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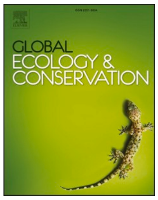

Mammal distribution and trends in the threatened Ebo 'intact forest landscape', Cameroon

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ABSTRACT

Intact forest landscapes (IFLs) are globally important for maintaining functional ecosystems. Ebo forest (~1400 km^2) in Cameroon is one of the largest remaining IFLs in the Cross-Sanaga-Bioko coastal forest ecoregion and harbours several IUCN Red-Listed threatened mammal species. We evaluated the status, trends, and distribution of mammals ≥ 0.5 kg in the Ebo forest over 12 years using guided recce and camera trap monitoring surveys, as well as local knowledge to inform future land use and conservation planning. Recce monitoring of six taxa (blue duiker *Philantomba monticola,* chimpanzee *Pan troglodytes,* forest elephant *Loxodonta cyclotis,* putty-nosed monkey *Cercopithecus nictitans,* medium sized duikers *Cephalophus* spp., and red river hog *Potamochoerus porcus*) showed that some are stable or increasing. Indeed, our recent camera trap data confirmed breeding *Gorilla gorilla* (western gorilla) and elephant. Distribution models for chimpanzees and elephants showed that their populations are concentrated in the centre of the forest, away from human pressure. Some other species, however, including red colobus *Piliocolobus preussi*, leopard *Panthera pardus*, African golden cat *Caracal aurata*, and forest buffalo *Syncerus caffer nanus* are either close to extirpation or have been extirpated within living memory. We conclude that the Ebo intact forest landscape retains an important mammal community, despite no formal legal protection. Ebo's future is uncertain, with two commercial logging concessions announced by Cameroon in 2020 and later suspended in response to national and international pressure. It is crucial to maintain Ebo's integrity to protect the biodiversity and function of this important part of the Cross-Sanaga-Bioko coastal forest ecoregion.

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1. Introduction

Large areas of central Africa are still intact in terms of forest cover (Grantham et al., 2020a; Potapov et al., 2017), wildlife (Plumptre et al., 2019) or both (Plumptre et al., 2021), including parts of Cameroon (Grantham et al., 2020b). Cameroon contains about 10% of the remaining central African tropical forests (Verhegghen et al., 2012) but is suffering ongoing forest losses: (3.2% loss of humid forests between 2002 and 2019; globalforestwatch.org). In addition to absolute losses, only *c*.12% of Cameroon's tree cover is now classified as 'intact' (>30% tree canopy; globalforestwatch.org). Of the three forest ecoregions found within Cameroon, the highly biodiverse Cross-Sanaga-Bioko coastal forest ecoregion is globally the rarest, and is confined to Nigeria, Bioko, and Cameroon (Olson et al., 2001). Within this ecoregion, only a handful of intact forest landscapes (IFLs) now exist (Potapov et al., 2017), threatening biodiversity and local livelihoods that rely on these forests for food, medicine, and water.

Like the rest of the region, much of Cameroon's remaining large mammals and their habitat are threatened by overexploitation, climate change, and land-use change (Abernethy et al., 2016, 2013; Benítez-López et al., 2017; Bush et al., 2020). Indeed, taxon-wide analyses of three of the largest species (forest elephant *Loxodonta cyclotis,* western lowland gorilla *Gorilla gorilla gorilla,* and central chimpanzee *Pan troglodytes troglodytes*) showed alarming recent reductions in both range and population trends, which show no sign of abating (Maisels et al., 2013; Strindberg et al., 2018).

The Ebo forest (~1400 km^2) constitutes 50% of the Yabassi Key Biodiversity Area (Key Biodiversity Areas Partnership, 2021), which in turn represents the most important tract of intact forest landscape in the Cross-Sanaga-Bioko coastal forest ecoregion (Potapov et al., 2017). Ebo is also visibly distinct on the 2020 Forest Landscape Integrity Atlas (Grantham et al., 2020a). The forest is a refuge for the rich biodiversity that characterises the region but which is now depleted across most of its range due to human pressure, including habitat loss, agriculture, logging and hunting (Mahmoud et al., 2019; Morgan et al., 2013). It is home to many threatened mammal species including Nigeria-Cameroon chimpanzee *Pan troglodytes ellioti*, western gorilla *Gorilla gorilla*, drill *Mandrillus leucophaeus*, Preuss's red colobus *Piliocolobus preussi* and African forest elephant *Loxodonta cyclotis* (Morgan et al., 2003; Oates, 2011), and has high avian and anuran diversity (Dahmen, 2013; Whytock and Morgan, 2010). Plant diversity and endemicity of Ebo is also high, with 29 new species to science discovered since 2005 (Cheek et al., 2021, 2018; Mackinder et al., 2010; van der Burgt et al., 2015).

Conservation work in more than 40 villages adjacent to Ebo forest was pioneered by San Diego Zoo Wildlife Alliance following the first documented observations of gorillas in the forest in 2002 (Morgan et al., 2003). Plans to gazette the site as a national park were initiated in 2006 but stalled and, in 2020, the government announced that two long-term logging concessions were to replace the proposed national park. This was strongly opposed by a range of stakeholders, including grassroots communities and international non-governmental organisations (NGOs). The protests resulted in the government suspending the logging concession decree on August 11th 2020. Various stakeholders, including local conservation NGOs are now proposing an inclusive and transparent local land use planning process for the forest to safeguard its rich diversity and to sustainably cater for the needs of surrounding communities.

