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Full-Length Research Article

Abundance and Foraging Ecology of the Black and White Colobus Monkey (*Colobus guereza* ssp. *guereza*) in Nech Sar National Park, Ethiopia

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ABSTRACT

We estimated the abundance of *Colobus guereza* ssp. *guereza* in the moist evergreen riparian forest part of Nech Sar National Park, Ethiopia. The survey was conducted using the distance sampling method. Based on a preliminary study, 17 newly cut line transects were randomly aligned across the study area. The survey data were then collected for three consecutive months. Transects were walked once per month for 14-16 days. Abundance estimates were analyzed using the program 'DISTANCE'. The half-normal key function with cosine adjustment fitted our data sets best. Mean group density and mean animal density were 14 animals km^{-2} and 102 animals km^{-2}, respectively, resulting in a mean estimated abundance of 2,153 animals distributed over the study area. The mean estimated group size was 7.24 with an estimated encounter rate of 1.72. Compared to similar studies from tropical forests in Africa, our population density estimates were intermediate between the mean values (100 to 168 animals km^{-2}). We conclude that such intermediate density estimates reflect the fact that guerezas have suffered from human-induced reductions in habitat availability. We also suggest that the natural forest is still in a reasonable condition that likely provides them with sufficient food supply to compensate for such intermediate densities. However, a replication of this study would lead to a more comprehensive abundance estimate. We also recommend studies that would address the activity-time budget and population demographics of these monkeys. Nonetheless, our results provide a reference point for future studies in this area, particularly to assess population trends of *C. g. guereza*.

Keywords: Density estimation; Detection; Distance sampling; Feeding preference; guereza; Line transect

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1. INTRODUCTION

The black and white colobus monkey (*Colobus guereza*) or the 'guereza' is a member of the Cercopithecidae family and the Colobinae (an arboreal Old World primate taxon) subfamily. *Colobus guereza* comprises eight subspecies (Grubb *et al*., 2003) and is widely distributed in the deciduous and evergreen forests of equatorial Africa (Jensz and Finley, 2011). Two of the eight subspecies, the *C. g. guereza* (Omo River guereza) and the *C. g. gallarum* (Djaffa Mountains guereza), are endemic to Ethiopia (Kingdon*et al*., 2008), where both subspecies are critically endangered due to the ongoing human disturbance. According to the IUCN and other existing reports, most colobine monkeys are not yet globally threatened. Nevertheless, many species are locally threatened. Therefore, data on population size and ecological (food) preferences of colobines are an important prerequisite for successful local and global conservation efforts, but these data are often lacking.

The ever increasing human population and its subsequent impacts on land use/cover change have been recognized as a prominent threat to global biodiversity, particularly in tropical forests (Chapman *et al*., 2002; Rovero*et al*., 2012; Addisu*et al*., 2012; Araldi*et al*., 2014; Edwards and Lucy, 2015; Galán-Acadia *et al*., 2018; Zinner*et al*., 2019). A recent review compiled by 28 authors, Estrada *et al*. (2017), showed that 60% of primate species are threatened due to habitat loss. Due to this habitat loss and resulting range reduction, black and white colobus monkeys often reach higher densities (315 to 800 individuals per km^2), especially in: small patches of forest along lakes and rivers (Leskes and Acheson, 1971; Rose, 1978; Dunbar, 1987; Kruger *et al*., 1998), selectively logged areas (Struhsaker, 1997), and isolated forests (Dunbar, 1987; Fashing, 2002). Likewise, in moist tropical forests exposed to low to moderate human disturbance, guerezas can reach mean densities of 100 to 168 individuals per km^2 (Fashing and Cords, 2000). However, in large areas of undisturbed moist forest, they have low densities (Bocian, 1997; Struhsaker, 1997).

