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Primate Communities Along a Protected Area Border: A Two-site Comparison of Abundance and Hunting Response in Bioko, Equatorial Guinea

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Abstract: Bioko Island, Equatorial Guinea is home to seven diurnal primate taxa, threatened with extinction largely due to high rates of illegal bushmeat hunting. The Gran Caldera Scientific Reserve (GCSR), one of two protected areas on Bioko, is the only remaining site where all seven taxa can be found. Historically, much of the wildlife in the GCSR has been passively protected due to its isolation, but a lack of effective law enforcement has allowed hunting to proliferate, and recent road and infrastructure development threatens more hunting in the future. Many calls have been made for the development of a comprehensive management plan to effectively protect the GCSR, but data are needed to understand the dynamics of the varying human-wildlife systems along its borders to develop well-informed and cost-effective management strategies. This study investigated the abundance and species richness of primates along the GCSR border near the village of Moka over four years (2011-2014), and compared results to those of a previous study near a similar GCSR-border village, Belebu. Although we found considerable inter-annual variation in the relative abundance of primates at Moka, the overall relative abundance there was significantly higher than at Belebu. We attribute this primarily to the higher observed hunting intensity at Belebu, differences in historical hunting patterns and accessibility, and the presence of a long-term research site and activities at Moka, which may deter hunters in the area. Further research is needed to provide greater resolution on complementary factors influencing abundance and distribution patterns. However, our results highlight the persistence of a notable primate community near Moka and emphasize the importance of understanding dynamics along protected area borders when planning for conservations. Relatively similar sites may require different approaches for effective management.

Key words: Bioko, hunting, bushmeat, surveys, protected areas

INTRODUCTION

Bushmeat, or the meat of wildlife from forests, has long been a dietary staple of people in tropical African forests (Asibey 1977; Afolayan 1980; Fa *et al.* 2002; Robinson & Bennett 2004). While wild harvest can be a sustainable and accessible protein-source (Albrechtsen *et al.* 2007), accelerating human population growth, increased use of firearms, and greater accessibility to remote forests has led to the commercialization of the bushmeat trade (Abernethy *et al.* 2013; Albrechtsen *et al.* 2007; Fa *et al.* 2005; Ziegler *et al.* 2016). The rapid growth of the bushmeat trade now threatens many taxa with

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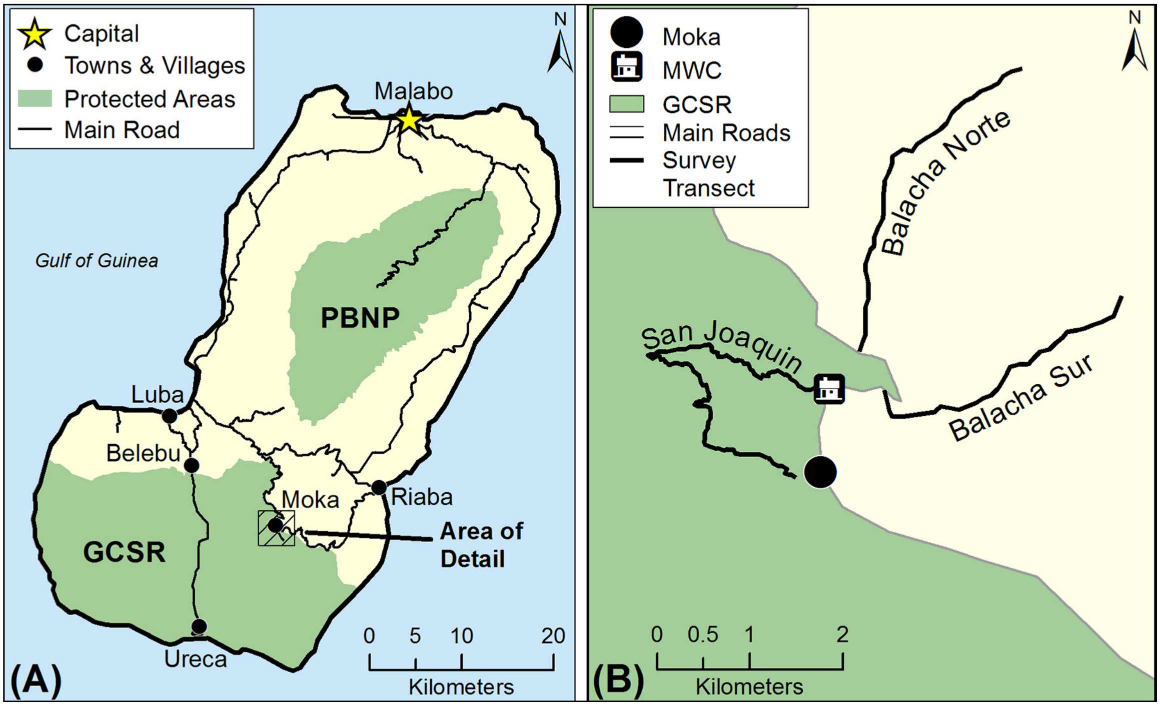

Figure 1. (A) A map of Bioko Island, Equatorial Guinea, including the study sites, major towns and roads, and Bioko's two protected areas: Pico Basilé National Park (PBNP), and the Gran Caldera Scientific Reserve (GCSR). Ureca, the only village within the GCSR is also shown. (B) A magnification of the Moka study area and the survey transects used to assess primate abundance and hunting pressure.