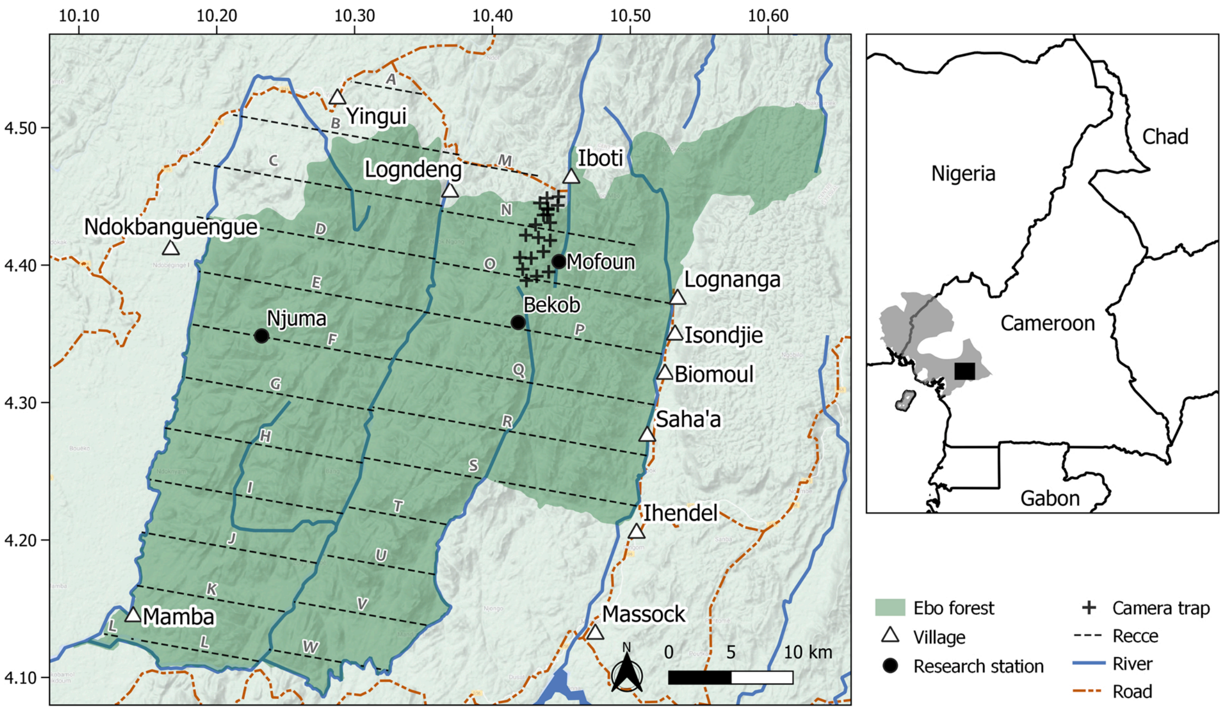

Fig. 1. (left) Map of the Ebo forest in Cameroon showing the 23 recce lines (A – W), 20 camera trap locations in 2019–2020, three long-term research stations, major inhabited villages and major rivers. (right) Map showing extent of the Ebo forest in Cameroon (black square) and Cross-Sanaga-Bioko coastal forests ecoregion (grey shading).

Here, we use data from multiple sources including large-scale systematic foot survey monitoring (recces), camera trap surveys, local knowledge, and opportunistic observations to estimate the distribution and long-term trends of mammals with a body mass ≥ 0.5 kg in the Ebo forest. We use this information to (a) evaluate the forest's importance for protecting mammal diversity in the diminishing forests of the threatened Cross-Sanaga-Bioko coastal forest ecoregion, and (b) inform future, community-led land-use and conservation planning.

2. Materials and methods

2.1. Study area

The Ebo forest comprises mixed high-canopy and secondary lowland and sub-montane forest, with annual rainfall ranging from approximately 2300 to 3100 mm per year (Abwe et al., 2019). Mean annual temperature ranges from 25 to 28 ^{o}C and although rainfall can occur year-round, there are two main seasons (wet and dry), with the months of May to September considered the wet season. Following civil war in the 1960s, local communities dispersed to the forest edge and there are no longer any active settlements in the forest interior. Villages at the forest edge practice subsistence farming and hunting, and there are also commercial forestry operations and oil palm plantations (Mahmoud et al., 2019). The rugged terrain, which reaches elevations of up to 1200 m above sea level, has offered some protection from the high levels of human pressure seen elsewhere in the surrounding region.

2.2. Mammal monitoring

In 2008, a foot survey monitoring system was designed for Ebo, consisting of 23 parallel reconnaissance lines placed 4 km apart generally called guided reconnaissance walks, but hereafter referred to as "recces" (Hall et al., 1998; Walsh et al., 2001, 2000; Walsh and White, 1999). Lines were aligned at right angles to the principal drainage pattern of the area (the Ebo and Dibamba Rivers). Total survey length was 345 km (mean line length 15 km, standard deviation (SD) 5.17), and covered the entire former proposed Ebo National Park (~ 1400 km^2; Fig. 1).

Field protocols followed the International Union for the Conservation of Nature (IUCN) Section on Great Ape's Best Practice Guidelines for recces and the international elephant monitoring guidelines (Hedges et al., 2012; Kühl et al., 2008; Maisels, 2008). Lines were walked following a compass bearing using the path of least resistance, with minimum cutting to limit damage to vegetation. This avoided the creation of new access routes for hunters and prevented the creation of new paths for wildlife, which can both result in biased estimation of wildlife abundance over time. Trained teams of two to three surveyors walked at a pace of approximately 1 km/h recording terrestrial and arboreal mammal signs or direct sightings on both side of the recce (Table S1). Sign age was estimated following (White and Edwards, 2000) (Table S1). Signs on the ground further than one metre to each side of the observer were not recorded to reduce variability in detection rates in different vegetation types. Categorical measures describing the weather, terrain, and canopy height were recorded at hourly intervals or when there was noticeable change. The guided recces were surveyed once in the dry season (approximately October - April), first in 2008–2009, then in 2012–2013, and subsequently each year over the dry seasons of 2016–2020.