Such a resilient characteristic of *C. guereza* to live in a degraded and fragmented area could explain the low priority given to its protection (Fashing, 2002). Given the impact that humans can have on primates (Rovero*et al*., 2015; Edwards and Lucy, 2015), obtaining accurate information on their abundance and population status is a prerequisite for successful wildlife conservation (Whitesides*et al*., 1988; Fashing, 2002; Rovero*et al*., 2012; Araldi*et al*., 2014). Primates have also been studied as they are good indicators of habitat disturbance (Rovero*et al*., 2012). Although *C. guereza* is not yet globally threatened (IUCN Red List, 2018), existing reports confirm that some of its subspecies are already classified as endangered and locally threatened in parts of its range (Kingdon*et al*., 2008, 2013).

Nech Sar National Park (NSNP) is one of the primary protected areas of Ethiopia well known for its diverse habitat types and wildlife (Duckworth *et al*., 1992; Jones, 2005). Regrettably, there are competing claims for the use of natural resources (Asebe, 2012; Girma*et al*., 2012). Much of the literature shows that the park has been under unceasing human disturbance (Bolton, 1970; Duckworth *et al*., 1992; Yisehak*et al*., 2007; NSNP Report, 2008; Demeke and Afework, 2011; Yosef*et al*., 2012; Belay *et al*., 2014; Aramde*et al*., 2011, 2014, 2016; Genaye*et al*., 2017; Shetie*et al*., 2017). As a result, the NSNP has been severely degraded and is now replaced by an invasive and encroaching plant species that threaten wildlife (Abraham Marye, personal communication, February 27, 2018). Of the various species of wild mammals in the park, monkeys have not yet been studied using appropriate sampling methods and their population size and/or status remains unknown. Therefore, from a wildlife conservation perspective, the main objective of the present study was to estimate the abundance of *C. g. guereza* within Arba Minch Groundwater Forest, a natural evergreen forest area within the NSNP. The second objective was to investigate the feeding ecology and/or habitat preference of *C. g. guereza* to infer whether it influences its distribution and density.

2. MATERIALS AND METHODS

2.1 Location of the study area

The NSNP is located at 5°51'-6°05'N and 37°32'-37°48'E in Arba Minch (Jacobs and Schloeder, 2001). It was established in 1974 and it covers 514 km^2 of the eastern Ethiopian Rift Valley (Jones, 2005). Water accounts for 15% of its area (Lake Abaya and Lake Chamo). The area has an elevation range of 1,108 m to 1,650 m asl. It exhibits a bimodal rainfall distribution (Bolton, 1970) and temperatures range from 17°C to 30°C. Our specific study area covers approximately 21.2 $km^2$of the park's natural evergreen forest (Belay *et al*., 2014), on its western escarpment (Figure 1). This continuous forest layer where most guerezas and other monkey species are abundant is commonly referred to as "Arba Minch Groundwater Forest" and it includes the Kulfo Riverine Forest.

