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Determining baselines and trends of Eastern chimpanzees and forest elephants in a Central African protected area after civil strife

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A B S T R A C T

Protected areas are crucial to safeguard Sub-Saharan Africa's extraordinary and abundant megafauna. In many of these areas, instability has derailed conservation efforts and impeded adequate wildlife monitoring. Discovered in 2004, Eastern chimpanzees are found in the Central Uele Basin in northern Democratic Republic of Congo (DRC) within the Bili-Uéré Protected Areas Complex (BUPAC), the largest contiguous protected area in the country. BUPAC is threatened by habitat destruction, mining, wild meat trade, and insecurity. BUPAC chimpanzees are part of the largest remaining continuous population of the species in Africa; they are also being behaviourally unique. Forest elephants were frequent in the 1960′s in the BUPAC but have declined significantly up to 2004–2007. We used line transects to estimate Eastern chimpanzee and forest elephant density in the BUPAC core area in 2016 and 2019 and compared these with the 2004–2007 surveys. A total of 37 and 137 two km long line transects were systematically placed in 5,841 km^2 and 6,176 km^2 survey areas in 2016 and 2019, respectively. We found that chimpanzee density did not change during the two survey periods but indicators for forest elephant density decreased eight-fold. Human activities were detected mainly along the core area periphery in both survey years, where they overlapped with centres of animal activity. The stable high density of chimpanzees is a positive outcome for the core BUPAC. However, despite being a conservation priority area that has received relatively intensified protection, declining forest elephant numbers are likely to reflect the high number of human conflict hotspots in vicinity as well as the increasing human population density around the core area. We propose by elevating the core area to National Park whilst strengthening on the ground enforcement and management structures as well as legal measures against poaching might ensure the long-term survival of such an important area in Africa.

1. Introduction

In Sub-Saharan Africa, protected areas (PAs) are critical for conservation of the unique biodiversity found in many parts of the continent (Brooks et al., 2001). PAs are crucial for the survival of Africa's extraordinary megafauna, particularly large primates and elephants (Ripple et al., 2016). In Central Africa, the recommended 17% for PA coverage recommended by Aichi Target 11 of (CBD Secretariat, 2010) has only been exceeded in the Central African Republic, CAR (17.98%) and the Republic of the Congo, ROC (36.67%). The Democratic Republic of Congo, DRC despite being the largest and Africa's most biodiverse country has only 13.85% of its total area protected (European Commission, 2021). DRC is amongst the countries with the lowest financial contribution to megafauna conservation (Lindsey et al., 2017). Such lack of funding of PAs undermines their effectiveness (Lindsey et al., 2018; Mansourian & Dudley, 2008; Watson, Dudley, Segan, & Hockings, 2014), though outright corruption even in situations where funding is sufficient, can be even more detrimental (e.g., Ayivor, Gordon, Tobin, & Ntiamoa-Baidu, 2020; Leverington, Costa, Pavese, Lisle, & Hockings, 2010; Tacconi & Williams, 2020). The result is that PA encroachment is common (Beyers et al., 2011; Gaynor et al., 2016; Nellemann, Redmond, & Refisch, 2010).

Since 1946, armed conflicts has affected as many as 71% of PAs in Sub-Saharan Africa (Daskin & Pringle, 2018). In these situations, the

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breakdown of law enforcement in PAs emboldens poachers to hunt large volumes of wild meat and take out wildlife products for example ivory (Thouless et al., 2016). Such increased killing of animals tend to finance the conflicts themselves and feed combatants. The result of protracted armed violence has invariably led to severe animal population declines in a large number of Sub-Saharan PAs (Beyers et al., 2011; Craigie et al., 2010; Daskin & Pringle, 2018). As an example, wild meat sales in urban markets of protected species from the Garamba National Park in the DRC, rose by 23% during times of conflict (De Merode & Cowlishaw, 2006). During the same war period in the DRC, in the Okapi Faunal Reserve forest elephant densities fell by half (Beyers et al., 2011) and half of the gorilla population were killed in the Kahuzi-Biega National Park (Yamagiwa, 2003). Bonobo densities in the Luo Scientific Reserve declined by over half (Hashimoto et al., 2008).

The Central Uele Basin in northern DRC is an important distribution area for the Eastern chimpanzee (*Pan troglodytes schweinfurthii*). This species was unknown until surveys between 2002 and 2004 revealed that Eastern chimpanzee populations in the Central Uele were the largest remaining continuous ones found anywhere in Africa (Hicks, 2010; Young, 2004). These chimpanzees are behaviourally unique, identified as the "Bili-Uéré Chimpanzee Behavioural Realm" (Hicks et al., 2019). This area still remains threatened by habitat destruction, mining, wild meat extraction and trade and armed conflict.

Within the Uele, the Bili-Uéré Protected Areas Complex (BUPAC, Fig. 1) is the core of Eastern chimpanzee occurrence within the Central Uele region. Surveys of Eastern chimpanzees in the BUPAC were not possible until 2002–2003 (Young, 2004) and were followed by Hicks (2010) more extensive fieldwork from 2004 – 2007. However, any further attempts to study the biodiversity of the BUPAC were hampered by armed conflict and also by the remoteness of the area. In 2017, a Congolese expedition could not reach the area because of inclement weather causing unfavourable road conditions (Kaswera, 2017).