extinction (Oates *et al.* 2004). In central Africa, hunting is one of the leading causes of decline of most larger-bodied mammals, especially primates and ungulates (Oates *et al.* 2004). Diurnal primates are among the most heavily hunted taxonomic groups in the region, comprising approximately 10-20% of carcasses recorded in market studies (Fa *et al.* 2000, 2006; Cronin *et al.* 2015). Extinction or decline of primate species can lead to negative cascading ecological effects in their communities (Wright *et al.* 2000, 2007; Abernethy *et al.* 2013, Effiom *et al.* 2013). Many primates have a primarily frugivorous diet, and thus provide crucial ecosystem maintenance functions, such as seed dispersal (Chapman & Onderdonk 1998; Lambert 2001; Poulsen *et al.* 2001, 2002). Tree diversity in hunted forests is lower than in non-hunted forests, and their composition is significantly different from non-hunted forests, largely due to the absence of large-bodied frugivores (e.g., primates) (Sork 1985; Chapman & Chapman 1996; Chapman & Onderdonk 1998; Effiom *et al.* 2013) .

Bioko Island, Equatorial Guinea (Figure 1) is home to numerous endemics, namely, six diurnal primate subspecies, and one endemic primate species (Table 1), all of which are threatened with extinction (IUCN 2016). The primary threat to these species is bushmeat hunting to supply the capital city of Malabo, where there is a large, thriving bushmeat market (Fa *et al.* 2000; Albrechtsen *et al.* 2007; Cronin *et al.* 2015). Over 100,000 kg of bushmeat are consumed annually on Bioko alone, according to several estimates (Fa *et al.* 2000; Albrechtsen *et al.* 2007), of which primates comprise approximately 20% of all carcasses (Cronin *et al.* 2015). While the causes of decline in diurnal primates on Bioko are well established, government led conservation efforts and management plans on Bioko have yet to lead to any profound successes, despite a presidential decree that bans primate hunting (Republic of Equatorial Guinea 2007). Approximately 40% of the island falls within the borders of two protected areas, giving Bioko great potential for conservation. The protected areas, however, have done little to impede hunting, as protected area borders are not well-marked, and environmental legislation is not strongly enforced (Colell *et al.* 1994; Cronin *et al.* 2010; 2016; Grande-Vega *et al.* 2013, 2016). Over time, the threat to primates on Bioko has continued to increase, due to an increase in hunting and demand for bushmeat (Butynski & Koster 1994; Fa 2000; Hearn *et al.* 2006; Cronin *et al.* 2010, 2015).

Table 1. Diurnal primate taxa present on Bioko Island, Equatorial Guinea and their IUCN Red List threatened category (IUCN 2016). Table adapted from Cronin *et al.* (2016).

Vernacular name	Binomial name	Red List category	
		Species	Subspecies
Bioko black colobus[a]	*Colobus satanas satanas*	Vulnerable	Endangered
Pennant's red colobus[a,b]	*Procolobus pennantii pennantii*	Critically Endangered	Endangered
Bioko drill[a]	*Mandrillus leucophaeus poensis*	Endangered	Endangered
Bioko Preuss's monkey[a,c]	*Allochrocebus preussi insularis*	Endangered	Endangered
Bioko red-eared monkey[a]	*Cercopithecus erythrotis erythrotis*	Vulnerable	Vulnerable
Crowned monkey	*Cercopithecus pogonias pogonias*	Least Concern	Vulnerable
Bioko putty-nosed monkey	*Cercopithecus nictitans martini*	Least Concern	Vulnerable

[a]Recognized by Grubb *et al.* (2003) as subspecies endemic to Bioko. [b]Recognized by Groves (2007) as a species (*Piliocolobus pennantii*) endemic to Bioko. [c]Allocated to the genus *Allochrocebus* following Grubb (2006).

Several previous surveys (Schaaf *et al.* 1990; Butynski & Koster 1994; Hearn *et al.* 2004; Cronin *et al.* 2013) focused primarily on remote areas of the island, and especially on areas within the GCSR. Primate abundance and hunting levels in areas bordering the reserve, however, have gone relatively understudied, with the exception of a brief study at Moka by Colell *et al.* (1994), undergraduate surveys as part of annual field courses at the Moka Wildlife Center (MWC) over the past decade, and surveys conducted by Cronin *et al.* (2016) at Belebu, another town bordering the GCSR. Colell *et al.* (1994) studied hunting in the Moka area by both surveying hunters and conducting hunter follows in 1992, finding that hunters more commonly used traps than guns, and that hunters gradually increased the length and extent of their hunting trips over the course of their study. At Belebu, Cronin *et al.* (2016) encountered dramatically fewer primates and more hunting signs than at other more remote sites, which was attributed to its long-term history of organized bushmeat hunting and transport and its close proximity to Luba, Bioko's second largest city.

This study makes use of student survey data from 2011-2014 at Moka, and incorporates data collected by Cronin *et al.* (2016) at Belebu to compare differences in primate abundance and hunting intensity between the two sites to inform conservation planning. We sought to: 1) describe primate abundance and species richness at Moka; 2) quantify the hunting intensity at the site, and, if possible, its impact on Moka's primate community (e.g., decreased abundance or reduced species richness); 3) compare data from Moka and Belebu to evaluate differences in primate abundance, species richness, and gun hunting between the two sites; and 4) provide recommendations to improve the efforts to conserve Bioko's primate populations.