3. Camera trap survey

From December 2019 to February 2020 we deployed 20 Reconyx HP2X Hyperfire 2 camera traps for *c.* 1800 trap nights in the north of the Ebo forest (Fig. 1) in an area covering approximately 39 km^2, first identified as important for gorillas in 2003 (Morgan et al., 2003), and later refined during monitoring activities conducted by the Ebo Forest Research Project (EFRP). Cameras were set to capture both video and images using medium sensitivity settings and installed at standard heights (*c.* 30–40 cm above ground level) on tree trunks (Wearn and Glover-Kapfer, 2019). The purpose of the camera trap study was to capture face and body shots of gorillas to identify individuals as part of an informal census, and to find hotspots of activity to inform future systematic surveys. However, other mammals ranging in size from forest giant pouched rat *Cricetomys emini* to forest elephant were also captured.

3.1. Estimating mammal trends and distributions using local knowledge

The EFRP has been working with local communities continuously since 2005. This has included monitoring from three permanent research stations between 2005 and 2017. Bekob research station was at the site of an abandoned village and was staffed continuously from 2005 to 2017, Moufon, also an abandoned village, from 2009 to 2011, and Njuma, previously a small hunting camp, from 2009 to 2017.

Monitoring activities from the research stations included providing logistical support to national and international researchers and students, collecting targeted data on the feeding ecology of chimpanzees (Abwe et al., 2020), and regular monitoring of trails and old abandoned roads for drills and other mammal species. Field teams (most from local villages) developed an expert understanding of the forest's natural history during research activities. Many of the field assistants had previously been commercial hunters, with a good understanding of the ecology and distribution of hunted mammal species. To make use of this extensive local knowledge, we conducted unstructured interviews with community leaders, current and former EFRP field assistants, hunters and farmers in Iboti, Logndeng, Lognanga, Isondje, and Biomoul villages (Fig. 1) throughout the study, and particularly in 2013, 2017 and 2020. Specifically, for each species, we asked three main questions during conversation and formal meetings: (1) where is each species found in the forest? (2)

have you perceived any change in the species' abundance and distribution? and (3) do you perceive the species to be common, uncommon or rare? This information was used to establish local perceptions of change in the abundance and distribution of focal mammal species. We also recorded the local names for each species in Banen and Bassa (local languages of the two main ethnic groups around the forest) to facilitate future community-led discussions on land and wildlife management.

4. Data analysis

4.1. Estimates of relative annual change

Simple sign detection data collected on recce surveys cannot be used to estimate absolute abundance, for example using Distance sampling approaches (Thomas et al., 2010), as detection probability is unknown. However, there was high inter-annual repeatability in the routes followed by survey teams allowing us to quantify relative change in detection rates of animal signs and observations. We calculated the combined, total number of all fresh, recent, and old signs (foraging, dung, vocalisation, nests, and digging) and direct sightings for five species with > 100 observations recorded (blue duiker *Philantomba monticola*, chimpanzee, forest elephant, greater spot-nosed monkey *Cercopithecus nictitans*, and red river hog *Potamochoerus porcus*). 'Red duiker' (*Cephalophus* spp.) was also included as a species group since signs of the individual species (*C. dorsalis* and *C. ogilbyi*) can be difficult to separate in the field. We then used generalised linear mixed models (GLMM) with a negative binomial error distribution to estimate the effects of year, year^2, canopy height (numeric values representing quartiles of % canopy height, coded as 1–4), canopy height^2, and visibility (visibility distance from 0 to > 15 m, coded numerically as 1–4) on lisign detection rates. Each recce line was treated as a sampling unit. Fixed effects were mean-centred and scaled by 1 SD to compare relative effect sizes (β).

We calculated a 'population' level sign detection rate and included species as a random intercept to allow for differences among species. Recce line ID was included as a random intercept to account for pseudoreplication, and we allowed the slope of year to vary for each species by including a year-by-species random slope term. We included recce line length as an offset (log transformed) to account for survey effort with the counts of the sightings as the response variable. We constructed five *a-priori* alternative models using combinations of the three fixed effects (year, canopy cover, and visibility; see Results Table 2) and compared relative goodness of fit using the Akaike's Information Criterion corrected for small sample size (AIC_c) (Burnham and Anderson, 2002). Inference was made from the top model after evaluating AIC_c values (see Results). Confidence intervals were obtained by non-parametric bootstrapping ($n = 500$ resamples). Models were fitted using the R statistical language and the glmmTMB package (Brooks et al., 2017; R Core Team, 2020). Uncertain records such as brief views of silent guenons at a distance or ambiguous spoor were discarded, but these were few ($n < 50$).

For two species (forest elephant and chimpanzee) sign detections from guided recces were georeferenced for surveys in 2008–2009, 2016–2017, 2017–2018 and 2018–2019. Data from 2019 to 2020 were mostly incomplete due to COVID-19 travel restrictions and these data were not included in the analysis. GPS data from 2012 were corrupted, and were therefore excluded from the analysis. We used the available data to (1) estimate initial occupancy ψ at time t_1, probability of extinction ϕ_t between t and $t+1$, the probability that a site was colonised γ_t, between t and t + 1, and probability of detection p for the four time periods, and (2) estimate the distribution of these two key species in the study area. We used the dynamic occupancy modelling framework (MacKenzie et al., 2003) implemented using the colext function of the unmarked R package (Fiske and Chandler, 2011). To transform the recce data into a format suitable for occupancy modelling, we overlaid a grid with 16 km^2 cells, which was then subdivided into a smaller, nested grid with 0.8 km^2 cells. We used the large grid as the primary sampling unit ($n = 96$ cells surveyed per year). The nested grid cells that intersected with the recces were used as the secondary sampling occasions (n = 350 cells surveyed per year) following Pollock's robust design for multi-season data collection and analysis. GPS locations of forest elephants and chimpanzees were assigned to the sampled small grid cells to create a binary presence/absence variable for each recce and survey year combination. We calculated relative support for seven alternative models (Table 1) that included covariates of survey year, mean elevation (m) using a 30″ pixel size (Global Solar Atlas 2, 2020) and distance to the nearest road (m) (primary, secondary and tertiary roads) (World Bank Group, 2017). We also calculated mean forest cover (Hansen et al., 2013) but this metric was highly correlated with mean elevation (Pearson's correlation coefficient of 0.73) and we retained only mean elevation for the analysis to prevent issues with multi-collinearity. This choice was arbitrary and any effect of elevation should also consider that forest cover changes with elevation. All covariates were mean-centred and scaled by 1 SD. Models were ranked using AIC values. R scripts for the analyses are available at https://github.com/rcwhytock/Ebo-mammal-trends.

