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Quantifying the scale and socioeconomic drivers of bird hunting in Central African forest communities

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Abstract

Global biodiversity is threatened by unsustainable exploitation for subsistence and commerce, and tropical forests are facing a hunting crisis. In Central African forests, hunting pressure has been quantified by monitoring changes in the abundance of affected species and by studying wild meat consumption, trade and hunter behaviour. However, a proportion of offtake is also discarded as bycatch or consumed by hunters when working, which can be overlooked by these methods. For example, remains of hornbills and raptors are found regularly in hunting camps but relatively few birds are consumed in households or traded in markets. Hornbill and raptor populations are sensitive to small increases in mortality because of their low intrinsic population growth rates, however, the scale and socioeconomic drivers of the cryptic hunting pressure affecting these species have not been quantified. We used direct and indirect questioning and mixed-effects models to quantify the socioeconomic predictors, scale and seasonality of illegal bird hunting and consumption in Littoral Region, Cameroon. We predicted that younger, unemployed men with low educational attainment (i.e. hunters) would consume birds more often than other demographics, and that relative offtake would be higher than expected based on results from village and market-based studies. We found that birds were primarily hunted and consumed by unemployed men during the dry season but, in contrast to expectations, we found that hunting prevalence increased with educational attainment. Within unemployed men educated to primary level (240 of 675 respondents in 19 villages), we estimated an average of 29 hornbills and eight raptors (compared with 19 pangolins) were consumed per month during the study period (Feb - Jun 2015) in a catchment of *c.*1,135 km^2. We conclude that large forest birds face greater hunting pressure than previously recognised, and birds are a regular source of protein for men during unemployment. Offtake levels may be unsustainable for some raptors and hornbills based on life history traits but in the absence of sufficient baseline ecological and population data we recommend that a social-ecological modeling approach is used in future to quantify hunting sustainability.

Introduction

Overexploitation is the greatest immediate threat to global biodiversity (Maxwell et al. 2016; Benítez-López et al. 2017) and a growing hunting crisis threatens forest species, ecosystems and food security in Asia, Africa and South America (Milner-Gulland & Bennett 2003; Abernethy et al. 2013; Ripple et al. 2016; Benítez-López et al. 2017). For affected taxa, the direct consequences of excessive hunting are population declines and, in some cases, extirpation (Maisels et al. 2001). The indirect consequences are manifold and include the disruption of trophic cascades, reduced ecosystem functioning and changes in forest structure (Abernethy et al. 2013). For example, hunting of frugivorous birds and monkeys in Brazil's Atlantic rainforest reduced carbon storage capacity through the disruption of seed dispersal processes (Culot et al. 2017). Unsustainable hunting can therefore have wide reaching consequences for ecosystems and people who rely on forest resources for subsistence and commerce.

In Central and West Africa, where bushmeat (hereafter 'wild meat'; Milner-Gulland & Bennett 2003) hunting is ubiquitous, there has been a focus on quantifying offtake of commercially valuable taxa, with an emphasis on the trade and consumption of large-bodied mammals (Fa et al. 2000; Brashares et al. 2004; Cowlishaw et al. 2005; Fa et al. 2006; Supplementary Material in Benítez-López et al. 2017). However, the focus on commercial markets may have underestimated the diversity and abundance of hunted species because bycatch and local consumption (e.g. in villages or by hunters) is overlooked. Consequently, offtake of other less valuable taxa may have been underestimated (Trail 2007; Fa et al. 2011). Extensive surveys of wild meat markets in Ghana failed to detect large-scale hunting of fruit bats (Kamins et al. 2011) and in Cameroon relatively few birds are sold in markets (Fa et al. 2006) but birds are killed regularly by hunters (Whytock et al. 2016). In West Africa, raptors are sold as 'fetish' for use in traditional medicine, witchcraft and as wild meat (Buij et al. 2016), but total numbers are low relative to mammals (e.g. in Nigeria: Fa et al. 2006), and this may have led to complacency over the threat that hunting poses to birds in the region.

It is widely acknowledged that hunting threatens game birds, hornbills and raptors in Asian and South American tropical forests (e.g. Thiollay 2005; Dasgupta & Hilaluddin 2012; Beastall et al. 2016), but evidence from Central and West Africa is equivocal. In the Republic of Congo and Gabon, hunting had a minimal effect on hornbills relative to mammals, and hunting appeared to indirectly 'benefit' some frugivorous hornbills due to competitive release (Poulsen et al. 2011; Koerner et al. 2017). In contrast, White-breasted Guineafowl abundance was lower in hunted forests in the Ivory Coast (Walter et al. 2010). Improved access to firearms in recent years may have made birds and arboreal mammals more accessible to hunters in Central Africa, and demand for smaller taxa such as rodents and birds is expected to increase when populations of large-bodied mammals decline (Fa et al. 2000; Cowlishaw et al. 2005). Thus, even if birds have not historically been threatened by hunting pressure, hunting regime shifts could now pose a threat, particularly in heavily hunted areas (Benítez-López et al. 2017).