METHODS

Study Area

Bioko Island, Equatorial Guinea (2017 km^2), a volcanic, continental island, located 37 km off of the coast of Cameroon (Figure 1), is a biodiversity hotspot and a key site for the conservation of African primate diversity (Oates 1996; Myers *et al.* 2000; Oates *et al.* 2004). Bioko spans an elevational range from 0-3,011 m asl, and a north-south precipitation gradient from 2,000 mm/year in the north to over 10,000 mm/year in the south (Font Tullot 1951; de Terán 1962). Two protected areas, Pico Basilé National Park (330 km^2; PBNP) and the Gran Caldera Scientific Reserve (510 km^2; GCSR), encompass approximately 40% of the island's land area. The GCSR encompasses the southern 25% of the island, which has far less human development and impact than the northern end of the island. Aside from the village of Ureka (< 80 individuals), no permanent human settlements exist within the GCSR.

This study took place near the village of Moka, located along the northeastern border of the GCSR at an elevation of 1,400 m asl on the eastern slope of Pico Biao. Moka is largely surrounded by an agricultural mosaic which transitions into montane forest away from the village. Annual precipitation at Moka is estimated to be 3,700 mm/year, with approximately 131 mm falling on average each November (when the surveys were conducted)

(Font Tullot 1951). Moka is a key agricultural site on Bioko, predominantly inhabited by the Bubi ethnic group, with an established history of hunting (Colell *et al.* 1994), although Bubis have restricted gun access (Butynski & Koster 1994; Grande-Vega *et al.* 2013). In recent years, agricultural activities have expanded greatly around the town (D.T. Cronin, pers. obs.), despite its location on the border of the GCSR.

Data Collection

Surveys were conducted from 2011 to 2014, between 04 November and 26 November of each year along established multi-use footpaths near the Moka Wildlife Center (MWC) (a facility operated by the Bioko Biodiversity Protection Program, an academic partnership between Drexel University and the National University of Equatorial Guinea). Reconnaissance ("recce") walk methodology (Walsh & White 1999) was used following Cronin *et al.* (2013, 2016) to travel more quickly, cover more ground, avoid unnecessarily cutting trails/ destroying habitat, and to increase the likelihood of primate encounters. In recce sampling, two to four researchers walk along the path of least resistance through the forest, following natural geographic features, and existing human and game trails to maintain a general compass bearing, and cutting vegetation only when necessary (Walsh & White 1999). Three recce transects were surveyed, San Joaquin, Balacha Sur, and Balacha Norte, all of which were approximately 4 km in length. Transects were measured and marked by researchers prior to beginning surveys using either a hip chain or 50 m tape measure. Surveys were conducted at a speed of approximately 1.15 km hr^{-1}, similar to the 1 km hr^{-1} rate established by Whitesides *et al.* (1988), and used in previous surveys on Bioko (Butynski & Koster 1994; Cronin *et al.* 2013, 2016). One transect was surveyed each day, twice per day (once in each direction), from approximately 0700–1100, and 1400–1800, unless faced with an extenuating circumstance (e.g., heavy rain). We alternated transects each day, in order to walk each transect an approximately equal number of times within our study period.

All survey data were collected by students trained by DTC (including DLF) and FM, who was present for all surveys, and recorded using a customized Cybertracker (v3.248) data collection program (Steventon 2002). Primate groups were counted to estimate relative primate abundance following Schaaf *et al.* (1990) and Cronin *et al.* (2013, 2016) due to difficulties associated with detection of hunted primates in steep terrain with dense vegetation (Whitesides *et al.* 1988). Upon each primate encounter, the following data were recorded: (1) time of observation (2) type of encounter (visual/ auditory), (3) location (GPS coordinates), (4) elevation, (5) species, (6) number of individuals, (7) sex of individuals, (8) vocalization type, (9) height in trees/canopy (Schaaf *et al.* 1990; Butynski & Koster 1994; Cronin *et al.* 2013). Any encounter within 50 m of the previous encounter was considered part of the same group (same species) or a polyspecific association, and was not recorded separately (Oates *et al.* 1990).

To quantify hunting pressure, any sign of hunting, such as shotgun shells, traps, batteries, hunting camps, carcasses, and gun shots were tallied categorically, and summed (Linder 2008; Cronin *et al.* 2013). Each individual sign was treated as a separate encounter, and no signs were collected to avoid detection, hostility from hunters, and hunter interference in data quality (picking up shotgun shells, batteries, etc.) (Linder & Oates 2011; Cronin *et al.* 2013, 2016).

Data Analysis

Sighting frequencies were calculated as the number of social groups, including solitary primates, sighted per kilometer of transect walked. We did not analyze the data to produce sighting frequencies of individuals, as estimating group size of primate groups in hunted forests is particularly unreliable (Ferrari *et al.* 2010), and previous primate surveys conducted on Bioko calculated group, not individual, encounter rates (Butynski & Koster 1994; Cronin *et al.* 2010, 2013, 2016). Sighting frequency (groups/km) is a measure of relative density, used in place of absolute density measurements (groups/ km^2) due to small sample sizes of each species and inherent difficulties in detecting hunted primates in dense forest (Fashing & Cords 2000; Marshall *et al.* 2008). Sighting frequencies and hunting sign encounter rates were compared to surveys conducted by Cronin *et al.* (2016) at Belebu, to compare abundance and hunting patterns between the two sites.