Elephant surveys in the 1970′s within the BUPAC indicated that this area was important for the species, where an estimated number of around 100,000 individuals were estimated (Ruggiero, 2017). Although no follow-up ground surveys were undertaken an aerial survey was carried out in 1976. In this survey around 6,000 savanna elephants were reported in the BUPAC savanna habitats, but forest elephants were not surveyed (Savidge, Woodford, & Croze, 1976). Another aerial wildlife survey conducted in 2013 showed that savannah elephant numbers had experienced a dramatic collapse, due likely to poaching (Elkan, Mwinyihali, Mendiguetti, Hamley, Mpaka, Nathanael, Nyembo, Faustin, & Selemani, 2013). BUPAĆs wildlife has experienced severe pressures from an increased demand for wild meat and ivory due to increasing human population in the vicinity of the park and from violent conflicts. population densities of large mammals declined over the last twenty years like in other Congolese PAs such as Garamba (Ondoua, Moundjim, Claude, Jiagho, Usongo, & Williamson, 2017).

In this paper, we estimated densities of Eastern chimpanzees and forest elephants using direct and indirect observations along line transects in 2016 and 2019 and compare these results with surveys from 2004 to 2007 in Hicks (2010). Our findings highlight the contrasting trajectories of the two high-profile species in our study area and suggest possible reasons for these differences. Given the conservation importance of the BUPAC we propose further conservation actions that could be undertaken to ensure the long-term persistence of this area's unique biodiversity.

2. Materials and methods

2.1. Study area

The study area (Fig. 1) is made up of three PAs in northern DRC: 1) Domaine de Chasse du Bili-Uélé (also Bili-Uere); 2) Réserve de Faune du Bomu (BRF) and 3) Domaine de Chasse du Bomu (BDC). Jointly, these three areas are referred to as the Bili-Uélé Protected Areas Complex (BUPAC). Along the North, it is flanked by the 680 km national frontier with the CAR and in the East, it borders South Sudan. In the North, the M'bomu River (also Mbomou or Bomu) constitutes the national and BUPAĆs limits whilst the Bili River delineates its southern border. Altogether, the BUPAC (approx. 43,400 km^2) is the largest contiguous protected area block in DRC.

The Bili-Uélé is a 32,748 km^2 hunting reserve founded in 1974. It was designated as IUCN protection category VI which grants the area the lowest protection level, allowing sustainable use of natural resources and human habitation (Fig. 1; World Commission of Protected Areas, WCPA, ID: 20324; UNEP-WCMC and IUCN, 2021). Directly adjacent to the Bili-Uélé, and up to the border with the CAR, is the BRF (6,531 km^2, WCPA ID: 555512073, IUCN Category Ib) and the BDC (4,125 km^2, WCPA ID: 555512064, IUCN Category II[1]). These areas were also created in 1974, for conservation, sightseeing and hunting tourism but also to control poachers along this border area. In the BRF, hunting and fishing are prohibited but these activities are allowed in the BDC via special permits. Hunting is forbidden for a long list of species including chimpanzees, savanna (*Loxodonta africana*) and forest (*Loxodonta cyclotis*) elephants (Loi 82.002, 1982).

2.2. Protection history

The vast BUPAC area has been difficult to protect efficiently due to insecurity and poor transportation infrastructure. Artisanal mining, poaching, the influx of pastoralists from the north, the continuous presence of local rebel groups and militia, and the large influx of refugees from the civil strife in CAR have posed significant threats (Akana, 2015; Hicks et al., 2010; Ondoua et al., 2017). As in most of the DRC, protection and research in the BUPAC, was obstructed by the First (1996–1997) and Second (1998–2003) Congo Wars, as well as by other more sporadic, localised armed conflicts. These clashes were amongst the deadliest since World War II claiming over 100,000 combatant fatalities and up to 5 million civilian deaths through malnourishment and preventable diseases (Butsic, Baumann, Shortland, Walker, & Kuemmerle, 2015; Coghlan et al., 2006). Since the official end of the war, the risk of death from violence declined by almost 30% by 2007, but mortality rates remains high, more than 55% above the reported baseline for sub-Saharan Africa (Coghlan et al., 2009). Even after the war, wildlife populations inside and outside PAs have been affected by weakened institutions, human movements, illegal extraction of minerals, wood, wildlife products and wild meat, as well as by the easy access to weapons (Beyers et al., 2011).

Fig. 2 highlights the distribution of battles, explosions and remote violence, riots and violence against civilians within the BUPAC for the period 2004–2019 (after Hicks, 2010 first survey, acleddata.com, Raleigh, Linke, Hegre, & Karlsen, 2010). Seven of these conflicts occurred in or along the BMCA boundary. Outside BUPAC, conflicts occurred both to the South and the North, but most conflicts occurred along the Northern national border. Civil strife and the ensuing lack of law enforcement was caused by the incursion of the Lord's Resistance Army (LRA) into Northern DRC from Uganda in 2005 (Agger & Hutson, 2014). Since, the BUPAC has experienced high levels of insecurity and violent conflict. The LRA incursions have drawn to the area military forces from DRC, Uganda and CAR, and recently the Regional Taskforce (RTF) of the Regional Cooperation Initiative against the LRA (RCI-LRA).

To address these issues, a community conservation project was started in 2002 by a Dutch NGO, the Wasmoeth Wildlife Foundation. Despite this, elephants continued to be poached and a large number of illegal miners invaded the area, leading to the withdrawal of the project

[1] The categorization of the Domaine de Chasse du Bomu as IUCN Category II, i.e., a National Park, appears a mistake. According to the legal designation (Decree n° 00023), it should be IUCN Category Ib like the Réserve de Faune du Bomu.