Rodents and small mammals such as blue duiker *Philantomba monticola* can tolerate high levels of hunting pressure (Cowlishaw et al. 2005), but hornbills and other relatively large-bodied birds are vulnerable to over-exploitation due to their slow life histories (Owens & Bennett 2000; Thiollay 2005; Sreekar et al. 2015). Known hunted species in Central Africa such as black-casqued hornbill *Ceratogymna atrata* and palm-nut vulture *Gypohierax angolensis* have low fecundity, producing a maximum of one (rarely two) offspring per annum, and population densities are intrinsically low (Stauffer & Smith 2004). Declines of other large-bodied birds with similar life-history traits also provide forewarning, and Africa's savannah vulture populations have undergone recent, continent-wide declines due to persecution and hunting for belief-based use and meat consumption (Ogada et al. 2015).

Contrary to SE Asia and S America, where commercial bird hunting is common (Thiollay 1984; Thiollay 2005; Beastall et al. 2016), in Africa the international and local trade of hornbill body parts is relatively small or almost non-existent, and hornbill skulls, feathers and other body parts are regularly discarded as wastage in forest hunting camps (e.g. in Cameroon). This suggests that, although hunting does occur, birds have relatively low commercial value (Whytock et al. 2016). Actually, hunters might consume birds instead of commercially valuable meat when working from forest camps, thus maximising profits (Whytock et al. 2016). However, hunters are reluctant to discuss potentially illegal activities for fear of recrimination, and establishing the scale and drivers of this cryptic, non-commercial hunting pressure is therefore challenging.

Here, we combined direct and indirect questioning, which gives respondents anonymity and prevents self-incrimination (Unmatched Count Technique: Nuno et al. 2013; Nuno & St John 2015), to quantify the scale, seasonality and socioeconomic drivers of bird hunting and consumption in Littoral Region, Cameroon. For comparison, we also quantified consumption of small mammals to compare relative offtake levels. Based on previous work in our study area, which found a relatively high number of bird remains discarded in forest hunting camps (Whytock et al. 2016), we expected that (1) birds would be hunted and consumed by younger, unemployed males with low educational attainment (i.e. the assumed demographic of hunters in our study area), and (2) bird offtake would be higher than estimated by market and village-based studies, assuming that most birds are consumed in the forest by hunters rather than sold commercially or extracted to villages.

Methods

Study area

Nineteen villages were surveyed in the Nkam and Sanaga Maritime departments of Cameroon's Littoral Region. Villages bordering the proposed Ebo National Park that use the forest for hunting were selected for surveys (ENP; Fig. 1). The ENP (*c.* 1,135 km^2) is characterised by lowland and sub-montane closed canopy forest, with subsistence farming and oil-palm plantations at its edge (Morgan 2008).

The Ebo Forest Research Project was established in 2005 and conducts a permanent programme of conservation research and education in the ENP and its surroundings. Local communities are therefore familiar with basic wildlife law in Cameroon. There has also been a highprofile increase in wildlife law enforcement in Cameroon during the past decade (Last Great Ape Organisation 2014) and very few hunters are thought to have the legal permits required to hunt wildlife or own a firearm (quantitative data unavailable). Hunters are therefore reluctant to discuss their activities for fear of prosecution.

Bird hunting prevalence

To quantify bird hunting prevalence, we used the Unmatched Count Technique (UCT: Droitcour 1991), which has been successfully used to quantify illegal hunting prevalence in East and Central African hunting communities (Nuno et al. 2013; Harrison et al. 2015; Nuno & St John 2015). We approached potential respondents ≥ 18 years old and asked if they would like to participate. A coin toss was used to randomly assign consenting respondents to a treatment or control group. We then used a scripted questionnaire (Supplementary Material) to record demographic variables (gender, age, place of upbringing, educational attainment and employment status) before asking two UCT questions, which were (1) How many of these activities do you do in the dry season? and (2) How many of these activities do you do in the wet season? The control UCT list included four non-sensitive activities, which were ‘transport commercial timber’, ‘buy from the market’, ‘farm work’ and ‘construction work’ and the treatment UCT list included the additional sensitive activity ‘hunt birds with a slingshot or gun’. Questionnaires, historic census data for the study area and additional information on the UCT method are given in Supplementary Material.

The UCT is dependent on respondents’ understanding and willingness to participate. We therefore asked respondents if the questionnaire was easy to understand, if they felt anonymous, and if they felt comfortable answering the questions. The interviewer also assessed how well respondents understood the interview, how willing they were to participate, and if they were perceived to be honest.

Surveys were conducted from February to June 2015, partially covering the dry and wet seasons, from Feb – Mar and Apr – Jun, respectively. A total of 789 people was approached in 19 villages, and ten individuals (1.27%) declined to participate. We excluded questionnaires with missing data, leaving a sample size of *n* = 675 questionnaires (*n* = 136 female control, *n* = 156 female treatment; *n* = 167 male control, *n* = 216 male treatment). The mean number of respondents questioned per village was 35.5 ±7.7 SE, and the mean number of interviews per month was 135 ±47.9 SE. Interviews lasted for a median of 7 minutes (range 1 – 25, Q1 = 4, Q3 = 10 minutes). Summary statistics for all questionnaire data are given in Table S1.