Table 1
Description of the seven alternative dynamic occupancy models specified *a-priori* to explore the effects of Year (Y), elevation (E) and distance to the nearest road (R) on chimpanzee and forest elephant initial occupancy ψ, colonisation γ, extinction ϕ, and detection *p* in the Ebo forest.

Model	Description
ψ(.)γ(.)ϕ(.)p(.)	Constant parameters (null)
ψ(.)γ(.)ϕ(.)p(Y)	Year dependent detection, all other parameters constant.
ψ(.)γ(Y)ϕ(Y)p(.)	Year dependent colonisation and extinction. Constant initial occupancy, and detection.
ψ(.)γ(Y)ϕ(Y)p(Y)	Year dependent colonisation, extinction, and detection. Constant (intercept only) initial occupancy.
ψ(R)γ(Y)ϕ(Y)p(Y)	Distance to nearest road dependent initial occupancy. Year dependent colonisation, extinction, and detection.
ψ(E)γ(Y)ϕ(Y)p(Y)	Elevation dependent initial occupancy. Year dependent colonisation, extinction, and detection.
ψ(ER)γ(Y)ϕ(Y)p(Y)	Elevation and distance to nearest road dependent initial occupancy. Year dependent colonisation, extinction, and detection.

4.2. Camera trap data

Camera trap placement was non-random (i.e. focused on potential gorilla feeding sites) and designed to maximise gorilla detection. As a result, these data were unsuitable for estimating absolute densities of bycatch species, for example using the random encounter model (Lucas et al., 2015). Targeted gorilla surveys are ongoing and the results are not considered or presented here, but we used the camera trap 'bycatch' to quantify relative capture rates of gorilla and other mammal species. Relative capture rates provide valuable baseline information that can be used to quantify future change. We used a high accuracy machine learning model and the Mbaza-AI user interface to automatically label species in camera trap images (Whytock et al., 2021). The top label was selected for each image based on the model's predicted accuracy. We then excluded images where the top label was predicted with an accuracy of < 70% (Whytock et al., 2021). We also verified the model's accuracy (percent correct labels) by manually checking all species/groups with < 100 detections. We calculated the proportion of images belonging to each species and species group using the final subset of images. Although the discarded images contain valuable information, a standardised sample of the data with known bias (i.e. the predictive accuracy of the machine learning model) is created by discarding uncertain labels and results can be compared systematically with new data (Whytock et al., 2021).

5. Results

5.1. Annual large mammal surveys

A total of 2296 observations were recorded during the survey period and 2212 observations were recorded for the six focal species (counts for all 18 observed species are given in Table S2).

Two of the GLMMs for sign detection rates had similar relative support based on ΔAICc of <3 (Table 2). All other models including the null had no support with ΔAICc >20 from the top model (Table 2). We used the top model for inference (ΔAICc 2.45 from the second-ranking model) (Table 3).

Conditional estimates from the top GLMM showed that the rate of change in sign detection rates varied among species (Fig. 2) but there was an average positive change (Table 2) and only encounter rates of unidentified 'red duiker' declined. Detection rates of chimpanzee, forest elephant, and blue duiker remained relatively stable over time, but the total number of signs for elephant was low (Table S2). Detection rates of putty-nosed guenon and red river hog increased substantially and non-linearly between 2016 and 2019 (Fig. 2).

6. Occupancy models

Three dynamic occupancy models for chimpanzee had similar support based on AIC (Table S3), but we chose to draw inferences using the top ranking, saturated model ψ(ER)γ(Y)ϕ(Y)p(Y) based on an assessment of the bootstrapped confidence intervals for the parameter estimates. These suggested that mean elevation and distance to the nearest road were both strongly correlated with chimpanzee initial occupancy ψ (Table 4). There was less support for time-dependence in colonisation γ and extinction ϕ, with confidence intervals from the top-ranking model including probabilities of 0 and 1 for 2016 and 2017 (Table 4). Mean detection rates p of chimpanzee declined over time, but confidence intervals were wide, indicating weak support for this trend (Table 4). Distribution maps of initial occupancy ψ showed that chimpanzee distribution is skewed away from the roads and human settlements that surround Ebo forest (Fig. 3).

A single dynamic occupancy model (ψ(E)γ(Y)ϕ(Y)p(Y)) for forest elephant had the strongest relative support based on AIC (Table S4). Forest elephant initial occupancy was positively correlated with mean elevation. Like chimpanzee, there was no strong support for time-dependence in forest elephant colonisation γ and extinction ϕ (Table 5). In contrast to chimpanzees, forest elephant detection rates increased during the study period (Table 5). Forest elephant distribution was highly localised in the north east of the forest (Fig. 3).

6.1. Camera trap survey

A total of 26,831 images were captured by the 20 camera traps between December 2019 and February 2020 (*c.*1800 trap nights).

Table 2
Model selection results for the negative binomial generalised mixed effects model examining change in sign detection rates (number of sign obersvations per recce) during the study. Species and recce ID were included as random intercepts, and year was included as a random slope (by species) in all models. Recce length (log-transformed) was included as an offset in all models to account for survey effort.

Model	df	AICc	ΔAICc
year + year^2 + visibility + canopy + canopy^2	11	2592.43	0.00
year + year^2 + visibility	9	2594.88	2.45
year + visibility + canopy + canopy^2	10	2618.96	26.53
year + visibility	8	2619.63	27.20
null	6	2648.63	56.20

Table 3
Standardised coefficient estimates (log-link scale) and bootstrapped 95% confidence intervals for the top generalised linear mixed effects model based on AICc.

