

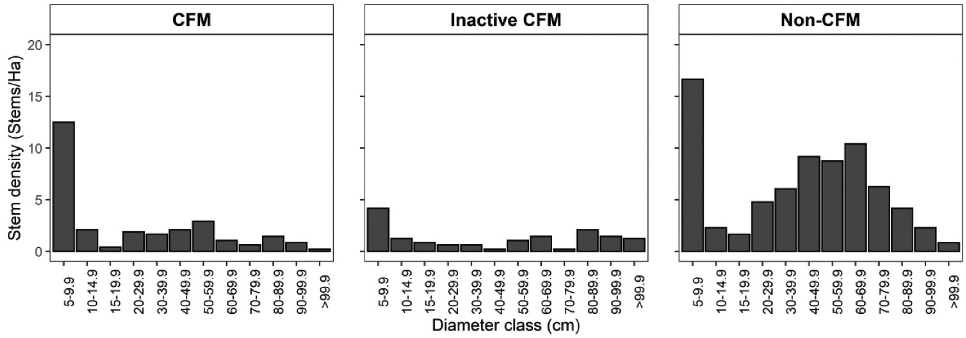

Figure 6. Stem diameter distribution profile for *Cynometra alexandri* (targeted for charcoal) in Budongo forest in 2016.

edge-interior distance and peaked at 1.5 Km in all the compartments, gradually decreasing and stabilizing at about 2 Km. There were no statistically significant differences in pole densities across compartments (Kruskal–Wallis test: χ^2 (2) = 5.361, p = .069).

Changes in basal area

There were significant differences in basal area among the compartments in 2003 (Kruskal–Wallis test: $\chi^2(2) = 22.017$, $p < .001$) with the highest average recorded in the non-CFM compartment. However, there were no significant differences in basal area in 2016 (Kruskal–Wallis test: $\chi^2(2) = 2.106$, $p = .349$). A comparison of temporal changes in basal area within the compartments showed a significant increase in the CFM compartment (Wilcoxon rank-sum test: Z = 2.667, $p = .008$). Although the rest of the compartments also registered increases in basal area, these changes were not statistically significant ($p > .05$).

Discussion

Tree composition

Our findings show a similar community composition of trees in all the compartments in 2003. However, in 2016, the composition in the non-CFM compartment showed little overlap with the rest of the compartments in the NMDS ordination plot (Figure 2). While natural disturbance regimes such as windfall and tree mortality could lead to changes in the composition and structure of trees, we attribute the observed changes to anthropological disturbance through illegal selective extraction of target tree species since there have been no records of notable recent natural disturbance episodes in BFR.

Levels of recent human activity in Budongo forest

Two main recent illegal extractive human activities that have potential to influence forest structure were recorded in Budongo forest: charcoal and timber extraction. Charcoal extraction was concentrated in areas within a one-kilometer forest-edge interior distance in the non-CFM and inactive CFM compartments while no recent sign of the activity was recorded in the CFM compartment. On the other hand, recent timber extraction occurred independent of the compartment and we recorded more signs further away from the forest edge and in plots with active human trails. Thus, illegal timber extraction in the sample compartments in BFR is being driven by resource availability and access (trails), irrespective of the management regime. Similar previous studies such as Sassen and Sheil (2013) in Mt. Elgon National Park, Eastern Uganda also reported evidence of human activity in areas beyond 1 km from the forest edge. We argue that local demand, resource availability and the nature of actors involved in the illegal extraction could provide plausible explanations for the widespread distribution of illegal timber harvesting and the clumped pattern for charcoal extraction in the forest.

Vigilance, leakage and nature of actors involved in illegal human activities

The CFM compartment benefits from heightened patrol activity and vigilance of CFM members. The members patrol the compartment three times a week and keep policing each other, thus any illegal activities are easily detected and reported. Previous studies (such as Chhatre & Agrawal, 2008; Nagendra, 2012) have underscored the critical role played by local rule enforcement and monitoring in ensuring success of collaborative forest management. However, since it is difficult to verify the actual perpetrators of charcoal processing in the areas where we encountered the signs, it is possible that the stricter rule enforcement by CFM members has helped to curb charcoal extraction in the CFM compartment and displaced the activity to the neighboring compartments. Such perverse incentives in form of leakage have been reported in similar studies in other countries (Ameha et al., 2016; Chakraborty, 2001; Wilson & Cagalanan, 2016). These have been linked to the narrow focus of most conservation projects that fail to utilize a landscape approach, effectively creating isolated spaces of successful conservation in a degraded neighborhood.