Bird consumption

Although illegal hunting activities are considered sensitive, *consuming* wild meat is generally considered non-sensitive. For example, confiscated meat is auctioned to the public by authorities for consumption rather than wasted, and many common taxa (e.g. tree pangolin *Phataginus tricuspis*) are openly consumed in villages and restaurants without fear of recrimination. We therefore used direct questioning to estimate bird consumption. We also quantified consumption of small mammals to allow us to compare bird offtake relative to better-studied species.

Respondents were asked to estimate the number of meals in the past week (none, 1 – 5, 6 – 10 or > 10) that contained meat from seven wild meat species or groups (*n* = 4 birds, *n* = 3 mammals). The list included three bird species considered vulnerable to hunting pressure because of their large body size (Ingram et al. 2015) and that have been recorded by previous wild meat studies in Cameroon (Whytock et al. 2013); palm-nut vulture, black-casqued hornbill and white-thighed hornbill *Bycanistes albotibialis*. These were also considered easy to identify using local names. A fourth bird group, ‘eagle’, was included to cover large raptors that were considered difficult for respondents to accurately identify to species level (i.e. Cassin’s hawk eagle *Aquila africana*, crowned eagle *Stephanoaetus coronatus*, European honey buzzard *Pernis apivorus* and African harrier hawk *Polyboroides typus*). The list of mammals included three species’ groups (squirrel, rat, and arboreal pangolins) chosen because they are openly consumed throughout the study area.

Ethics statement

We followed the Code of Ethics of the American Anthropological Association 2009. Before answering the questionnaire, all respondents were given a clear explanation of the study's purpose and asked if they would like to participate (Supplementary Material). All data were collected anonymously, and the names of participating villages have been anonymised to reduce ethical concerns (St John et al. 2016). No formal ethics approval was received as the study was conceived and funded independently, but it was judged to be ethically sound by reviewers of funding applications and by collaborators from the authors' respective institutions. Research was conducted with permission from Cameroon's Ministry of Scientific Research and Innovation, permit number 045/MINRESI/B00/C00/C10/nye.

Data analysis

Bird hunting prevalence

We used linear mixed effects models to analyse UCT data. The baseline, average hunting prevalence in the population was first estimated for each UCT question by including card type (treatment or control) as a fixed effect and *n* list items as the response. Village was included as a random intercept to account for pseudoreplication (n = 19 villages). Prevalence was calculated as the percentage change from the intercept (control card) to the estimate for the treatment card (n = 675 respondents).

For each UCT question, we examined the effects of gender, age, place of upbringing, educational attainment and employment status on the response (*n* list items) by constructing models with two-way interactions between card type (treatment or control) and each demographic variable to calculate the prevalence of the sensitive activity. Village was included as a random intercept to account for pseudoreplication. We also initially included *n* years in the current village as a fixed effect but it was highly correlated with age (r = 0.63), and since the effects of these two variables would likely be indistinguishable in the model only age was retained in the analysis.

To select the 'best' demographic model we generated all possible fixed effect combinations and compared model fit using corrected Akaike Information Criterion (AICc) (Burnham & Anderson 2002). Models were only considered where interactions between card type and demographic variables were present alongside their constituent main effects (n = 33 models). Confidence intervals (95%) were bootstrapped from 500 re-samples. Where confidence intervals did not include zero this was considered strong evidence of an effect and its direction.

A key assumption of the UCT is that the addition of the sensitive item in the treatment list does not influence the way in which participants respond to the control items (design effect). We tested for this using the ict.test function in the R package list (Blair & Imai 2010) before conducting analyses, finding no evidence of an effect (H_0 = no design effect, $P > 0.05$).

Bird and mammal consumption

Most respondents indicated that relatively few meals (none or 1 - 5) per week contained meat from a given species (Fig. S1), and we modelled the effects of season and demographic variables on wild meat consumption using a binomial generalised linear mixed effects model. A global model was constructed with wild meat (i.e. birds and mammals combined) consumed in the past week (yes or no) as the response variable (7 species x 675 respondents = n 4725 yes or no answers), month (i.e. month of questioning) as a categorical fixed effect and demographic variables as categorical fixed effects (other than age, which was continuous). Species and village were included as random intercepts. The full model did not converge and we chose to exclude place of upbringing to reduce the model's complexity, and because most individuals originated from the Littoral Region (Table S1). To quantify how demographic factors differentially affected bird and mammal consumption, we included two-way interactions between each of the demographic variables and a binary categorical variable 'bird or mammal', expecting mammals to be consumed more often than birds in the general population. The best model was selected using ΔAICc as described for the UCT analysis, with the criteria that demographic factors were only considered alongside their interactions, and likewise interactions were not considered without their constituent main effects. This constrained the total number of possible models to $n = 32$. To estimate the probability of consuming a given species we extracted the conditional modes of the intercept from the random intercept term for species.