Variable	β	-95% CI	+ 95% CI
Intercept	-3.52	-4.00	-2.95
Year	1.31	0.92	1.66
Year^2	0.67	0.58	0.77
Visibility	0.22	0.18	0.27
Canopy height	-0.28	-0.36	-0.20
Canopy height^2	-0.07	-0.11	-0.04

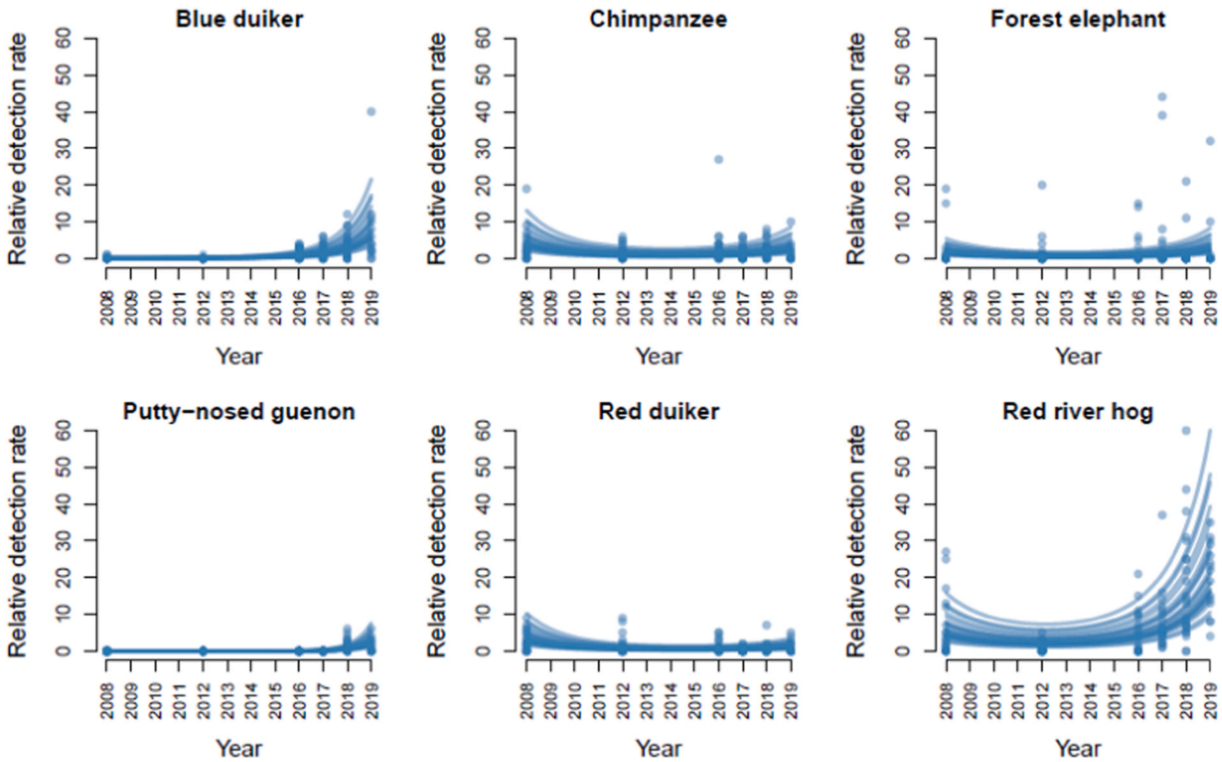

Fig. 2. Annual change in relative sign detection rates during the six survey periods between 2008 and 2019. Estimated trends are based on conditional modes of the intercept for each species and the random year-by-species slope. Individual lines for each species plot show the conditional intercepts for the 23 recce lines. Non-focal predictors and the offset for recce length were set to their mean values.

Table 4
Back-transformed coefficient estimates β and 95% confidence intervals for the top chimpanzee dynamic occupancy model ψ(ER)γ(Y)ϕ(Y)p(Y).

Variable	β	-95% CI	+ 95% CI
ψ intercept	0.33	0.22	0.46
Elevation	0.62	0.48	0.74
Distance to road	0.63	0.50	0.74
γ intercept	0.42	0.24	0.63
Year (2016)	0.12	0.00	0.88
Year (2017)	0.16	0.00	0.98
ϕ intercept	0.10	0.01	0.53
Year (2016)	0.62	0.03	0.99
Year (2017)	0.02	0.00	1.00
p intercept	0.36	0.27	0.46
Year 2016	0.33	0.22	0.47
Year 2017	0.27	0.15	0.42
Year 2018	0.22	0.09	0.44

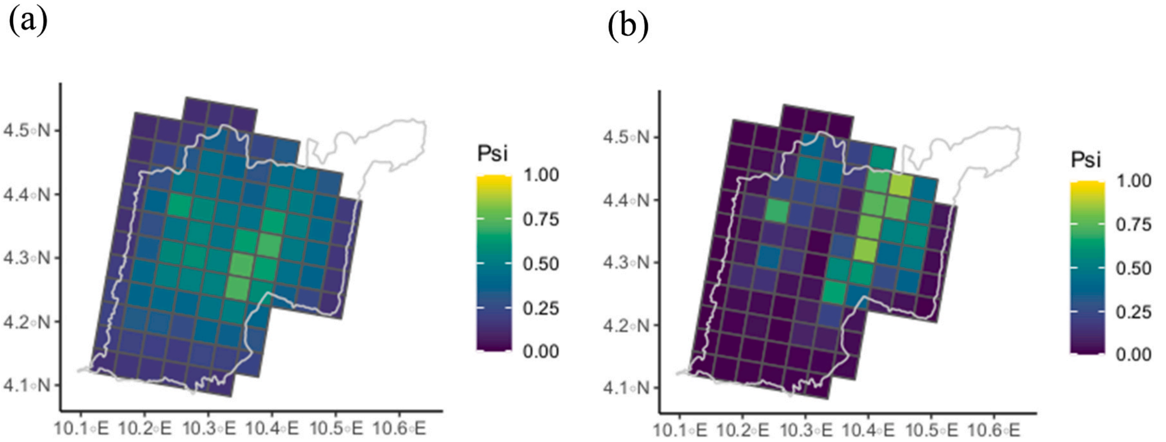

Fig. 3. Estimated distributions (initial occupancy probability ψ) in the Ebo forest for (a) chimpanzee and (b) forest elephant, predicted from the dynamic occupancy models.