While charcoal is widely used as a cooking energy source in most urban and peri-urban areas of Uganda (Banana et al., 2014; MWE, 2016; Namaalwa et al., 2007; Sassen et al., 2015), its extraction in Budongo forest is generally perpetuated by resource-limited households seeking to obtain an extra income for basic survival. The CFM members reported this to have been a relatively easier group on which to enforce rules, compared to the powerful elites involved in timber trade. Our key informants attributed the difficulties they faced in controlling illegal timber extraction in the CFM compartment to the nature of the actors involved in the business. They described timber business in the area as a complex activity involving a network of powerful and well-connected actors whose credentials and *modus operandi* are often too sophisticated for the CFM groups to deal with. The difficulty of controlling illegal extraction where the perpetrators are highly connected to powerful individuals has been reported in a recent study in Northern Uganda (Branch & Martiniello, 2018). During the key informant interviews, the CFM committee members reported incidences of harassment, assaults, and threats in the line of duty by individuals whom they suspected to be colluding with local politicians and state agencies mandated to protect the resource. In his study on decentralization in forests in Masindi district, Muhereza (2005) reported the failure of the established institutions to control illegal timber harvesting in Masindi district – a situation that persists to the present day.

Additionally, the CFM agreement requires all impounded resources to be reported to NFA but to the dismay of the CFM committee, the ultimate direct reward for their vigilance is often a simple word of “thank you” and occasional “praises” in the media, which hardly translate into meaningful benefits for their households. Moreover, there is a dire information gap on what happens to the impounded resources once they leave the CFM group. As clearly reported by a CFM committee member:

> "We try to stick to our part of the bargain and protect the forest resources but our partner [NFA] does not seem to care enough to reward us for our patrol effort and vigilance. They do not tell us what happens to the impounded timber, which we suspect does not reach Kampala [the NFA headquarters]".

In such a supposedly "collaborative" environment marred by suspected trickery and ulterior motives on the part of the state agency, as perceived by the local conservation groups, the powerful actors behind illegal timber extraction become the ultimate winners since they stand to easily "buy" their way out once caught. In their study in Kibale National park in western Uganda, Mackenzie and Hartter (2013) attributed the success of local rule enforcement to the profitability that these efforts brought for the local community conservation groups. The perceived incentive to enforce conservation rules on powerful actors and the needed institutional support is not adequate in our case study.

The apparent scarcity of the target timber tree species amidst a high demand and perceived unfairness and lack of transparency creates an institutional regime that cannot effectively combat the illicit activity. Indeed, previous studies have reported the widespread extraction of timber, even in parts of the reserve where all extractive human activities are officially banned (Babweteera et al., 2018; Gombya-Ssembajwe et al., 2007). Therefore, our findings from this case study reinforce the argument that from an institutional viewpoint, the attributes of the resource in question and the actors involved (Andersson & Ostrom, 2008; Gibson et al., 2005; Ostrom, 2008; Vatn, 2005) play important roles in determining the outcomes of forest tenure reforms.

Our results also underscore the role that accessibility plays in resource extraction. We recorded more human activities in plots that had active human trails. The human trails (including those meant for research) are used to illegally access and extract forest resources. A similar finding was reported by Sassen and Sheil (2013) and in a study by Fashing et al. (2004) in Kenya, where evidence of human activity was associated with the presence of research and management trails.