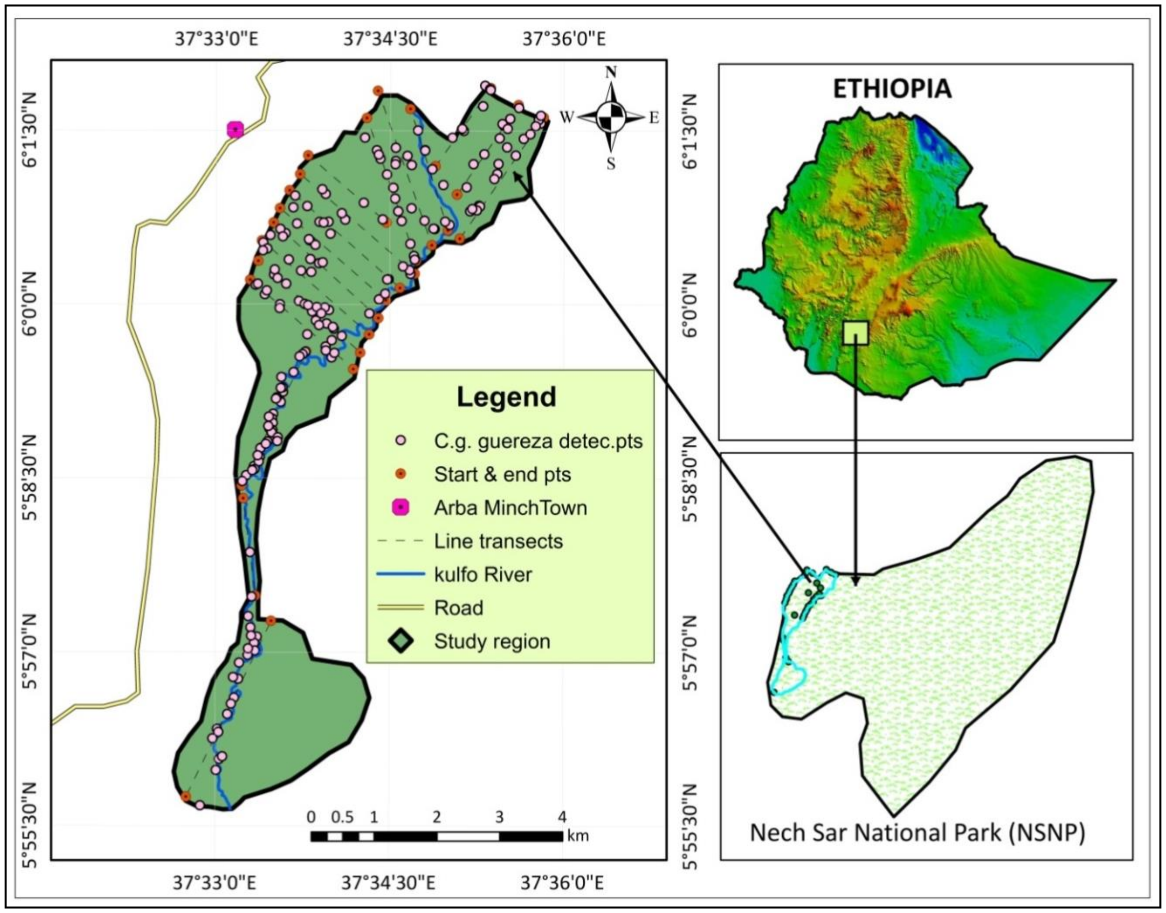

Figure 1. Location of the study region, the natural evergreen forest within the NSNP that is home to most monkey species, but where high levels of logging activity are prevalent.

2.2 Key assumptions in the distance sampling method

We used canonical distance sampling (Buckland *et al*., 1993, 2001, 2010), a widely used and effective method for surveying primates (Struhsaker, 1997; Buckland *et al*., 2001; Marshall *et al*., 2008; Thomas *et al*., 2010; Tagg and Willie, 2013). To ensure that we obtained accurate abundance and/or density estimates, the critical assumptions of this method were carefully considered during our survey: (1) line transects were randomly placed with respect to the distribution of animals; (2) all animals directly above or on the line were recorded with certainty, here *C. g. guereza* (Figure 2) must be recorded directly above or on the line with certainty; (3) distance to recorded animals was recorded at their initial location, i.e., before they moved toward or away from the observer; (4) individual sightings were independent events; (5) distance and/or angle were measured accurately and precisely. We referred to the number of individuals seen by the observer in each encounter as the group size; (6) sufficient sightings are required to estimate abundance. That is, 69-80 observations are preferable to accurately model a capture function (Marshall *et al*., 2008).

Figure 2, The study taxon, *C. g. guereza*. A male Colobus (**Fig. 2A**) taking a ground pause during large group play (**Fig. 2B)** (photographed by Solomon on 27 March 2018).