Primate sighting frequencies were compared among survey sites and years using the non-parametric test (Wilcoxon–Mann–Whitney test (Linder & Oates 2011; Cronin *et al.* 2013, 2016). The alpha level was set at 0.05 for all statistical tests and adjusted using Bonferroni correction procedures. All statistical analyses were conducted using R (v3.2.2; R Core Team 2015).

RESULTS

Sighting frequency and temporal change in Moka

The three transects were surveyed a total of 57 times (San Joaquin: 24 surveys - 81.28 km; Balacha Norte: 13 surveys - 46.66 km; Balacha Sur: 20 surveys - 70.26 km), resulting in a total survey effort of 198.2 km and 151 total encounters, for an average encounter rate of 0.75 groups/km. Visual identifications were confirmed for 119 encounters, resulting in a sighting frequency of 0.56 groups/km. Five of the seven diurnal primate species occurring on Bioko were encountered in the Moka area: *Cercopithecus erythrotis, C. pogonias, C. nictitans, Allochrocebus preussi,* and *Mandrillus leucophaeus*. The two colobine species present on Bioko, *Colobus satanas* and *Procolobus pennantii* were not encountered.

Overall sighting frequencies of all primate species each year in Moka were compared to every other year using the Wilcoxon–Mann–Whitney test. Sighting frequency was significantly higher in 2013 (0.82 groups/km) and 2014 (0.72 groups/km) than in 2011 (0.45 groups/km), and significantly higher in 2013 (0.72 groups/km) than in 2012 (0.37 groups/km) (Wilcoxon–Mann–Whitney: 2011-2013: $W = 101.5$, $p < 0.005$; 2011-2014: $W = 157$, $p < 0.01$; 2012-2013: $W = 61.5$, $p < 0.05$) (Table 2).

In all four years, *C. erythrotis* was the most frequently sighted primate (Table 2). In 2011, the only other primate species sighted was *M. leucophaeus* (Table 2). In 2012, the only other sighted primate species was *A. preussi* (Table 2). In 2013, three species were sighted at relatively low frequencies (*M. leucophaeus, A. preussi, and C. nictitans*) (Table 2). In 2014, three species were sighted, again, at relatively low frequencies (*M. leucophaeus, C. nictitans,* and *C. pogonias*) (Table 2; Figure 2).

Species richness in Moka

Species richness (i.e., the number of species encountered) varied by year, and by transect. More species were observed in 2013 and 2014 (4 species) than in 2011 and 2012 (2 species), but within years, the composition of species encountered varied among transects (Figure 2). The most species were observed on Balacha Sur in 2011 (2 species), 2013 (3 species), and 2014 (3 species) (Figure 2). In 2012, the most species were sighted on San Joaquin (2 species) (Figure 2). Across all years, the fewest species were sighted on Balacha Norte, as only *C. erythrotis* was sighted on this trail (Figure 2).

Hunting in Moka

Both gun hunting and trapping signs were encountered on all trails each year, with some

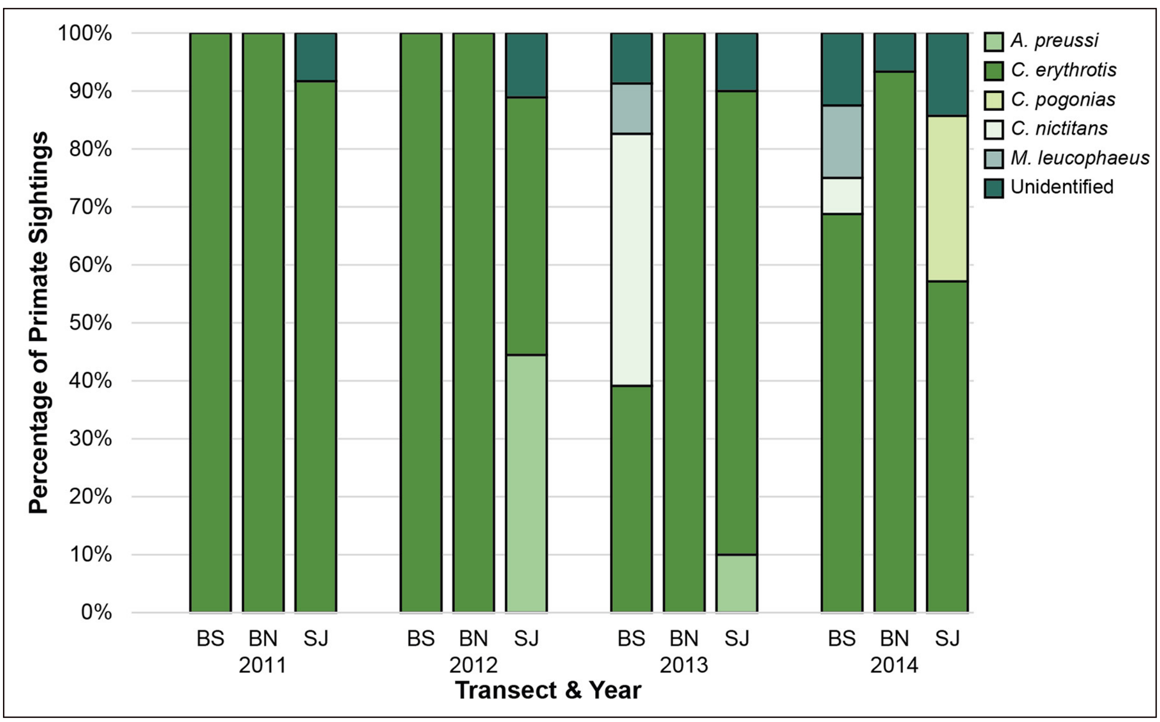

Figure 2. The percentage of each species sighted per transect per year during surveys in Moka from 2011 – 2014.