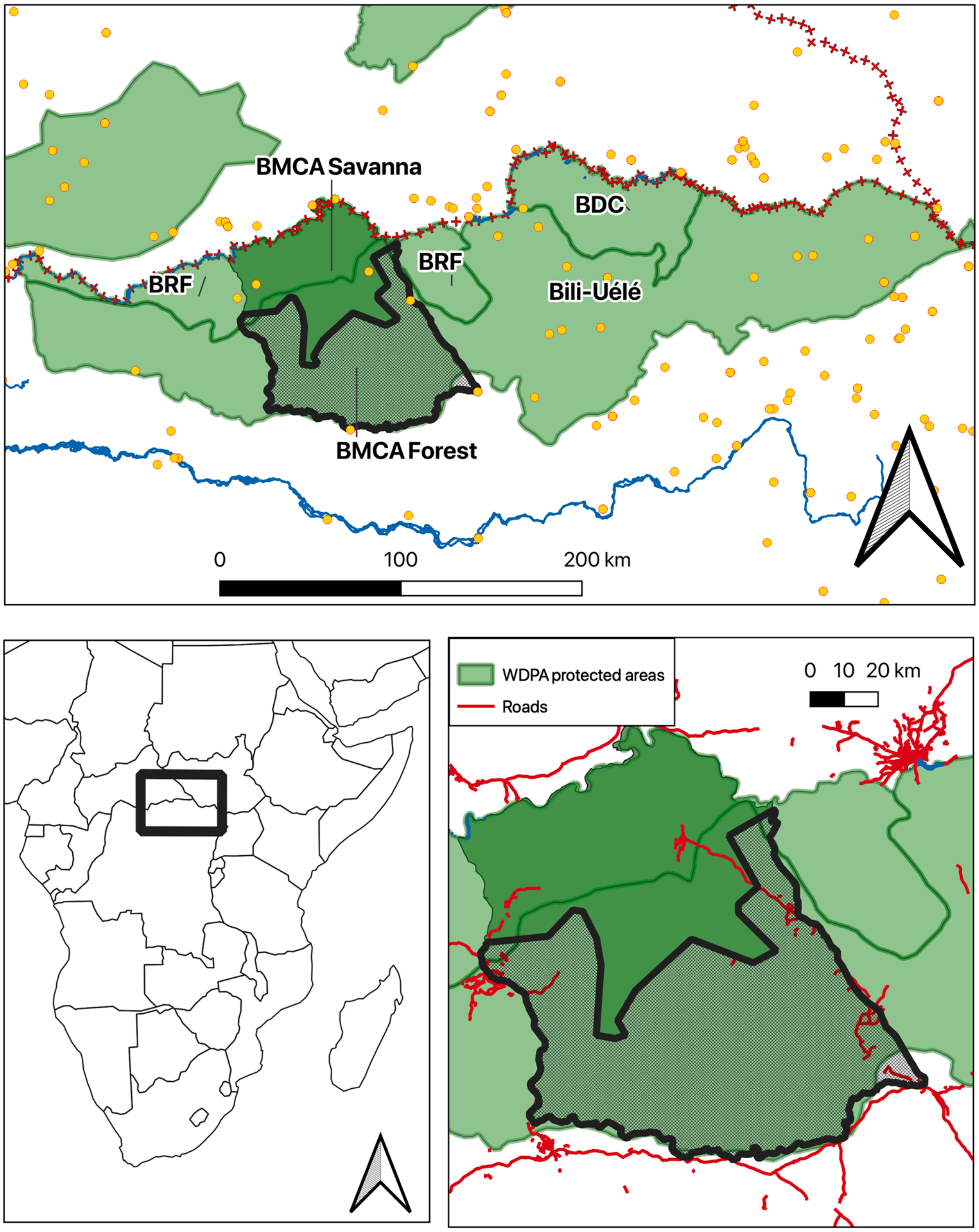

Fig. 1. Map of the Domaine de Chasse du Bili-Uélé, also named Bili-Uere, the Réserve de Faune du Bomu (BRF), Domaine de Chasse du Bomu (BDC) and the Bili-M'Bomu Core Area (BMCA) which is composed of parts of the Bili-Uélé and the Bomu R.F. areas. The BMCA contains a savannah area in the north and a forest area in the south. The study was conducted in the forested BMCA area. Highlighted are all protected areas in the selected map areas, settlements, and the locations of battles, explosions and remote violence, riots and violence against civilians from 2004 to 2019 (acleddata.com, Raleigh et al., 2010). The map was created using QGIS version 3.18.0-Zürich (https ://qgis. org/en/site/) from public domain map datasets from Open Street Map (www.open-street map.org), diva-gis (diva-gis.org), Humanitarian Data Exchange, HDX (data. humdata.org) and UNEP-WCMC and IUCN (2021) for the boundaries of the Protected Areas.