Conditional modes of the intercept were also used to estimate the number of carcasses consumed per month by the most common class of respondent in the dataset (unemployed male educated to primary level, $n = 240$ individuals). This was done by first calculating the total number of meals consumed per week for each species based on consumption probability estimates, then multiplying the result by 50. This was assuming 50 g of meat per day based on Cameroon's per capita meat carcass availability in 2013 (14.5 kg per person per year or approximately 40 g of meat per day) from the Food and Agriculture Organization of the United Nations' data (www.fao.org/faostat). We adjusted this figure to 50 g because meat consumption in our study area (forest zone) is likely to be higher than the average in Cameroon, which includes data from the Sahel. The final figure was extrapolated to estimate the total number of carcasses consumed per month based on average body mass estimates (Table S2) for each species or group (body mass estimates were taken from Fa et al. 2006 for mammals and del Hoyo et al. 2016 for birds). For 'rat' we used the body mass estimate for giant pouched rat *Cricetomys* sp. and for 'eagle' we averaged the mean adult body mass of Cassin's hawk eagle, crowned eagle, European honey buzzard and African harrier hawk. For pangolins, we used the body mass estimate for tree pangolin. R statistical software and the lme4 and MuMIn packages were used for analyses (Barton 2015; Bates et al. 2015; R Core Team 2015).

Results

Bird hunting prevalence

Bird hunting was a dry season activity and prevalence increased with educational attainment (Fig. 2, Fig. S2, Tables S3 & S4), reaching 12.1% in respondents educated to secondary level or above (n = 142 respondents). Models that included other demographic variables had little support (Tables S3 & S4).

Bird and mammal consumption

Probability of wild meat consumption (i.e. mammals and birds combined) in the previous week was best explained by the full model that included interactions between taxa (bird or mammal) and each of the demographic variables (age, employment status, education level, gender and month) (Tables 1 & S5 Fig. 3). As expected, mammals were consumed more often than birds (Fig. 3).

Mammal consumption increased slightly with age although the effect was small (Table 1), and age had almost no detectable effect on bird consumption (Figs. 3a & 3b). We detected a weak relationship between educational attainment and mammal consumption, but the interaction between educational attainment and taxa showed that bird consumption was significantly lower when respondents were educated to secondary level or above, which contradicted results from the unmatched count technique (Figs. 3c & 3d). For both birds and mammals, the main effect of employment status showed that consumption was lower when respondents were employed (Figs. 3e & 3f).

In agreement with expectations, bushmeat (birds and mammals combined) was consumed more often by men. The interaction between taxa and gender showed that the difference in consumption between men and women was more extreme for birds, although the effect was marginally non-significant (Figs. 3g & 3h; Table 1). Seasonally, the probability of consuming both birds and mammals declined as the wet season progressed from February to May, before peaking again in June (Figs. 3i & 3j). The interaction between taxa and month showed that bird and mammal consumption did not differ significantly in February and June, but mammals were consumed more frequently in March, April and May.

Offtake estimates for individual species or groups

Among birds, hornbills were consumed in the greatest numbers, with an estimated average of approximately 17 black-casqued hornbills and 12 white-thighed hornbills consumed per month in the catchment by the 240 unemployed males educated to primary level (Fig. 4). Raptors were consumed in lower numbers by this demographic, with an average of seven palm-nut vultures and one ‘eagle’ consumed per month. Squirrels were the most frequently consumed mammal in this group of respondents, followed by rats and pangolins, respectively (Fig. 4).

Respondent understanding

All respondents found the interview easy to understand and 99% felt anonymous. For respondent comfort, 60.6% felt uncomfortable after answering questions. This was close to expectations given that 55.1% of respondents were shown the treatment card with the illegal activity. The interviewer also reported high levels of perceived comprehension, willingness to answer and honesty (Table S1).

Discussion

Results show that bird hunting and consumption are widespread and occur at relatively high levels in Cameroon’s Littoral region, and estimated annual offtake exceeds that estimated by previous surveys of hunting camp wastage, wild meat sales and village offtake (c.f. Table 1 in Whytock et al. 2016). Evidence from hunting camp surveys (*n* = 13 camps surveyed for one year) suggested that approximately two white-thighed hornbills and 1.5 black-casqued hornbills are killed per month in the ENP on average (Whytock et al. 2016). In contrast, our results indicate these figures could be as high as 12 and 17 individuals per month, respectively, based on the estimated numbers consumed by 240 male respondents (36% of 675 total respondents). Despite these high offtake levels, relatively few hornbills have been recorded as wild meat in Cameroon and elsewhere in Central Africa (Abernethy et al. 2013; Supplementary Material in Benítez-López et al. 2017), thus highlighting the low-profile and hidden nature of bird hunting in the region. More generally, relative offtake estimates showed that during some months (particularly February and June) unemployed men consumed black-casqued hornbills and white-thighed hornbills as often as rats and pangolins (Fig. 4), indicating that wild birds are an important source of protein for this demographic.