Table 2. Primate sighting data for each species from 2011 to 2014 (N = number of groups sighted, S.F. = sighting frequency (groups/km), % = percentage of all sightings).

Species[a]	Moka												Belebu*		
	2011			2012			2013			2014					
	N	S.F. (grps/km)	%	N	S.F. (grps/km)	%	N	S.F. (grps/km)	%	N	S.F. (grps/km)	%	N	S.F. (grps/km)	%
Cer	30	0.43 (0.10)	94	16	0.31 (0.078)	76	22	0.60 (0.19)	76	29	0.57 (0.16)	78	9	0.11 (0.045)	53
Cpo	0	0	0	0	0	0	0	0	0	2	0.042 (0.012)	5	6	0.047 (0.023)	35
Cni	0	0	0	0	0	0	1	0.023 (0.007)	3.5	1	0.021 (0.006)	3	0	0	0
Apr	0	0	0	4	0.085 (0.021)	19	1	0.026 (0.008)	3.5	0	0	0	1	0.007 (0.007)	5
Mle	1	0.014 (0.003)	3	0	0	0	2	0.047 (0.015)	7	1	0.021 (0.006)	3	0	0	0
Csa	0	0	0	0	0	0	0	0	0	0	0	0	1	0.016 (0.016)	6
Unk	1	0.14 (0.003)	3	1	0.016 (0.004)	5	3	0.085 (0.027)	10	4	0.08 (0.024)	11	0	0	0
Total	32	0.45 (.11)		21	0.39 (0.098)		29	0.82 (0.26)		37	0.72 (0.21)		17	0.18 (0.061)	

[a]Mle -*Mandrillus leucophaeus*; Csa - *Colobus satanas*; Ppe - *Piliocolobus pennantii*; Cer - *Cercopithecus erythrotis*; Cpo - *Cercopithecus pogonias*; Cni - *Cercopithecus nictitans*; Apr - *Allochrocebus preussi*.

variation by trail and year (Table 3). Hunting signs largely comprised of shotgun shells, followed by traps, batteries, and miscellaneous hunting signs (e.g., carcasses, entrails). The highest gun sign encounter rate occurred in 2013, with a considerable decrease in 2014 (Table 3). Snares were encountered an average of 4.07 times more frequently in 2011 and 2012 than in 2013 and 2014 (Table 3).

Differential species composition and sighting frequency per site

While species richness was comparable at both sites (Belebu, 4 species; Moka, 5 species), the overall primate sighting frequency was significantly higher at Moka (0.56 groups/km) than Belebu (0.18 groups/km) (Wilcoxon–Mann–Whitney: W = 534, p <0.00001) (Figure 3). All individual species sighting frequencies were higher at Moka, except for *C. satanas*, of which no sightings were made at Moka, while a single sighting occurred at Belebu resulting in a sighting frequency of 0.016 groups/km. Two species were sighted at Moka that were not sighted at Belebu (*M. leucophaeus*, 0.017 groups/km; *C. nictitans* 0.009 groups/km).

Differential response to gun hunting per site

Belebu (5.56 signs/km) had a higher overall hunting sign presence than Moka (1.22 signs/km), a higher gun sign encounter rate (Belebu, 2.89 signs/km; Moka, 0.83 signs/km), and a higher trap sign encounter rate (Belebu, 2.66 signs/km; Moka, 0.40 signs/km). Overall sighting frequency of primates was higher in Moka, where fewer hunting signs were encountered.

DISCUSSION

While several other studies have documented primate abundance and hunting pressure on Bioko Island and Cronin *et al.* (2015) assessed the impact of gun hunting on Bioko's diurnal primate species, this is the first study to highlight and assess relative abundance of primates and hunting pressure near two semi-urbanized towns on Bioko. Prior to this study, no primary data in the Moka area on Bioko was published. Overall primate sighting frequency was higher in Moka, where fewer hunting signs were encountered; however, differences in elevation (Cronin *et al.* 2016), distance from roads (Cronin *et al.* 2017) and habitat may also play a role, and require further research. A prominent hunting presence was revealed at both of the census locations in this study (Belebu, 5.56 signs/km; Moka, 1.22 signs/km). According to Cronin *et al.* (2015), primates have become a key portion of the bushmeat market in Malabo, the capital of Bioko.