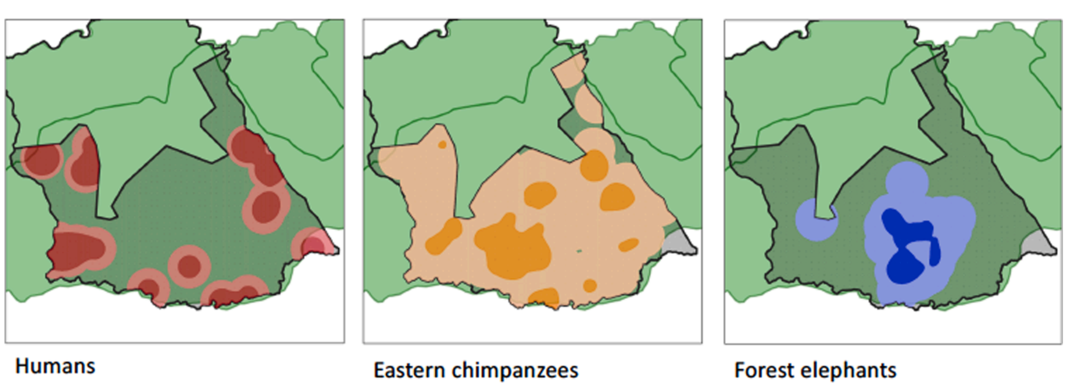

Fig. 2. Centres of activities of humans, Eastern chimpanzees and forest elephants in the forested zone of the Bili-M'Bomu Core Area (hatched light grey). Centres of activities are defined by Kernel density distributions constructed from all observations for the target species. Shown are the third (light) and fourth (dark) quartile, i. e., Kernel densities equal or larger than the median for each species or species group, which are represented by different colours.

in 2007 (Hicks, 2010). A second protection attempt was started in 2015. More recently, the Congolese Institute for the Conservation of Nature (*Institut Congolais pour la Conservation de la Nature,* ICCN, a State enterprise) and the African Wildlife Foundation (AWF) formed a strategic partnership to protect and participatively manage a biodiversity rich core area within the BUPAC (African Wildlife Foundation, 2015; Akana, 2015). An area of 10,532 km^2, the Bili-M'Bomu Core Area (BMCA), was identified and designated as priority for conservation because it is one of the most biodiversity-rich and relatively unimpacted zone within the BUPAC. The aim of the partnership was to intensify protection within this core area by increasing the number and presence of ecoguards. Habitats include gallery forests in the southern part and wooded and grassy savannas in the north. The present study was conducted in the southern forest landscape, around 6,176 km^2 or about 59% of the BMCA (Fig. 1).

2.2.1. Ecological setting

About 6% of the "Northeastern Congolian Lowland Forests" ecoregion is found within the BUPAC (Burgess, 2005). This ecoregion is regarded as "globally outstanding" with high levels of mammalian endemism. Most habitats remain largely unstudied but are known to be threatened by "mining, logging, largescale human population movements as a result of war, and the bushmeat and wildlife use that accompany these other threats" (Burgess, 2005). Northern BUPAC is part of the "East Sudanian Savanna" ecoregion, which is regarded as "bioregionally outstanding" (Burgess, 2005). Knowledge of species diversity and composition within these areas is largely lacking.

Open forest-savanna mosaic of woodland, shrubland and savanna grassland is dominant in the North and primary moist tropical forest in the South. The Gangu River flows from East to West along the middle of the BMCA, surrounded by a very large area of near-pristine primary vegetation with almost no human presence except brief visits to fish by small Azande fisher-folk groups during the dry season (Hicks, 2010). Climate is humid tropical with a clear dry season of up to 3 or 4 months (Hicks, 2010).

Although deforestation primarily affects the periphery of the BMCA, both inside and outside, the central part of the BMCA has remained relatively untouched (AWF, unpublished). Annual deforestation rate between 2001 and 2010 in BMCA forests, largely protected by the presence of ICCN ecoguards, was 0.14%. This was below the national average of 0.31% to 0.34% reported by Butsic et al. (2015) for the same time period, but also less than rates estimated within a 5-km zone around the BMCA, within the nominally protected BUPAC area, but without ecoguard presence (AWF, unpublished). Moreover, whilst deforestation increased only marginally between 2001 and 2009 versus 2010 and 2018 (0.14% and 0.17%, respectively), the 5-km periphery sustained losses that almost doubled from 0.37% to 0.61% during the same time interval. These data clearly demonstrate the positive impact of ICCN ecoguards on habitat protection in the BMCA.

2.3. Estimation of densities and distributions using line transect surveys

To ensure comparability between the 2004 and 2007 results in Hicks (2010) we applied the same line transect method in our two surveys. One survey was conducted in 2016 (in May and September) and another one in 2019 (June to September) using systematically placed 2 km long line transects across the BMCA's southern forest area. During the 2019 survey we covered the entire forest area (6,176 km^2) but in the 2016 survey we excluded the North-Western part and covered 5,841 km^2; this area fully overlapped with the 2019 survey. The 2016 survey was planned as a pilot study to primarily assess chimpanzee numbers.

We allowed for a coefficient of variation (CV) for an estimated density of 25%. Considering that Hicks (2010) encountered 105 chimpanzee nest groups along 160 km of transects in his 2005 survey, we estimated that 112.5 km of transects needed to be surveyed (equation 2.4 in Buckland, Rexstad, Marques, & Oedekoven, 2015, p. 24). For 2019, we tightened the target CV to 15% and based the calculation on 24 nest groups observed over 74 km transects in 2016, resulting in 411 km planned transects. We used DISTANCE 6.2 software (Thomas et al., 2010) to generate regularly spaced 2 km long transects. A total of 56 transects were planned for 2016 and 211 for 2019, slightly increasing that year's planned length of transects to 422 km. Transects were oriented perpendicular to the direction of major watercourses and major roads crossing the area.