Previous research in the ENP suggested that hunters consume birds instead of commercially valuable species in forest camps (Whytock et al. 2016), perhaps to maximise profits. This is supported by our results, which show that birds are rarely consumed by educated women in employment but commonly consumed by unemployed men, probably when hunting and living in the forest for long periods. This could also explain why so few birds are recorded during studies of bushmeat offtake in villages and markets, which often fail to account for social desirability bias or evasive responses to direct questioning (Nuno & St John 2015).

Bird hunting and consumption were predominantly dry season activities, but a peak occurred during the wet season in June. Although average monthly rainfall in June is high, in southern Cameroon there is a brief dry period at the beginning of the month (Stauffer & Smith 2004). Thus, hunters may be exploiting improved weather conditions and maximising their efforts during this time. Most households also rely on locally farmed cassava *Manihot* sp., plantain *Musa* x *paradisiaca*, yam *Dioscorea* sp. and other crops for subsistence, and domesticated meat (chicken, pork) and fish are also consumed regularly. Bushmeat hunting is known to fluctuate in response to the seasonal availability of other food sources (Milner-Gulland EJ & Bennett 2003), and this might also explain the seasonal patterns in bird hunting and consumption seen here.

The timing of the peak in hunting activities is concerning, however, since longitudinal studies of both black-casqued and white-thighed hornbills in Cameroon show that breeding occurs in June (Stauffer and Smith 2004), when females are likely to be confined to nest cavities and males provisioning food. High levels of hunting during this stage of the reproductive cycle could therefore reduce fecundity and population viability through the selective killing of provisioning males or, if hunters are raiding nests, the loss of adult females and young.

Results from UCT questioning suggested that bird hunting prevalence was positively correlated with educational attainment, whereas direct questioning contradicted this finding and showed that consumption declined as educational attainment increased. We suggest this contradictory result is due to social desirability bias, and better educated individuals probably gave evasive responses to direct questions. Thus, the anonymity provided by the UCT method revealed higher levels of hunting prevalence in this demographic. This is supported by similar work in Tanzania that also found hunting prevalence increased with educational attainment using the UCT method (Nuno et al. 2013). The link between education and hunting prevalence therefore requires further investigation. For example, do young men in education use hunting to pay for school fees and living costs, or to pay for non-essential items such as alcohol and cigarettes (Coad et al. 2010)? Or, are educated individuals generally wealthier and therefore able to afford a gun? Alternatively, can cultural reasons explain why educated individuals hunt birds, such as a reduced influence of cultural taboos? Answering these questions could prove valuable for socioeconomic initiatives aimed at decreasing hunting pressure through improved access to education and economic development.

Life-history and demographic data for affected species is sparse, making it difficult to assess hunting sustainability and population trends. Raptors were found at lower densities in hunted vs non-hunted forests in French Guiana (Thiollay 1984), and Asian forest hornbills have undergone widespread declines due to hunting pressure (Dasgupta & Hilaluddin 2012; Beastall et al. 2016). We therefore speculate that populations of large-bodied raptors and hornbills are also declining in our study area, and comparisons can be made with species that share similar life-histories. For example, population viability analysis for the Egyptian vulture *Neophron percnopterus*, which shares broad life-history traits with the raptors included in this study, showed that small reductions in survival rates of territorial and non-territorial birds (-0.015 and -0.008, respectively) significantly decreased time-to-extinction (Carrete et al. 2009). Based on density estimates from the literature, the ENP could support approximately 1702 palm-nut vultures (two pairs / km^2 and a juvenile population equal to 50% of the adult population; del Hoyo et al. 2016). Our estimates of *c.*84 individuals killed per annum (5% of the population) would therefore represent a reduction in survival of -0.05, five times greater than that needed to decrease Egyptian vulture time to extinction.

Crowned eagles (IUCN Near Threatened), which are also known to be hunted in the study area (Whytock & Morgan 2010) have a much slower generation time than palm-nut vultures, maturing at *c*.5 years of age and requiring *c*.500 days to produce a single offspring, and are already considered rare in the ENP (Whytock & Morgan 2010). Therefore, even if only 20% (n = 2.4 individuals) of the approximately 12 'eagles' consumed per annum were crowned eagles this level of offtake would be sufficiently high to have a negative impact on populations. Black casqued and white-thighed hornbills have a more rapid generation time and are more abundant than large raptors in the ENP (Whytock & Morgan 2010). However, nest success rates for both species show high inter-annual variation linked to fruit availability, and within a 25 km^2 study area in Central Cameroon the number of active nests ranged from 0 to 38 per annum over a four-year period (Stauffer & Smith 2004). Alongside greater hunting pressure during the breeding season, these stochastic breeding cycles probably increase population sensitivity to hunting pressure.