Table 5
Back-transformed coefficient estimates β and 95% confidence intervals for the top forest elephant dynamic occupancy model ψ(E)γ(Y)ϕ(Y)p(Y).

Variable	β	-95% CI	+ 95% CI
ψ intercept	0.08	0.02	0.28
Elevation	0.87	0.7	0.95
γ intercept	0.00	0.00	1.00
Year (2016)	0.02	0.00	1.00
Year (2017)	0.03	0.00	1.00
ϕ intercept	0.00	0.00	1.00
Year (2016)	1.00	0.00	1.00
Year (2017)	0.47	0.00	1.00
p intercept	0.09	0.04	0.19
Year 2016	0.59	0.34	0.8
Year 2017	0.68	0.37	0.89
Year 2018	0.66	0.21	0.94

After excluding images labelled with < 70% confidence by the machine-learning algorithm, a total of 13,616 images were retained. Blue duiker were the most commonly captured species in the high-accuracy image subset, followed by forest giant pouched rat *Cricetomys emini*, and red duiker species (Fig. 4). Manual validation of a random sample of 100 images by co-author RW identified Ogilby's duiker *Cephalophus ogilbyi* and bay duiker *Cephalophus dorsalis* in the red duiker category. After manually verifying species or groups with < 100 labels, we also re-labelled the 'monkey' category to species level, with most identified as Preuss's monkey *Allochrocebus preussi*. The 'pangolin' category was also re-labelled, and all detections were of white-bellied pangolin *Phataginus tricuspis.* Notably, no leopard, golden cat, water chevrotain *Hyemoschus aquaticus* or forest buffalo were detected.

6.2. Local knowledge

Approximately 73 hunters in three villages (Logndeng, Iboti, and Lognanga) were interviewed by co-author DM in 2013 and 2017. Communities in the surrounding villages of the Ebo forest were happy to discuss their knowledge of mammal distributions and trends (Table 6).

7. Discussion

Central African forest mammals continue to decline in the face of multiple direct and indirect human pressures. Cameroon has lost a large proportion of its tropical forest, and much of the remainder is now fragmented or degraded. Many once-widespread Central African forest mammals are now confined to the last intact forest landscapes (Grantham et al., 2020b; Plumptre et al., 2019). The Cross-Sanaga-Bioko coastal forest zone has suffered some of the greatest losses, with fewer than five IFLs remaining in this rare and highly biodiverse landscape (http://www.intactforests.org/data.ifl.html). Along with the three National Parks of Korup, Takamanda and Mount Cameroon, and the Ndokbou-Makombe forest unit, the Ebo forest is one of the most important remaining IFLs in the Cross-Sanaga-Bioko coastal forest ecoregion. The unprotected status of Ebo, however, and its proximity to the largest population centres in Cameroon has left the forest's mammals and birds open to multiple threats, including hunting and land-use change

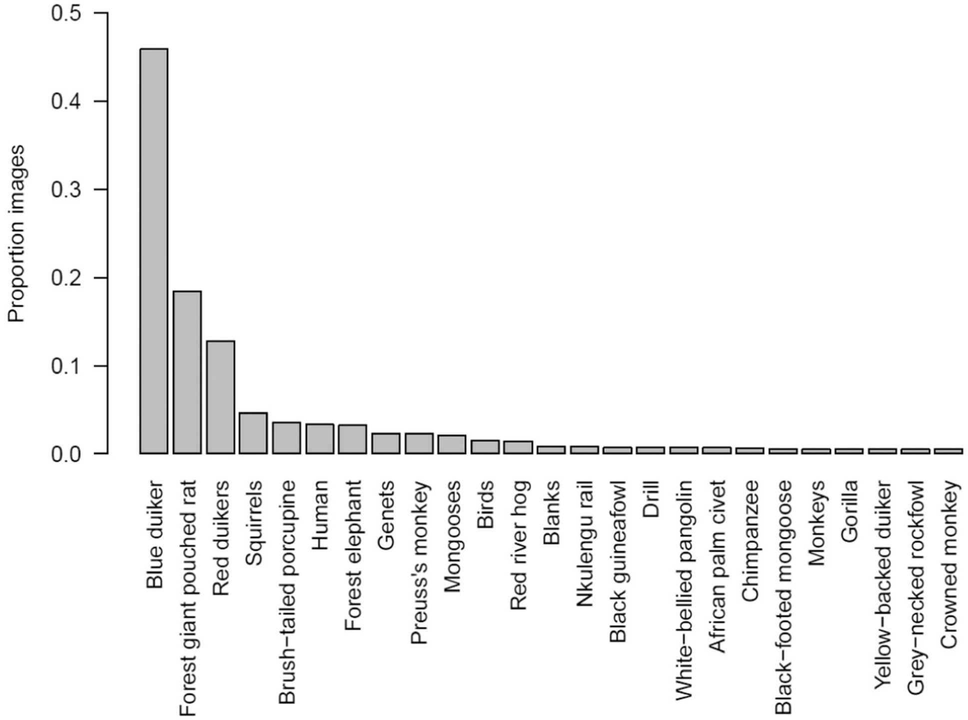

Fig. 4. Proportion of images labelled for each taxa (or as 'blank') by the Mbaza AI machine learning model after excluding images with < 70% predicted accuracy. Species or groups with < 100 observations were verified manually by co-author RW.

(Mahmoud et al., 2019; Whytock et al., 2018).