Field teams were composed of ICCN staff and ICCN ecoguards. Prior to the start of sampling, 2-day workshops were organized to train or retrain field teams in theory and practice. The 2016 survey was conducted by three teams composed of a guide and two observers each and the 2019 survey by four teams of 10 people each (3 observers, 2 guides to open paths, 2 ecoguards for safety and 3 porters). A Global Positioning System (Garmin Map60 Sc) was used to locate the start and end points of each transect. All data was recorded on a Runbo Q5 rugged android handheld PDA using the Cybertracker (http://www.cybertracker.org/) data collection app before being downloaded to SMART-ER 3.2.1 (http://smartconservationtools.org/) software for management, mapping, and analysis. Any signs left by chimpanzees and elephants (i.e., dung, vocalizations and foot prints) or humans (camping sites, cartridge cases and traps) and direct observations were recorded together with time, habitat, location, and the perpendicular distance to the animal or the centre of dung piles or centre of chimpanzee nests (White and Edwards, 2000). Any observation was recorded as new if either direct sighting indicated different individuals, or the signs were at least 30 m apart from each other. Dung was identified by experienced field guides to species. Age of chimpanzee dung was estimated as fresh, recent, old or hardened. Elephant dung was aged according to dung survey standards (Hedges & Lawson, 2006). We recorded height, type and estimated age of chimpanzee nests as fresh, recent and old (Hicks, 2010; Tutin & Fernandez, 1984). Fresh nests are those with green, unwilted vegetation or associated with fresh dung or urine; recent nests contain either dry vegetation and starting to change colour; old nests contain dead vegetation either in still intact nests or disintegrating nests.

2.4. Data analysis

2.4.1. Animal signs per kilometre walked

We report the number of signs for each identified species per walked km to compare results between surveys and with other studies where the number of observations was too low to estimate densities.

2.4.2. Density estimation by indirect observations

We estimated densities when at least 40 observations - dung, nests or direct visualizations – with distance measures were available (Buckland et al., 2001). Animal densities and the associated 95% confidence intervals and the coefficients of variation (%CV) were calculated using the R package "Distance" 1.0.2 (Miller, Rexstad, Thomas, Marshall, & Laake, 2019) in the R 4.0.5. statistical environment (R Core Team, 2021). Sightings of old or hardened dung and old chimpanzee nests were excluded from the analysis. Density calculations used the key functions half-normal, hazard rate and uniform in combination with the adjustment terms cosine, simple polynomial, and Hermite polynomial (Buckland et al., 2001). We selected the best model based on the lowest Akaike's Information Criterion, AIC, value (Burnham, Anderson, & Huyvaert, 2011), except when the analysis indicated spikes of observations with zero distance from the line transect (Buckland et al., 2015). In our case, spikes likely stemmed from rounding errors under difficult field conditions where trails could often not follow an exact straight route leading to small distances being assigned a value of zero distance. Because the hazard-rate model is particularly sensitive to such spikes and tends to fit implausible shapes for spiked data, we excluded it in such circumstances (Thomas et al., 2010). We stepwise fitted detection functions to the data by truncating the largest 0%, 5%, 10%, etc. distances from the observation results till the detection function at the truncation distance was larger than 0.1 as recommended by Buckland et al. (2001).

For forest elephant density estimates were based on dung, and for chimpanzees on nests. Dung and nest density was converted to animal density using defaecation and decay for dung and nest building and decay rates for chimpanzee nests, respectively. Lacking site-specific and habitat-specific data on any of these rates, we used published data as widely applied for elephants and duikers (Bobo et al., 2014; e.g. Hicks, 2010; Hicks et al., 2014; Kamgaing et al., 2018). We applied minimum and maximum published values, subsequently called minimum and maximum scenarios, to assess the impact of different rate estimates on the density estimate and determined the final "95%" confidence interval, CI, as the minimum 95% CI for the minimum density estimate and the minimum 95% CI for the maximum density estimate. Published production rates for Eastern chimpanzee nests was 1.09 nests days^{-1} from Uganda (Plumptre & Reynolds, 1996) and decay rates were 45.9 days (Plumptre & Reynolds, 1996) and 144 days (Skorupa, 1988 in Plumptre & Reynolds, 1996), both from Uganda. Following Hicks et al. (2014) for the same study area a proportion of nest builders of 0.83 per nest was applied (Kühl, Maisels, Ancrenaz, & Williamson, 2008). Elephant defaecation rates ranged from 12.2 to 19.8 dung days^{-1} in CAR and Cameroon, respectively (Ruggiero, 1992; Tchamba, 1992) and decay lasted from 23.3 to 90 days in Gabon (Laguardia et al., 2021; Poulsen et al., 2017). We also applied the intermediate defaecation rate of 17 days^{-1} and the decay of 43.7 days to compare our estimates with those of Alers, Blom, Kiyengo, Masunda, and Barnes (1992), who surveyed several forest areas of Zaire, now DRC.

2.4.3. Distribution

To display the spatial distribution of human and animal densities, we constructed Kernel density distributions from all observations for the target species or animal group using QGIS 3.18.3 (QGIS). The optimal bandwidth h_{opt} for the Kernel estimation was calculated following Stewart Fotheringham, Brunsdon, and Charlton (2000, p. 149, equation 6.16) with the required standard distance between transects being calculated in QGIS. To depict centres of density and activity, we display the third and fourth quartile, i.e., Kernel densities equal or larger than the median for each species or species group.