Quantifying hunting sustainability in complex socio-ecological systems is challenging in general (Akçakaya et al. 2011; Van Vliet et al. 2015; Woodhouse et al. 2015), and inadequate assessments not only run the risk of overestimating sustainability, potentially resulting in overexploitation, but also risk harming the livelihoods and wellbeing of resource users if estimates are overly conservative (Woodhouse et al. 2015). Dynamic modeling techniques and agent-based models can offer novel insights by incorporating individual and spatial uncertainties in decision-making, for example from imperfect population monitoring (Van Vliet et al. 2015, Bunnefeld et al. 2017). Given the likely vulnerability of affected birds based on their life histories (Owens & Bennett 2000; Sæther & Bakke 2000; Trail 2007; Sreekar et al. 2015), the secretive nature of hunting activities, and because birds appear to be an important source of protein for unemployed men, we have avoided making a simplistic assessment of hunting sustainability here and recommend that future work firstly begins to monitor populations trends of affected species in the study area, and secondly investigates hunting sustainability using the suggested modeling techniques.

Conclusion

There is an urgent need to quantify hunting sustainability and to assess the population status of affected birds throughout their Central African range. Pending further assessment in other locations and in light of other threats such as habitat loss, we recommend that palm-nut vulture, black casqued hornbill and white-thighed hornbill are re-classified as Data Deficient (from Least Concern) by the International Union for the Conservation of Nature's Red List of Threatened Species™.

Biodiversity and livelihoods are threatened by unsustainable resource use in West and Central African forests. By providing respondents with anonymity and combining direct and indirect questioning techniques, our results reveal widespread, cryptic hunting of non-commercial taxa in Cameroon's forest communities.

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Table 1. Parameter estimates (log odds, difference from the intercept) from the top generalised linear mixed effects model explaining the probability of wild meat consumption in the past week.

Variable	**Estimate**	**SE**	**Z**	**P**
Intercept*	-0.58	0.81	-0.72	0.47
Employment (employed)	-2.39	1.03	-2.33	0.02
Employment (temporary)	-0.06	0.37	-0.15	0.88
Education (secondary+)	-1.01	0.26	-3.86	< 0.001
Education (no formal)	-0.30	0.26	-1.14	0.26
Gender (female)	-0.74	0.16	-4.55	< 0.001
Month (March)	-1.20	0.29	-4.14	< 0.001
Month (April)	-0.84	0.61	-1.37	0.17
Month (May)	-2.57	0.59	-4.38	< 0.001
Month (June)	0.35	1.06	0.33	0.74
Taxa (mammal)	1.42	1.04	1.37	0.17
Age	-0.01	0.01	-0.88	0.38
Education (secondary+):taxa (mammal)	0.81	0.31	2.64	0.008
Education (no formal): taxa (mammal)	-0.52	0.33	-1.59	0.11
Taxa (mammal):age	0.01	0.01	1.70	0.09
Taxa (mammal):month (March)	2.00	0.35	5.79	< 0.001
Taxa (mammal):month (April)	0.91	0.29	3.18	0.001
Taxa (mammal):month (May)	1.40	0.31	4.47	< 0.001
Taxa (mammal):month (June)	0.56	0.52	1.09	0.28
Taxa (mammal):employment (employed)	0.83	1.07	0.78	0.44
Taxa (mammal):employment (temporary)	-0.41	0.43	-0.97	0.33
Taxa (mammal):gender (female)	0.36	0.20	1.82	0.07

*Intercept: February bird consumption estimate for male educated to primary level and unemployed in the past 12 months

Figure 1. Proposed Ebo National Park (shaded, inset) and departments (dashed lines, inset) in Littoral Region, Cameroon. Locations of villages surveyed are not shown for ethical reasons (St. John et al. 2016).

Figure 2. Education level and the estimated prevalence (filled circle ±95% CI) of bird hunting during the dry season. The estimated baseline prevalence (gray circle ±95% CI) for the population is also shown.

Figure 3. Effects of season, socioeconomic and demographic factors on the probability of consuming a wild bird or mammal in the past week estimated from the generalised linear mixed effects model for bird consumption. Estimates and confidence intervals have been back-transformed to the probability scale, and summary statistics for the model are given in Table 1. Densities of raw data points for yes (1) or no (0) answers are also shown.

Figure 4. Estimated number of individuals consumed (assuming 50 g of meat per meal) per month for each species or species group (conditional modes of the intercept ±95% CI from a generalised linear mixed effects model for bird consumption) by unemployed males educated to primary level (*n* = 240 respondents). Non-focal fixed effects were set to their median value for continuous variables or most common level for categorical variables. Dashed gray lines show the estimated mean monthly offtake. The y-axis is on a log-scale.