Influence of human activities on forest structure

Compared to the 2003 dataset, we recorded marginal increases in stem density across all diameter-size classes in the CFM and non-CFM compartments in 2016 while slight decreases were recorded in the inactive CFM compartment for size-classes <30 cm (Figure 4). Since our study did not use a typical repeated sampling method where measurements are made in the same plots, it is possible that some of the differences could be due to local variations within the compartments. However, our record of species-specific human activities in the compartments illustrates the effect that they could have on forest structural attributes. At an aggregate scale, the general outlook of the forest points to an improved forest condition over time based on the slight increases in the Basal Area and stem density. Also, the inverse J-shaped curve of the SCD that we observed for all species combined shows that there is adequate recruitment. However, the highly size- and species-specific nature of the extractive human activities has resulted in non-negative SCD slopes for most target tree species which would require deliberate management interventions to enhance their establishment and recruitment. While previous studies such as Mwavu and Witkowski (2009) reported a healthy regeneration and recruitment patterns of target timber tree species in BFR, our case study reveals the contrary. This could partly be because their sample included seedlings and saplings (<5 cm DBH) yet our focus was on stem sizes that are targeted for extractive use. Even the target tree species that registered negative slopes (*K. anthotheca* and *G. cedrata*) had low stem densities averaging 1–2 stems per hectare.

While advocates of the intermediate disturbance hypothesis argue for moderate and controlled disturbances to maximize species diversity (Sheil & Burslem, 2003), they contend that extreme disturbances could lead to species loss and/or even extinction. Even in cases where the positive ecological importance of rule-breaking is emphasized (Robbins et al., 2006), unless the disturbance by the rule-breakers mimics natural disturbance patterns, they are bound to result in unsustainable utilization and possible losses of preferred species. In our study area, with the current level of human activity and its species-specific nature coupled with the weak institutional regime for rule enforcement, unless regulatory measures are urgently instituted, Budongo forest could witness localized losses of target tree species in the near future.

We recorded a few stems in the target size class for poles (5–14.9 cm DBH) near the forest edge in all the compartments. This could be attributed to the fact that 'controlled' extraction of construction poles for noncommercial use is permitted in all the compartments. However, instituting the control levels and verifying whether extraction is for noncommercial use remains a rather vague concept in the forest management plans. Even the forest management plan that the "controlled" extraction levels are based on uses datasets that do not have records of stems <10 cm DBH. Since some of the human activities such as fuelwood collection, pole cutting, and non-timber forest products target small-sized stems, they could have a differential effect on the sapling or shrub layer (Banana et al., 2007) and present challenges for adaptive management of forestry resources (Folke et al., 2002).

Conclusion and policy implications

The CFM arrangement in BFR has been effective in controlling illegal charcoal processing. We attribute this success to the vigilance of the CFM groups in rule enforcement and monitoring efforts and the fact that the perpetrators of the illegal charcoal processing are fellow local community members on whom local by-laws and sanctions can be effectively applied. However, we did not find significant differences in the count of recent signs of timber extraction among the studied compartments. Although most of the signs were recorded in plots further away from the forest edge, there was no clear spatial pattern in the distribution of the activity, suggesting that the pit-sawyers operate where ever there are a target species of merchantable size regardless of the management regime. We attribute this to inadequate rule enforcement as a result of the CFM group members' perceived lack of transparency on the part of NFA in handling the impounded timber and the connectedness of actors involved in illicit timber trade in the area. It is therefore important that the agency embraces downward accountability and transparency in CFM-related transactions. Additionally, the NFA, together with relevant government authorities should support CFM groups to effectively enforce exclusion rules by apprehending the rule breakers that are reported and subjecting them to face the law.

In terms of forest structure, the individual SCD of the target tree species portrayed an inadequate recruitment pattern. Therefore, there is a need for deliberate management interventions to enhance and promote regeneration and recruitment of these species *in situ*. Measures such as assisted natural regeneration, enrichment planting and strict harvesting controls need to be urgently instituted to abate possible local extinction of the target timber tree species.

Given the notable positive ecological outcomes of CFM amidst the documented challenges, we recommend that the government of Uganda and conservation agencies take a keen interest in learning from the CFM pilot schemes in different forests. This will help to re-adjust their designs to match current local realities as they pursue the envisaged "*win-win*" management outcome.

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