Here, we show that the Ebo forest retains high mammal diversity, and that populations of some IUCN Red-Listed species appear to be relatively stable. However, it should be noted that our trends are based mainly on indirect observations of animal signs. Future work should attempt to update the methods used to generate more robust population estimates, such as systematic camera trapping across the entire landscape. Two of these threatened species - Nigeria-Cameroon chimpanzee and forest elephant - are now confined to Ebo's central zone, where human incursion remains relatively low and the mountainous terrain offers some protection: indeed, our results showed that the highest levels of forest cover were also at the highest elevations, where it is difficult to extract timber or farm. Other species - guereza, all of the felids, several monkey species and western gorilla - are now very rare or have been locally extirpated. Some of these animals are widely distributed across the central African forests (leopard and golden cat, guereza colobus) and the Ebo forest comprises only a very small proportion of their global range. Other species have much more restricted ranges, however, such as Preuss's red colobus (Linder et al., 2021), drill (Morgan et al., 2013) and Preuss's monkey (Oates, 2011). For these, the Ebo forest represents a significant proportion of their remaining global distribution. Local extirpation in Ebo suggests that these taxa could face extinction in the coming decades without dedicated and meaningful conservation action, including adequate protection from land-use change and illegal hunting.

Of the seven taxa with sufficient data to statistically quantify long term trends in sign encounter rates, most were stable or increasing. We believe these trends are robust, since changes in detectability are accounted for during occupancy analyses. In addition, the same seven field assistants participated in all the guided recce surveys from 2008 to 2019, reducing observer bias. Although the drivers behind these trends are unknown, ongoing community conservation work and education programmes led by the EFRP, as well as the near-permanent presence of EFRP field assistants in long-term research stations (Bekob, Mofoun and Njuma) for over a decade, may have resulted in relatively low offtake of chimpanzee, red river hog, and duikers. Local community initiatives, such as the active 'Clubs des Amis des Gorilles' (Gorilla Guardians) have been actively monitoring the gorilla habitat for threats since 2012, and community leaders, government officials and staff at the Ministry of Forest and Wildlife have also shown strong willingness to engage in conservation work with the EFRP. The presence of conservation researchers can offer protection to wildlife in the local area (Kely et al., 2021; Laurance, 2013; Tagg et al., 2015). Long term increases in red river hog encounter rates might also indicate that populations are responding positively to release from non-human predation. Leopard and golden cat are likely to have been extirpated from the Ebo forest long before surveys began in 2008, and these top predators are now only remembered by older hunters (> 60 years old).

The Ebo forest is considered vital to the long-term survival of the Nigeria-Cameroon chimpanzee (Morgan et al., 2011), the rarest of the chimpanzee subspecies. Results from occupancy models, sign encounter rates and local knowledge suggest that chimpanzees remain widespread and populations are likely to be stable based on both trends in encounter rates and occupancy estimates. However, estimated distribution maps show that chimpanzees avoid the forest edge and roads, indicating their vulnerability to human pressures. Chimpanzees continue to be hunted throughout most of southern Cameroon for meat, and their status in Ebo should continue to be

Table 6
Perceived distribution and status of mammals ≥ 0.5 kg in the Ebo forest based on informal interviews with local communities, hunter knowledge, and ad-hoc observations (direct, camera traps, signs). Protected status in Cameroon (A: Rare or threatened with extinction; B: species that benefit from partial protection and can be captured or killed under license; C: Species not listed in class A or B, and birds of annex III of the Convention on International Trade in Endangered Species), and IUCN Red List classification (2021) (LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered; CR: Critically Endangered) are also shown. Names are given in English, French and local Banen and Bassa languages.