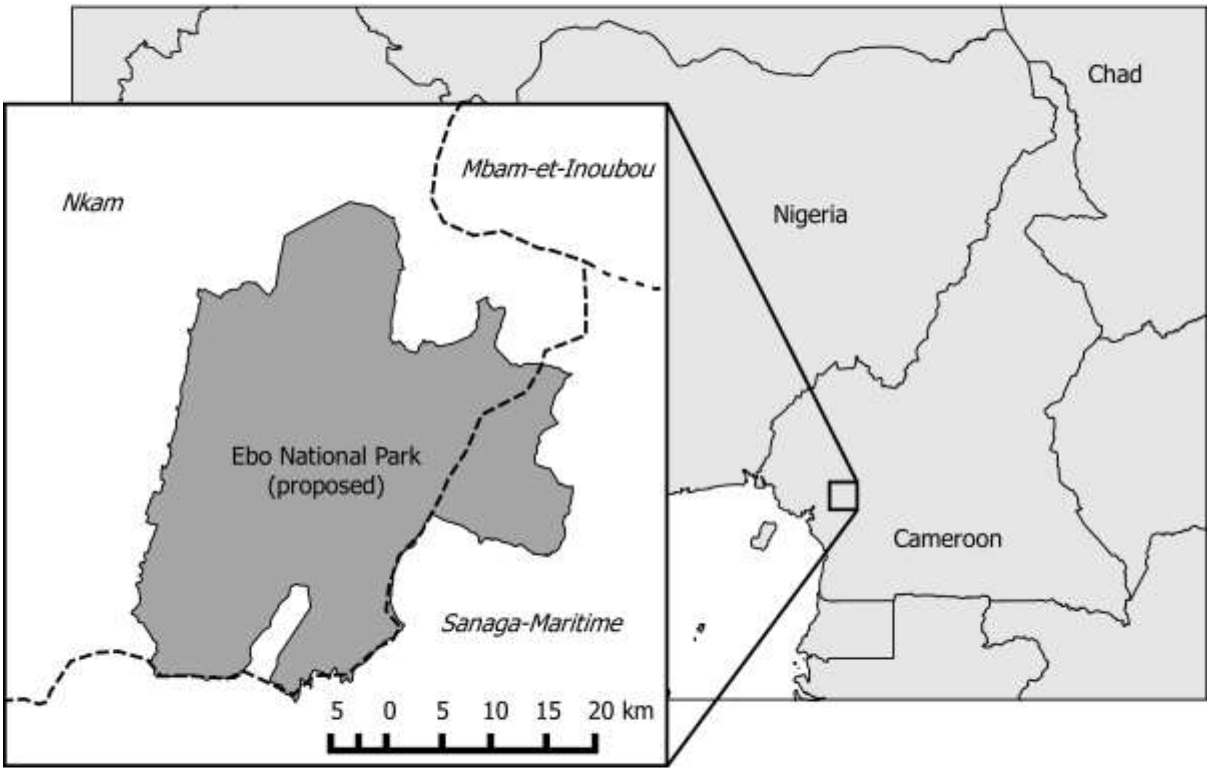

Chad
Nigeria
Cameroon
Nkam
Mbam-et-Inoubou
Ebo National Park
(proposed)
Sanaga-Maritime
5 0 5 10 15 20 km

Figure 1

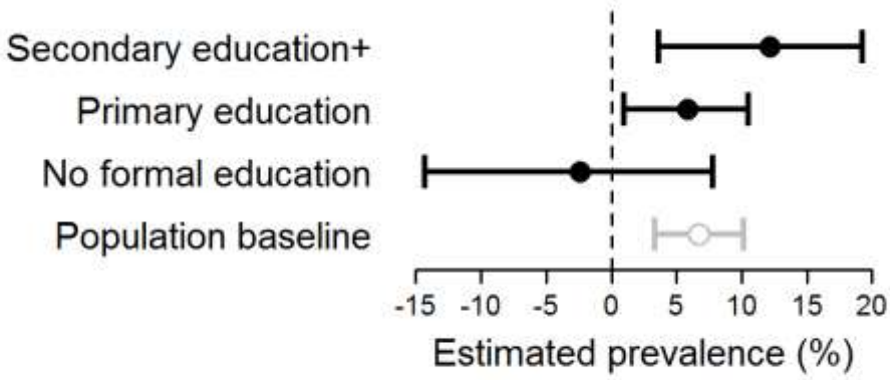
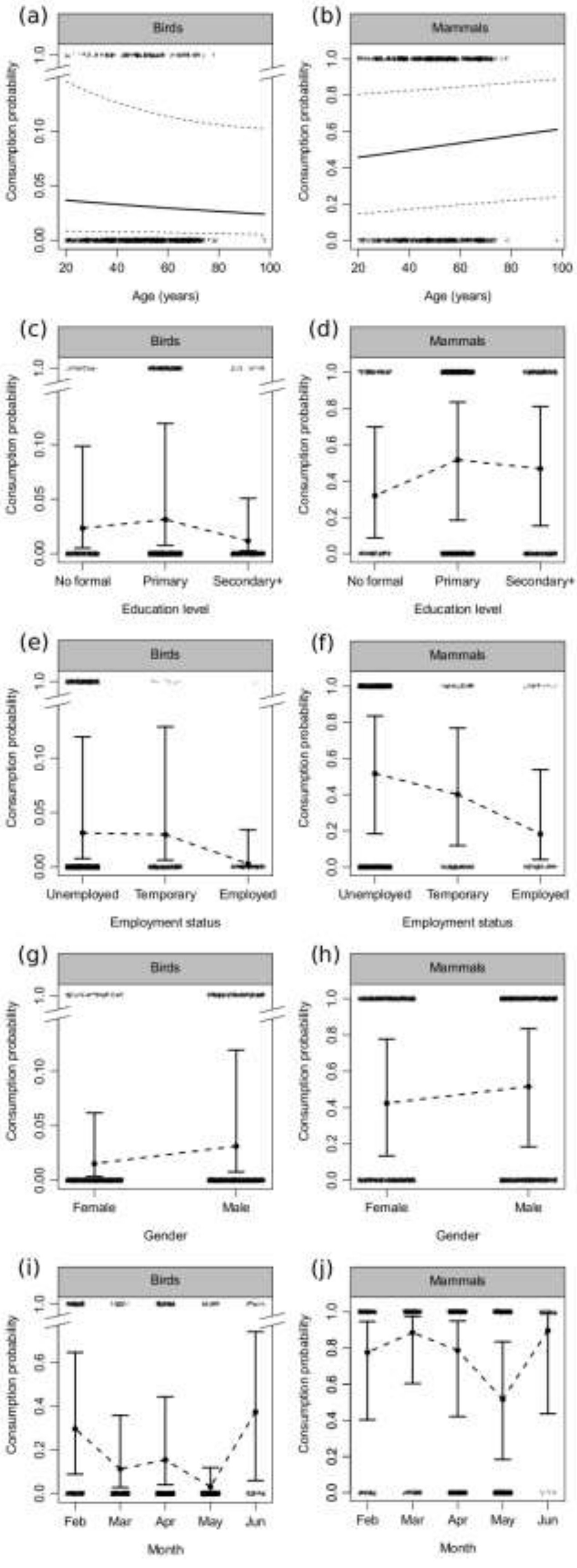