3. Results

3.1. Distance sampling effort

The total number of transects surveyed was 37 in 2016 and 173 in 2019, representing 66% and 82% of the planned 56 and 211 transects, respectively. The shortfall of surveyed transects was caused by inaccessibility, overlap with large rivers or bad weather. The shortfall appeared geographically random, as depicted by the locations of the 2019 survey in Fig. 1C. In 2016, an effort was made to cover the whole 2 km length of each transect and the total survey effort was, thus, 74 km. In 2019, the emphasis was to survey as many transects as possible but to allow for shorter distances to be covered if the terrain was prohibitive. A total of 268.9 km (78%) of the planned 346 km was surveyed, mean length = 1.6 km, min = 0.3 km, max = 1.9 km).

3.2. Densities

Table 1 summarizes all density estimates.

Eastern Chimpanzees: In 2016, 53 nests were encountered, and three vocalizations heard, giving an overall encounter rate of 0.84 observations km^{-1}. The best truncation percentage was 5% resulting in a truncation distance of 15.2 m. The best selected model was the half-normal model (AIC = 265.7) resulting in a density of 0.814 animals km^{-2} (0.43–1.54) under the minimum nest scenario and of 0.26 animals km^{-2} (0.14–0.49) under the maximum nest scenario, resulting in a final "95%" CI of 0.14 to 1.54 animals km^{-2} (Table 1). The second-best model

Table 1
Density estimates of Eastern chimpanzees and Forest elephants.

survey year	all obs. km^{-1}	dung/nests/sightings km^{-1}	model parameters			minimum scenario (observed scenario for monkeys)					maximum scenario					final "95% CI"	
			best model	d_{trunc} [m]	Cramer von Mises p	prod. [day^{-1}]	decay [days]	mean density [km^{-2}]	95% CI	CV	prod. [day^{-1}]	decay [days]	mean density [km^{-2}]	95% CI	CV	best model	2nd best model
Eastern chimpanzees																	
2016	0.84	0.80	hn	15.2	0.35	1.09	45.9	0.8	0.4–1.5	32.6%	1.09	144	0.3	0.1–0.5	32.6%	0.1–1.5	0.1–1.4
2019	1.24	0.99	uni-cos	15	0.06	1.09	45.9	1.7	1.2–2.4	16.7%	1.09	144	0.5	0.4–0.8	16.7%	0.4–2.4	0.4–2.1
Forest elephants																	
2016	1.14	1.14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2019	0.31	0.27	hn_cos	4.2	0.019	12.2	23.3 ± 6.06	0.15	0.1–0.3	42.7%	19.8	90	0.02	0.01–0.05	33.9%	0.01–0.33	0.01–0.33

Obs.: observations; d_{trunc}: truncation distance; prod.: production; CV: coefficient of variation.

was the uniform cosine model (AIC = 266.6), resulting in a similar final "95%" CI of 0.13 to 1.37 animals km^{-2}. Density estimates had a relatively low precision with a coefficient of variation of 32.6%. In 2019, 266 nest and 22 indirect signs (food remains, footprints, signs of debarking and faeces) were encountered, giving an overall encounter rate of 1.24 observations km^{-1}. The best truncation percentage was 15% resulting in a truncation distance of 15.0 m. The best selected model was the uniform cosine model (AIC = 1173.4) resulting in a density of 1.69 animals km^{-2} (1.22–2.35) under the minimum nest scenario and of 0.54 animals km^{-2} (0.39–0.75) under the maximum nest scenario, resulting in a final "95%" CI of 0.39 to 2.35 animals km^{-2} (Table 1). The second-best model was the half-normal cosine model (AIC = 1176.0), resulting in a similar final "95%" CI of 0.36 to 2.10 animals km^{-2}. Density estimates had a much higher precision than in 2016 with a coefficient of variation of 16.7%. Although the encounter rate of 0.84 and 1.24 observations km^{-1} in 2016 and 2019, respectively, were markedly lower than the 2005 encounter rate of 3.03 nests km^{-1}, estimated densities were largely overlapping between 2016, 2019 and 2005 of 0.13–1.37, 0.36–2.10 and 0.66–2.08 animals km$^{-2,}$ respectively, whereby the 2005 estimates used the same range of nest production and decay rates as the 2016 and 2019 estimates.

Forest elephants: Across the whole area in 2005, Hicks (2010) observed 2.73 signs km^{-1} (160 km transects) and for a subsection, the Gangu forest, 1.18 signs km^{-1} (356.8 km transects) were recorded between 2004 and 2007. The encounter rate was 26 indirect observations (0.35 observations km^{-1}) in 2016 and 81 indirect and one direct observation (0.31 observations km^{-1}) in 2019. Animal densities were not estimated in 2016 because of small sample size. In 2019, the best truncation percentage was 20% resulting in a truncation distance of 4.2 m. The best selected model was the hazard rate model (AIC = 71.9) resulting in a density of 41.43 (21.6–79.41) dung piles km^{-2}. The application of production and decay rates resulted in an animal density of 0.02 elephants km^{-2} (0.01–0.05) under the minimum nest scenario and 0. 15 animals km^{-2} (0.07–0.33) under the maximum nest scenario, resulting in a final "95%" CI of 0.01 to 0.0.33 animals km^{-2} (Table 1). The second-best model was the half-normal cosine model (AIC = 106.3), resulting in an identical final "95%" CI of 0.01 to 0.33 animals km^{-2}. Density estimates had a relatively low precision with a coefficient of variation of 42.7% and 33.9% for the minimum and maximum scenarios, respectively. Applying the production rate (17 dung days^{-1}) and decay rates (43.7 days) in Alers et al. (1992), resulted in 0.06 animals km^{-2} (0.03–0.11) with a coefficient of variation of 33.9%.