2.3 Protocol of line transect data collection

Based on a preliminary study, 17 newly cut line transects (ranging from 1.67 km to 3 km in length and 300 m apart) were randomly aligned across the study are to fully capture the distribution of *C. g. guereza* (Figure 1). Survey data were then collected for three consecutive months, from February to April 2018. Transects were walked once per month and each survey effort took between 14-16 days each month. Censuses started in the early morning (6:30-7:00). Breaks of approximately two to three hours were taken at noon (depending on daily weather conditions) and then resumed from 14:00-14:30. Counts ended in the late afternoon from 17:30-18:00 (Peres, 1999; Chapman and Lambert, 2000; Mammides*et al*., 2008). We maintained a pace of 1.5 km per hour during transect walks (Magnusson, 2001). Data were collected such that the observer (detector) was followed by a data recorder. To normalise data collection, we took 10-15 minutes to collect data for each detection (Marshal *et al*., 2008). Collection data were noted on a standardised data sheet (Altman, 1974). To avoid recording bias, surveys were not conducted during inclement weather and/or fog. Surveys were conducted with the assistance of the park's wildlife wardens, trained fieldwork assistants, and scouts (for safety reasons).

When guerezas were encountered online transects, the following data were recorded: Time of sighting, GPS location of detection from the line, distance advanced from the starting point, group size detected, animal-observer distance (AOD) to the first detected individual, perpendicular distance (PD), group activity, and gross habitat type (Whitesides*et al*., 1988; Fashing and Cords, 2000; Plumptre and Cox, 2006; Araldi *et al*., 2014). The following instruments were used for data collection: Nikon Laser Force

Rangefinder Binocular (10 x 42 configuration; to focus on the species surveyed), Digital Camera (SONY 20.1X), GPS (Gramin 64; to record the GIS location of the species surveyed), Compass (Suunto M3), Leica Geosystems Distance Meter (DIST X 310; to measure the angle and distance of the AOD to the animal sighted). Survey personnel dressed appropriately for the weather conditions and followed recommended procedures for data collection (Araldi *et al*., 2014).

2.4 Data collection on the foraging ecology

Foraging data were recorded when guerezas were observed manipulating, chewing, or mouthing food (Oates, 1974; Fashing, 2001b; Addisu *et al*., 2010a). First, we recorded plant species on which the arboreal guereza was observed foraging and/or engaging in other behavioural activities because we suspect that this plant is an ecologically important species preferred by these monkeys (e.g., due to its larger and/or denser canopy, nutrient content). Second, we recorded plants located within a five-metre-wide strip around the capture centre (Altmann, 1974; Fashing, 2001a; Addisu*et al*., 2010a; Wong and Sicotte, 2007).

2.5 Statistical analysis

Abundance estimation was analysed using the program DISTANCE (version 7.1), a canonical software (Buckland *et al*., 1993; 2001; Thomas *et al*., 2010). We first compared models to select the appropriate key function that best fit our datasets (Buckland *et al*., 2001). The half-normal key function (with cosine fitting) showed the lowest Akaike's Information Criterion values(AIC = 1120.11 AICc = 1120. 1327 and Delta AIC 0.00 at 95% CI), among the other models that were run simultaneously. Likelihood and absolute measures of model fit (χ^2 goodness-of-fit test, Q-Q plots, Kolmogorov-Smirnov test, and Cramér-von Mises test) were used to assess model fit. The degree of variance was tested using the standard error, coefficient of variation, and 95% CI. The MS -excel was used to analyse the foraging composition by assessing the proportion of different food items and the type of species consumed (Addisu *et al*., 2010a).

2.6 Ethical note

We conducted the study without any possible manipulation of *C. g. guereza*. We conducted the field study with permission from Ethiopian Wildlife Conservation Authority (EWCA) and Nech Sar National Parks' Office. During data collection, we adhered to the legal requirements and complied with the wildlife research laws in Ethiopia.

3. RESULTS

3.1 Population density and abundance estimates

We collected a total of 195 detections of *C. g. guereza* (67, 68, and 60 detections in February, March, and April, respectively) for a total survey effort of 113.4 km (Table 1). The number of animals observed in each month (total group size) was 521, 423, and 465 respectively, giving a total observed population size of 1,409 animals in the study area. A high number of detections were recorded from three line transects: LT_{15} with 244 animals, LT_{13} with 150 animals, and LT_{17} with 133 animals. They accounted for 37.4% of the total detections.