English name	French name	*Scientific name*	Banen	Bassa	Legal class	IUCN	Perceived Distribution	Perceived Status
Western gorilla	Gorille de l'ouest	*Gorilla gorilla*	Imbess	Paki	A	CR	Limited to *c*.25 km^2 in the north-east of forest	Very rare
Chimpanzee	Chimpanzé	*Pan troglodytes ellioti*	Mouyeu	Nyée	A	EN	Throughout	Common
Drill	Drill	*Mandrillus leucophaeus*	Somo	Ntin	A	EN	Mainly in north	Rare
Preuss's red colobus	Colobe bai de Preuss	*Piliocolobus preussi*	Soonyam	Soonyam	Not listed	EN	Highly sporadic signs	Very rare or extirpated
Guereza	Colobe guereza	*Colobus guereza*	Efololo	Kakikoe	A	LC	Living memory only	Extirpated
Preuss's monkey	Cercopithèque de Preuss	*Allochrocebus preussi*	Nten	Nten	A	EN	Throughout	Common
Red-capped mangabey	Cercocèbe à collier blanc	*Cercocebus torquatus*	Musako	Kaki	A	EN	Sporadic	Rare
Red-eared monkey	Moustac à oreilles rousses	*Cercopithecus erythrotis*	Neesok	Bidoh	A	VU	Throughout	Uncommon
Crowned monkey	Mone couronné	*Cercopithecus pogonias*	Mboit	Issuni	B	NT	Throughout	Common
Putty-nosed monkey	Hocheur	*Cercopithecus nictitans*	Nihinde	Binda	C	NT	Throughout	Common
Mona monkey	Mone	*Cercopithecus mona*	Neesok/ item	Ntet	B	NT	Throughout	Common
Calabar Angwantibo	Potto de Calabar	*Arctocebus calabarensis*		Yoga	A	NT	Sporadic	Uncommon
Water chevrotain	Chevrotain aquatique	*Hyemoschus aquaticus*	Pupayé	–	A	LC	Sporadic	Rare
Red river hog	Potamochère	*Potamochoerus porcus*	Akondaf	Goïbikaï	B	LC	Throughout	Common
Bushbuck	Guib harnachée	*Tragelaphus scriptus*	–	–	C	LC	Sporadic	Rare
Bay duiker	Céphalophe à bande dorsale noir	*Cephalophus dorsalis*	Isso	So	B	NT	Throughout	Common
Ogilby's duiker	Cephalophe d'Ogilby	*Cephalophus ogilbyi*	Ibindi	So	B	LC	Throughout	Common
Blue duiker	Céphalophe bleu	*Philantomba monticola*	Hissiel	Iseie	C	LC	Throughout	Common
Yellow backed duiker	Céphalophe à dos jaune	*Cephalophus silvicultor*	Edindi	So-Kouha	B	NT	Throughout	Rare
Forest Elephant	Éléphant de forêt	*Loxodonta cyclotis*	Missek	Njök	A	CR	Concentrated in the centre-east of the forest but moves from South to North	Rare
Forest Buffalo	Buffle nain	*Syncerus caffer nanus*	Gnéit	–	B	NT	Living memory	Extirpated
Leopard	Leopard	*Panthera pardus*	–	Likok-Linjêl	A	VU	Living memory	Extirpated
African Golden cat	Chat doré	*Caracal aurata*	–		A	VU	Living memory	Extirpated
African palm civet	Nandinie	*Nandinia binotata*	–	Ba'ah	C	LC	Throughout	Common
African civet	Civette d'Afrique	*Civettictis civetta*	Mib-kitsop	Simbangoa	B	LC	Sporadic	Rare
Genet species	Genette	*Genetta* spp.		Mbanhée	B	LC	Sporadic	Rare
Black-foooted mongoose	Mangouste à pattes noires	*Bdeogale nigripes*	Idoutou	Mbaghé	C	LC	Throughout	Common
Other forest mongooses	Mangouste	Herpestidae	Gwanbaké	Mbaghé	C	–	Throughout	Common
Brush-tailed porcupine	Porc-épic ou Athérure africain	*Atherurus africanus*	Miquike	Nyik	C	LC	Throughout	Common
Cane rat	Aulacode (Hérisson)	*Thryonomys swinderianus*	Sakak	Mbép	C	LC	Large distribution in the forest, found almost everywhere	Common
Forest giant pouched rat	Rat d'Emin	*Cricetomys emini*	Meloh	Kôsi	C	LC	Large distribution in the forest, found almost everywhere	Common
Giant pangolin	Pangolin géant	*Smutsia gigantea*	Ko-nomo	Jock-ka or Soso-ka	A	EN	Living memory only	Extirpated
Black-bellied pangolin	Pangolin à longue queue	*Phataginus tetradactyla*	Ya'ak-Atsik	Ka ńbongo nwèl	A	VU	Throughout	Common
White-bellied pangolin	Pangolin à écailles tricuspides	*Phataginus tricuspis*	Ya'ako	Ka	A	EN	Throughout	Common

monitored for this reason. Indirect threats such as climate change (Carvalho et al., 2020; Sesink Clee et al., 2015) and disease (Calvignac-Spencer et al., 2012; Huijbregts et al., 2003; Walsh et al., 2003) also pose a risk to fragile populations. More work should be done to understand and predict long-term responses to environmental change in the Ebo forest.

The encounter frequencies of some range-restricted primate species, including Preuss's red colobus, red-capped mangabey, drill and western gorilla have declined over the years (with very few or no records during the recce surveys) and there are increasing fears of local extirpation (Linder et al., 2021). Commonly encountered in the northwestern section of Ebo forest and the adjacent Makombe and Ndokbou forest from 2000 (Dowsett-Lemaire and Dowsett, 2001), Preuss's red colobus have not been observed in Ebo or adjacent forest since 2012, although a recent survey around Mont Sinai (south of Ndokbou forest) recorded vocalisations for the species (Bowers-Sword, 2020). Korup National Park seems to be the only hope for the long-term survival of Preuss's red colobus (Linder et al., 2021). Ebo was a stronghold for drills (Morgan et al., 2013) but the species' vulnerability to hunting and habitat destruction (Astaras et al., 2008) means they are now encountered only rarely. Fewer than 300 wild Cross River gorillas *Gorilla gorilla diehli* survive, and if determined to belong to this gorilla subspecies (Dunn et al., 2014), the Ebo gorillas may account for 5–8% of the global Cross River gorilla population. The geographical isolation of this gorilla population coupled with poaching and habitat destruction put the Ebo gorillas in particular peril.

In March 2020, the government of Cameroon designated the Ebo forest as two forest management units (FMU) for commercial logging. Despite national and international protests against the project, the decree classifying the forest as an FMU was signed and published on July 22nd 2020. It was feared that logging would destroy vital habitat and exacerbate hunting pressure on already vulnerable populations of great apes and other range-restricted and endangered species. However, more pressure on the government from grassroots communities and a wide range of national and international pressure groups led to the suspension of the initial decree on August 11th 2020. Different stakeholders, including concerned government departments (Ministry of Forestry and Wildlife, Ministry of Economy, Planning and Regional Development and the Ministry of the Environment, Nature Protection and Sustainable Development), major donor partners, NGOs and civil society organisations are now in consultation with grassroots communities and local councils to initiate an inclusive local land-use planning process. If negotiated well, this process could result in a more sustainable future for the people of Ebo and its biodiversity.

8. Conclusion

The Ebo forest retains an important mammal community and trends in sign encounter rates and occupancy estimates for forest elephant and chimpanzee suggest that populations of some of the threatened species appear to be stable, despite no formal legal protection of the site. Our results show that it is crucial to maintain the Ebo 'intact forest landscape' to protect the unique mammal communities and other biodiversity in the Cross-Sanaga-Bioko forest ecoregion.

CRediT authorship contribution statement

R.W. wrote the manuscript and analysed the data. R.W., E.E.A, A.A.A, M.K., V. R.V.N., D.M.M. and B.M. collected the data. F.M., B. M., E.A. and R.W. designed the survey methods and S.S advised on analytical approaches. All authors contributed critically to drafting the manuscript. We declare no conflicts of interest.

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.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2021.e01833.

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