Of Bioko's seven diurnal primate species, our surveys revealed the presence of five species persisting at Moka, and four at Belebu (Cronin *et al.* 2016). While species composition and abundance in our surveys varied from year to year, the regularity with which primates were encountered at Moka suggests that five species continue to persist in the area, and the comparably sparse encounters at Belebu suggests the contrary. *C. erythrotis* was the most commonly sighted species at Moka and Belebu, in accordance with previous studies on Bioko (Butynski & Koster 1994; Cronin *et al.* 2016), while the other five species [*A. preussi* (Moka, Belebu), *C. satanas* (Belebu), *C. pogonias* (Moka, Belebu), *C. nictitans* (Moka), and *M. leuocophaeus* (Moka)] were encountered at a much lower frequency. *P. pennantii* and *C. satanas* were not encountered in the Moka area, implying extremely low densities, as in the case of *C. satanas*, or extirpation in the areas surrounding Moka, as has been suggested for *P. pennantii* (Cronin *et al.* 2013, 2016, 2017). *C. satanas* has recently been observed opportunistically near Moka along the rim of the Biao crater (1 individual; D. Montgomery, pers. obs. 2013), and on the northwest flank of Pico Biao (1 individual: D. Venditti, pers. obs. 2016; 2 groups: D. L. Forrest, pers. obs. 2017). Colell *et al.* (1994) described a single *P. pennantii* carcass, reported to be taken near Pico Biao in 1992; however, *P. pennantii* is now believed to be restricted to a single small population in the southwestern corner of Bioko (Cronin *et al.* 2016, 2017). Colobus monkeys are largely understood to be highly sensitive to hunting, due to their large body size, their sluggish and conspicuous manner of movement, and low level of visual alertness (Oates 1996). On Bioko, Cronin *et al.* (2016) found that both *C. satanas* and *P. pennantii* are the most vulnerable species to hunting. Examples with other colobine species from mainland Equatorial Guinea (Kümpel *et al.* 2008), Uganda (Struhsaker 1999), Tanzania (Marshall 2007), and a comprehensive analysis of all red colobus species (Struhsaker 2005) substantiate this claim. The high vulnerability to hunting of both colobine species on Bioko likely account for their absence at our study site.

Despite the higher sighting frequency at Moka, the primate communities of both Moka and Belebu are reflective of hunted forests on Bioko (Cronin *et al.* 2016) and the Congo Basin (Linder & Oates 2011; Rovero *et al.* 2012). As in other recent surveys on the island (Cronin *et al.* 2013, 2016), the majority of sightings consisted of smaller bodied primates

Table 3. Hunting sign totals and encounter rates per km during surveys at Moka (2011 – 2014; this study) and Belebu (2011-2012; Cronin *et al.* 2016).

Hunting Sign Type	**Moka**				**Belebu**
	2011	**2012**	**2013**	**2014**	
Gun Hunting Signs					
Balacha Norte	5	16	24	9	-
Balacha Sur	22	18	19	8	-
San Joaquin	11	17	14	6	-
All Trails	38	51	57	23	354
Trap Hunting Signs					
Balacha Norte	0	24	0	5	-
Balacha Sur	18	10	3	4	-
San Joaquin	15	0	0	0	-
All Trail	33	34	3	9	284
Total Hunting Signs					
Balacha Norte	5	40	24	14	-
Balacha Sur	40	28	22	12	-
San Joaquin	26	17	14	6	-
All Trails	71	85	60	32	638
Gun Sign E. R. (km^{-1})					
Balacha Norte	0.69	1.13	2.36	0.45	-
Balacha Sur	1.07	1.05	1.64	0.43	-
San Joaquin	0.30	0.77	1.46	0.52	-
All Trails	0.59	0.96	1.64	0.46	2.89
Trap Sign E. R. (km^{-1})					
Balacha Norte	0.00	1.70	0.20	0.25	-
Balacha Sur	0.40	0.58	1.57	0.22	-
San Joaquin	0.88	0.00	0.00	0.00	-
All Trails	0.51	0.64	0.09	0.18	2.66
Overall Hunting Sign E.R. (km^{-1})					
Balacha Norte	0.69	2.83	2.56	0.70	-
Balacha Sur	1.95	1.64	1.64	0.65	-
San Joaquin	0.97	0.77	1.46	0.52	-
All Trails	1.25	1.60	1.72	0.64	5.56