Table 1. Sampling effort, number of observations, total observed group size, mean observed group size, and mean encounter rate(of *C. g. guereza*)collected during three-month line-transect surveys (February, March and April 2018) in NSNP, Ethiopia.

Line transects (LT_x)	**Survey effort (Km)**	**No. of detections /month/LT_x**			**Total no. of detections on each LT**	**Mean, group size**	**Mean, encounter rate**
		Feb.	Mar.	Apr.			
LT_1	2.40	2	6	7	107	7.13	2.08
LT_2	1.73	4	6	4	105	7.5	2.7
LT_3	1.53	4	3	3	90	9	2.18
LT_4	2	2	3	1	43	7.17	1
LT_5	2.64	5	2	2	61	6.77	1.14
LT_6	2.36	3	4	7	98	7	1.78
LT_7	1.63	2	0	0	10	5	0.41
LT_8	2.45	5	2	0	48	6.85	0.95
LT_9	2.35	2	2	2	36	6	0.85
LT_{10}	2.33	3	4	3	76	8.2	1.43
LT_{11}	2.61	3	2	2	51	7.29	0.89
LT_{12}	2.29	4	0	5	60	6.69	1.31
LT_{13}	2.19	6	6	3	150	10	1.52
LT_{14}	2.21	4	4	5	88	6.46	1.96
LT_{15}	2.4	9	13	12	244	7.12	4.7
LT_{16}	1.57	0	2	0	9	4.5	0.42
LT_{17}	3.1	9	9	4	133	6.04	2.37
Total	113.4	67	68	60	1409	6.89	1.63

Using the DISTANCE data analysis software, we estimated group densities, population densities, and abundance of *C. g. guereza* in our study region within the Arba Minch groundwater forest (Table 2). The half-normal key function (with cosine adjustment) showed us the lowest values of the Akaike's Information Criterion (AIC = 1120.11; AICc = 1120. 1327 and Delta AIC 0.00 at 95% CI). This resulted in a mean estimated abundance of 2,153 ± (1765-2540; 95% CI) animals (individual *C. g. guereza*) distributed over an area of 21.2 km2, with a population density and group density of 102 ± (83-120; 95% CI) animals km^{-2} and 14 ± (12-17; 95%

CI) animals km^{-2}, respectively. The mean estimated group size was 7.24 with an estimated encounter rate of 1.72 n/L (group sighted per km travelled). The detection probability function (p) was 0.5 and the probability density function at zero distances, f (0), was 0.7 (i.e., more than 70% of animals were detected at zero distances along the trial).

Table 2. Summary of estimated parameters for detection function, detection probability, encounter rate, density, and abundance of *C. g. guereza* in NSNP, Ethiopia (collected from February-April 2018). Counts were fitted to a half-normal detection function.

Estimator	Estimate	SE	%CV	df	95%CI	
f(0)	0.7	0.004	5.28	194	0.063	0.08
P	0.5	0.03	5.28	-	0.42	0.52
ESW	14.25	0.75	5.28	-	12.84	15.81
ER	1.72	-	14.96	16	1.25	2.36
E(S)	7.24	0.27	3.74	193	6.73	7.79
DS	14.03	4.58	5.87	20.2	11.5	16.55
D	101.55	18	6.3	22.5	83.27	119.83
N	2153	163	6.3	2.5	1765.46	2540

Parameter estimated: f (0), the probability density function of observed distances evaluated at a distance of zero meter; p, probability of observing (detecting) an animal at distance x; ESW, effective strip width (in meters); ER (n/L), encounter rate of clusters (group sighted per km walked); DS, an estimate of the mean density of clusters per km²; D, an estimate of density of individuals per km², E(S), an estimate of the expected value of cluster size; and N, an estimate of number of individual colobus in the studied region. Precision (degree of uncertainty) measurements were: SE, standard error; %CV, the coefficient of variation (i.e., standard deviation as a percentage of the mean); df: degree of freedom; and 95% CI, 95% confidence interval.