Humans: The encounter rate of human activities was 0.15 signs km^{-1} in 2019; in 2016, signs were not recorded.

3.3. Distributions

Spatial distributions of animal and human activities are shown in Fig. 2 for the 2019 survey, when both were recorded. Signs of human activities were most abundant on the periphery of the surveyed BMCA forest area, especially where roads are located, but reached relatively deep into the forest in some areas (see numbered locations in Fig. 2A). Eastern chimpanzees were found anywhere with an activity centre in the south-central part of the BMCA. Activity centres overlapped with human activity centres in three main locations (see locations 2 to 4 in Fig. 2B). Elephants were mainly concentrated in the central part of the study, with one major overlap zone with human activities (see location 3 in Fig. 2C).

4. Discussion

4.1. Methods

We estimated animal densities using line transect surveys from indirect signs (dung, nests) and direct observations. The estimations using indirect signs need to be based on information on the production and the decay of these, so as to translate their density into animal density. Many line-transect surveys rely on production and decay rates estimated at other sites due to the effort required to estimate defaecation rates under natural conditions as well as large samples of rotting dung in native habitats (e.g., elephants: Barnes, 2001). Whilst production rates vary little, decay rates can vary significantly. The published elephant dung decay difference was fourfold (23.3 versus 90; Laguardia et al., 2021) and the published chimpanzee nest decay was threefold (45.9 versus 144; Plumptre & Reynolds, 1996). Consequently, all estimates in our study using animal signs must be interpreted taking the above caveat into consideration. Unfortunately, the reality of research and conservation in a difficult area like BUPAC is that logistics, inaccessibility, security issues and lack of finances are extremely limiting, forcing is to focus on the efficient monitoring of temporal, with-in area trends, which are not affected by the quantification of production and decay rates, and which allows meaningful density estimates despite lack of precision as in so many other studies. Notwithstanding this methodological limitation, line-transect-based estimates using published decay rates can be robust, as already demonstrated for savannah elephants in which estimates were found to be as precise, and sometimes more precise than, those from aerial surveys (Barnes, 2001). Given this, it is fundamental to generate appropriate estimates of dung and nest decay rates for use in future studies, as suggested by Breuer, Mavinga, and Breuer-Ndoundou Hockemba (2009). Other novel methods, such as distance sampling using camera traps (Howe, Buckland, Després-Einspenner, & Kühl, 2017), DNA sampling of dung (Moore & Vigilant, 2014) or the use of unmanned aerial vehicle (UAV) or drones (e.g. for elephants, see Aerial Surveys & Borders, 2022 or orangutans Milne et al., 2021) are techniques that are becoming more available and affordable for the successful monitoring of terrestrial vertebrates. The detection of environmental DNA (eDNA), the nuclear or mitochondrial DNA released from an organism into the environment, can also be used to reveal the presence of a species (Ishige et al., 2017). New developments such as the capture of eDNA from air has the potential to revolutionise future terrestrial monitoring, as in the case of eDNA in aquatic environments (Lynggaard et al., 2022).

4.2. Densities and distributions

Our surveys report the second estimated densities of Eastern chimpanzees and Forest elephants in our study area. The scale of the study area includes core areas for Eastern chimpanzees and Forest elephants. These species range also outside the study area, but the roads and human activities, as shown in Fig. 2, box the study area in, this making the study area a core area as indicated by the activity centres of all investigated large mammals being within this core area.

For Eastern chimpanzees and forest elephants, two high-profile species found in the study areas, we were able to compare population densities for three separate time periods, covering 14 years. We found no detectable change in overall chimpanzee density between the first survey in 2005 (0.66–2.08 animals km^{-2}) and our 2019 survey (0.36–2.10 animals km^{-2}). However, the estimated density for 2016 appeared markedly lower (0.13–1.37 animals km^{-2}) but this is likely caused by the much lower precision in 2016 (32.6%) compared to 2019 (16.7%). Though deforestation increased during the last two decades (see above) in the BMCA periphery, located within the nominally protected BUPAC, the fact that Eastern chimpanzee numbers were relatively stable throughout the study period may reflect the extra protection offered by the presence of ICCN ecoguards. Surveys of Eastern chimpanzees within BUPAC but outside BMCA are, however, missing and are urgently needed.

By contrast to the stable density of Eastern chimpanzees found, the encountered 0.35 and 0.31 signs km^{-1} of forest elephants in 2016 and 2019, respectively, were markedly lower than those reported for the whole area in 2005 (2.73 signs km^{-1}), corresponding to an eight-fold decrease, and a sub-section between 2005 and 2007 of 1.18 signs

km^{-1}. This drastic decline of signs of forest elephants in the line transect surveys strongly indicates decreases abundance despite that the elephant abundance was not quantitatively assessed in 2005 nor in 2016. The estimated 0.01–0.33 animals km^{-2} in 2019 was also drastically lower than Ruggiero (2017) estimate of about 2.3 elephants km^{-2} (from an estimate of 100,000 forest elephants in the 1970′s in the whole BUPAC area). Such a remarkable population decline is related to the intense poaching reported in the early 2000′s in the BUPAC (The Wasmoeth Wildlife Foundation, 2006), part of the overall dramatic population decline of forest elephants in Central Africa at the start of the 21st century (Maisels, Strindberg, Blake, Wittemyer, Hart, & Williamson, 2013).