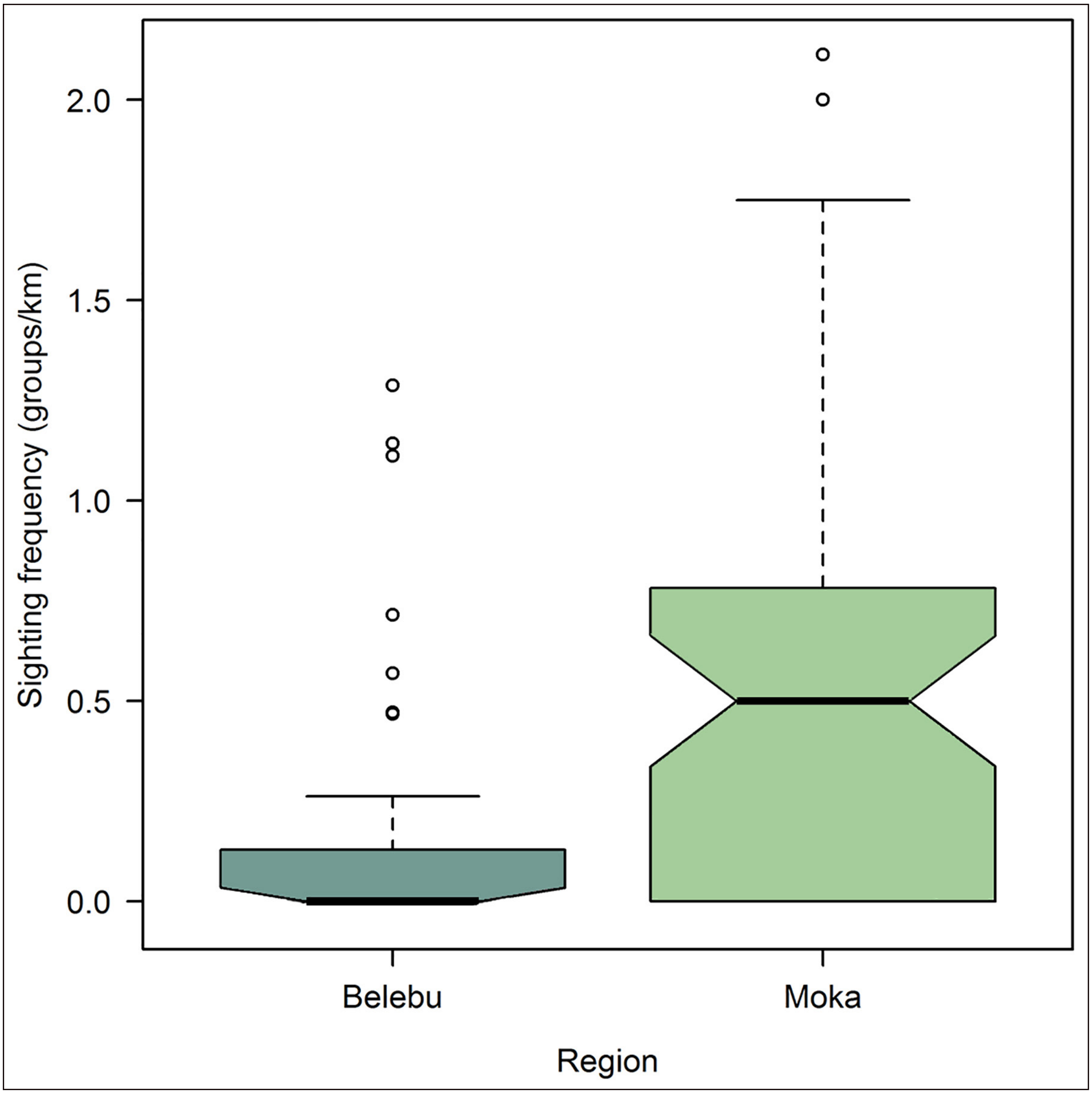

Figure 3. Comparison of primate sighting frequencies at Belebu and Moka. Notches indicate standard deviations from the mean sighting frequency values.

(e.g., *C. erythrotis*), while larger, more conspicuous species were encountered at either low rates (e.g., *M. leucophaeus, C. satanas*), or not at all (e.g., *P. pennantii*). *C. erythrotis* is the smallest diurnal primate occurring on Bioko (Butynski *et al.* 2009), and is most resilient to hunting pressure (Cronin *et al.* 2016). In contrast, the larger-bodied species, *M. leucophaeus, C. satanas,* and *P. pennantii*, are all vulnerable to hunting pressure and, thus, are expected to be encountered at lower frequencies (Cronin *et al.* 2016). *P. pennantii* and *C. satanas*, respectively, had the highest and second-highest vulnerability indices of all of Bioko's primates (Cronin *et al.* 2016) and, accordingly, were only opportunistically encountered or absent in our surveys. The high proportion of *C. erythrotis* encountered during our surveys relative to larger-bodied primate taxa lends further support to Cronin *et al.*'s (2016) suggestion that *C. erythrotis* may compensate for the loss of other diurnal primate taxa on Bioko. Other recent studies in Cameroon (Linder & Oates 2011) and Tanzania (Rovero *et al.* 2012) have shown similar trends with respect to the primate community composition in highly-hunted versus lesser-hunted forests (fewer larger-bodied primates, chiefly colobines, and equal or greater smaller-bodied primates, chiefly cercopithecines). Both Linder & Oates (2011) and Cronin *et al.* (2016)

propose that this phenomenon could be attributed to competitive release, which may also be the case in our study.

Habitat degradation is often cited as a leading cause of primate population decline in west and central Africa (Oates 1996; Rovero *et al.* 2012; Barelli *et al.* 2015) and may play an important role in primate community dynamics at both of our study sites. The abandonment of former pastureland in Moka in the early 1990s allowed secondary forest to reclaim some areas of previously lost or degraded habitat. This potentially led to increased habitat, in some areas around Moka (Butynski & Koster 1994). However, in recent years, there has been considerable habitat loss near both Moka and Belebu, concentrated along their primary access roadways (main road to Luba and Malabo, Moka; Luba-Ureka road, Belebu), due to agricultural expansion (D.T. Cronin, D.L. Forrest, pers. obs.). Net habitat gain may be insignificant or even negative, as a result, but it is also likely that hunting efforts will be, at least in the short term, concentrated in areas just beyond agricultural expansion and along roads, due to easier accessibility.