Secondary education+
Primary education
No formal education
Population baseline
-15 -10 -5 0 5 10 15 20
Estimated prevalence (%)

Figure 2



(a)
Birds
Consumption probability
Age (years)
(b)
Mammals
Consumption probability
Age (years)
(c)
Birds
No formal
Primary
Secondary+
Education level
(d)
Mammals
No formal
Primary
Secondary+
Education level
(e)
Birds
Unemployed
Temporary
Employed
Employment status
(f)
Mammals
Unemployed
Temporary
Employed
Employment status
(g)
Birds
Female
Male
Gender
(h)
Mammals
Female
Male
Gender
(i)
Birds
Feb
Mar
Apr
May
Jun
Month
(j)
Mammals
Feb
Mar
Apr
May
Jun
Month

Figure 3

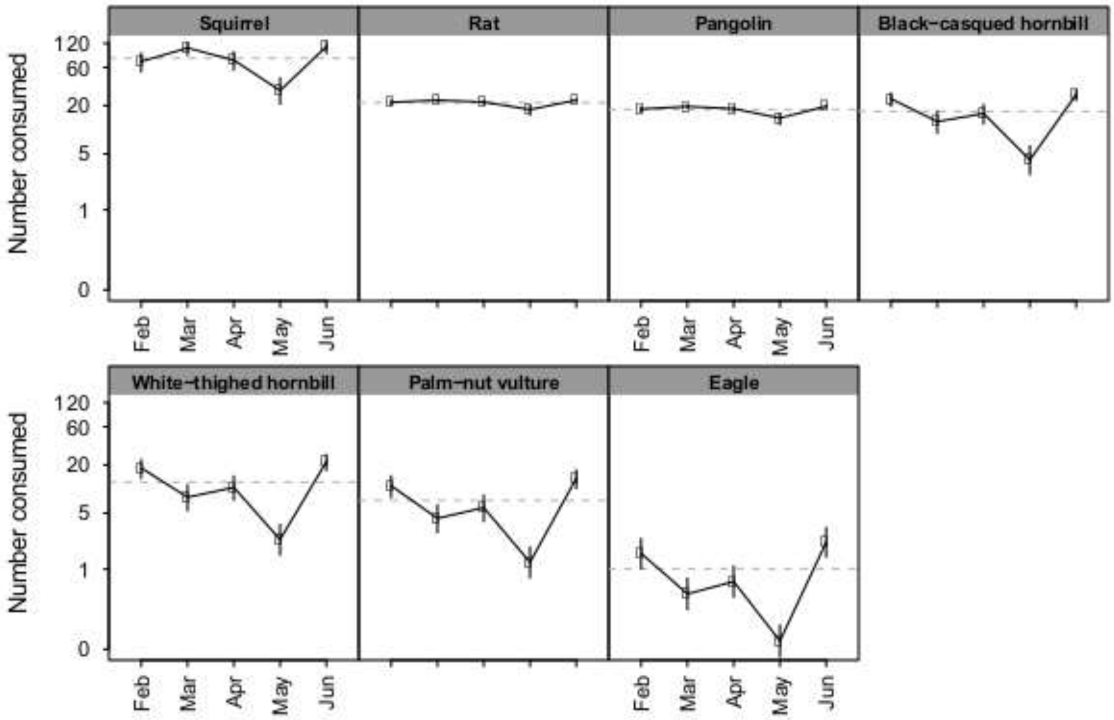

Squirrel
Rat
Pangolin
Black-casqued hornbill
White-thighed hornbill
Palm-nut vulture
Eagle
Number consumed
120
60
20
5
1
0
Feb
Mar
Apr
May
Jun

Figure 4