According to Maisels et al. (2013), forest elephant populations have shrunk to less than 10% of their potential size and now occupy less than 25% of their potential range. In the DRC, Maisels et al. (2013) showed that extremely low elephant densities are typical throughout the country. These low densities are characterized by 0–100 elephant dung piles km^{-2}; our estimated dung densities of 41 (22–79) dung piles km^{-2} fall into this category. This drop in elephant numbers is likely to have been caused by the increasing human population density, rising hunting intensity, aggravated by poor governance, and proximity to expanding infrastructure. Hunting for subsistence by park-adjacent communities, together with illegal poaching for ivory, are also implicated (Maisels et al., 2013) especially because of lack of law enforcement following the incursion of the Lord's Resistance Army (LRA) into northern DRC (Agger & Hutson, 2014). A recent investigation has also revealed that the LRA have engaged in high levels of elephant poaching and ivory trafficking to sustain their activities (Agger and Hutson 2013). Elephant ivory poaching for ivory has been a major force causing the collapse of forest elephant populations by half in the Okapi Faunal Reserve, also in northeastern DRC and not far from BUPAC (Fig. 1; Beyers et al., 2011). Globally, ivory trade is the primary reason for elephant decline (Wittemyer, Northrup, Blanc, Douglas-Hamilton, Omondi, & Burnham, 2014). In contrast to elephants, pressure on chimpanzees is likely to have been much less. Although these apes are often killed for their meat, it is probable that hunters would target abundant and more animals (e.g. duikers) that can be more easily caught using cheap methods such as cable snares (Fa, Funk, & Nasi, 2022). The high hunting pressure on forest elephants, as evidenced by the steep decline between 2005 and 2019, seems to be specific to this species, in turn indicating that the main problem of hunting thus far in the BMCA is hunting for ivory by the LRA to finance their insurgent activities (see also Agger & Hutson, 2014; Wittemyer et al., 2014).

4.3. Conservation

Although research on the importance of carbon stocks in tropical forests in Africa is increasing (see Cuni-Sanchez et al., 2021), the impact hunting-induced extinctions of plant–animal mutualisms in the long-term dynamics of these forests is little known. For the Amazon, Peres, Emilio, Schietti, Desmoulière, and Levi (2016) have shown that defaunation of the most harvest-sensitive species will lead to losses in aboveground biomass up to 37.8% of carbon stocks. These findings highlight the importance of managing populations of large frugivorous vertebrates because their loss will not only diminish the biodiversity value of important conservation areas, but also will have consequences on the functional ecology of these ecosystems. In BMCA, therefore, efforts to protect forest elephants as well as medium-sized and large animal populations will ensure the survival of the forests in which they are found. To achieve this, significant reductions in illegal ivory poaching and the uncontrolled killing of animals for wild meat. This is not straightforward. However, there are three main strategies that can be used to secure the future of BMCA and its wildlife. First, we advise to carefully plan that the BMCA is declared a National Park to strengthen the legal mechanisms against poaching and poachers. This should be done with participatory mapping and zoning with the communities surrounding the area considering local livelihoods in order to achieve community support (Henson, Williams, Dupain, Gichohi, & Muruthi, 2009; Nackoney, Rybock, Dupain, & Facheux, 2013). The strengthening of governance is already under way via the efforts of the AWF and ICCN. At present, the BMCA is staffed only by 25 ecoguards and five ICCN managers; the coverage of only one guard per 440 km^{-2} is, thus, minimal, and requires an urgent substantial increase to enable more consistent protection across the site. We also advise that a buffer zone using community forests around BMCA, where a system of sustainable hunting and non-timber forest product collection for local people is implemented. Important will be that these community forests are managed to achieve sustainable hunting with maximum yields in order to contribute to local food security. Currently, the periphery around BMCA is experiencing increased human densities (AWF, unpublished) and double the amount of deforestation rates than inside the BMCA (see above). Thus, management of the periphery for sustainable use together with more effective guarding of the inside areas could deflect and reduce the current hunting pressure inside the BMCA, as evidenced by human activities on the boundaries, but also in more central parts of the BMCA (see Fig. 2A). Achieving this will need engagement with communities alongside strengthening the protection capacities of BMCA staff. The proposed participatory mapping and landscape planning (Henson et al., 2009; Nackoney et al., 2013) for both, the BMCA and the buffer zone, is an essential step as it has been shown that direct participation and engagement of local communities and stake holders is crucial for conservation strategies to be successful and lasting (e.g., Velázquez et al., 2009). Second, establishing long-term ecological and conservation-related research, rather than the short-term approach typical for much of academic research, has the potential to bolster protection alongside contributing to the local economy (Campbell, Kuehl, Diarrassouba, N'Goran, & Boesch, 2011). Third, the fate of some large mammals, especially forest elephants, will depend on successful control of poaching for the still lucrative ivory trade, which depends primarily on the capacity of the state to establish lasting peace and reining in the LRA, but which will be complex, require international support and will take time.

CRediT authorship contribution statement

Stephan M. Funk: Conceptualization, Data curation, Methodology, Writing – original draft. **Julien Nkono:** Investigation, Data curation, Methodology, Writing – review & editing. **Alain Lushimba:** Investigation. **Julia E. Fa:** Conceptualization, Writing – review & editing. **David Williams:** Conceptualization, Supervision, Project administration, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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