While both the towns of Moka and Belebu are positioned along the border of the GCSR, relative primate abundance and hunting sign encounter rates differed between the two, likely due to the accessibility and land-use history of these towns. Our results indicate a higher hunting presence in Belebu than in Moka, and correspondingly fewer primates in Belebu than in Moka. The forest near Belebu is more accessible to most hunters, as Belebu is only 7.5 km from Luba, Bioko's second largest town, on the Luba-Ureka Road, and, as a result, nearer to Malabo, the largest town and location of the main bushmeat market. Belebu also has a long history of plantation agriculture of both cocoa and palm, fueling both forest loss and/or conversion, and gun hunting for bushmeat and management of agricultural pests, e.g., squirrels (Butynski & Koster 1994). Small-scale commercial agriculture also occurs in Moka, but expansion has occurred more recently, and a greater amount of intact forest remains directly surrounding the town (D. T. Cronin, D. L. Forrest, pers. obs.). Elevation is often considered an important environmental predictor of primate abundance, as higher elevation are typically associated with lower densities of primates (Barelli *et al.* 2015). This holds true on Bioko (Cronin *et al.* 2016); however, our high elevation site (Moka) had a higher sighting frequency than the lowland site (Belebu). Higher sighting frequency on trails around Moka (montane forest) than Belebu (lowland forest) indicate that hunting pressure likely has the dominant impact on primate abundance. Other environmental factors may also play a role in the species richness and abundance at each site, and further research is necessary to investigate the impact of these ecological differences.

The results from these two towns on the boundary of the GCSR support the persistence of a number of significant issues: (1) the borders of the GCSR are permeable to hunters; (2) the legal existence of protected areas on Bioko is not sufficient to deter hunting, especially of threatened primates, which are critically important to the maintenance of ecosystem processes; and (3) the development of management strategies for the GCSR needs to account for site-specific differences in accessibility, long-term history, hunting patterns, and species assemblages, such as prioritization of the location of forest patrols, and selective positioning of bushmeat checkpoints. With the understanding of the limitations in implementing a management strategy for a protected area (limited funding, personnel, equipment, etc.), it is imperative to consider key access points, hunted areas, and the current ecological state of the area. Belebu and Moka are two of only four large towns within 2 km of the GCSR, and are the most accessible of the four. By studying the primate abundance and hunting levels in key locations nearing the reserve borders, we can better understand the pathways of entry into the reserve, level of use in different portions of the reserve, and prioritize limited resources. We contend that the difference between primate abundance in Belebu and Moka is due, in large part, to the greater accessibility and history of hunting in Belebu.

With this understanding, the current expansion of agriculture at Moka, and the completion of the new road through the GCSR to Ureka, we reiterate the recommendation made in Cronin *et al.* (2017) that the implementation of a management plan for the GCSR is of critical importance to the preservation of its diurnal primate taxa. Included in their recommendations were the creation and implementation of 'ranger bases' at primary access points to the GCSR and 'bushmeat checkpoints' along key transit routes between protected areas. Belebu, situated 7.5 km from the entrance to the Luba-Ureka road (Figure 1), is highly accessible to hunters coming from Luba. A checkpoint directly after Belebu along the Luba-Ureka road, coupled with vehicle searches by INDEFOR-AP, the protected area management authority would limit the amount of off-take by preventing vehicle access to the reserve. There are two major roadways leading directly to

Moka, and an extensive trail system surrounding the town. While this accessibility, coupled with the Moka Wildlife Center, have provided the infrastructure for ecotourism, and has already lead to some success in this area, heavy hunting pressure and subsequent decreases in primate abundance near the town threatens to reduce, if not eliminate, the ecotourism market in the town. Increasing the number of eco-guard patrols in the area, coupled with military support may decrease the hunting presence.

Both Belebu and Moka were put forth as sites in Cronin *et al.*'s (2017) GCSR conservation strategy, and our study highlights the importance of these two sites to primate conservation along the GCSR border, and as access points for illegal activities. Continued hunting and defaunation in towns like Belebu and Moka along the GCSR border will, in time, lead to hunters moving further into the GCSR, reaching core areas which still maintain high densities of all 7 diurnal primate species (Cronin *et al.* 2017). The newly constructed road from Luba to Ureka has already enabled hunters to have vehicle access to formerly remote areas of the GCSR and contributed to increased hunting activity in the southern extent of the reserve (D.T. Cronin, unpublished data, 2015-2016). Forest patrols by INDEFOR-AP should be targeted in areas of known hunting, including Moka, Belebu, and other easy-access areas of the GCSR.

Finally, long-term research sites and the associated presence of researchers and students have been shown to contribute to significantly higher primate abundance and lower hunting intensity (Campbell *et al.* 2011; N'Goran *et al.* 2012). The Moka Wildlife Center has been a site for long-term research, educational, and conservation activities since 2006, and the consistent presence of researchers and students have likely contributed to the lower levels of hunting and higher primate abundance observed at Moka relative to Belebu in our study. Furthermore, all of the surveys at Moka were carried out by students conducting research at the Moka Wildlife Center, revealing the value of student research for informing conservation in an understudied area of the island. These student surveys occur annually, and provide a consistent source of data to frequently update the status of primate populations, as well as the effects that hunting and agriculture are having on primate populations at Moka. While much of the scientific literature has focused on more remote areas of the island, our results detail the persistence of notable primate populations, and highlight the importance of understanding the dynamics of wildlife populations in more disturbed, human-dominated landscapes on Bioko when planning for conservation.

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