The following histogram (Figure 3) displays a uniformly decreasing probability of detection as a function of increasing (perpendicular) distance from the line-transect. It shows that some heaping of detections occurred at distant sightings. Due to a large canopy, most observations were collected within a short cut-off distance (30 m), beyond which we collected little or no data. Such a histogram shape with a monotonically decreasing detection function indicates that a proper sampling protocol was followed.

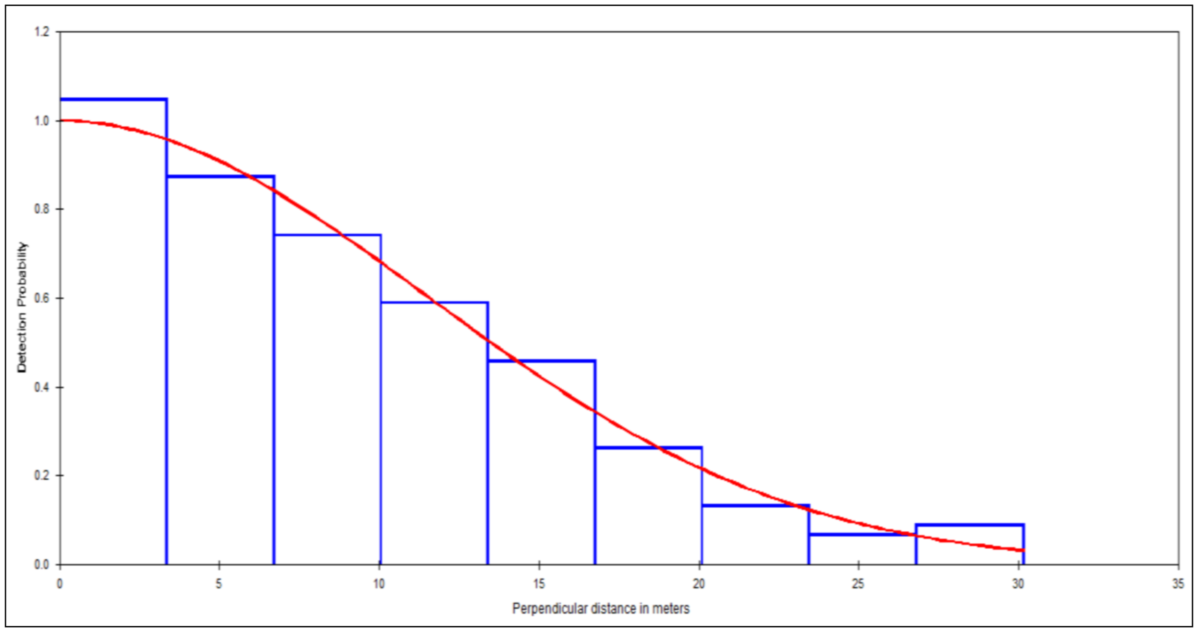

Figure 3. A detection histogram which depicts the probability of detection as a function of perpendicular distance (m) from the line transect.

3.2 Feeding ecology of *C. g. guereza*

For each detection of *C.g. guereza*, we recorded all plant species (trees, shrubs, climbers, and/or lianas) located within a 5 m radius of the observation center (Fashing, 2001a). The record data ranged from 5-35 individuals, and this totaled approximately 975-6,825 individual plant species (and lianas) from the total sightings made (195 detections). However, only those plant species that were included in Guerezas' foraging list were included in the data analysis. Of the 62 foraging events, 14 plant species most frequently foraged by guerezas were listed. This observation included the specific part of the plant that was eaten by the monkeys. Among the 14 preferred plant species, *Ficus* spp. followed by *Prunus africana* and *Trichilia* spp are proved to be the most favourite food sources for guerezas in the study area (Figure 4).

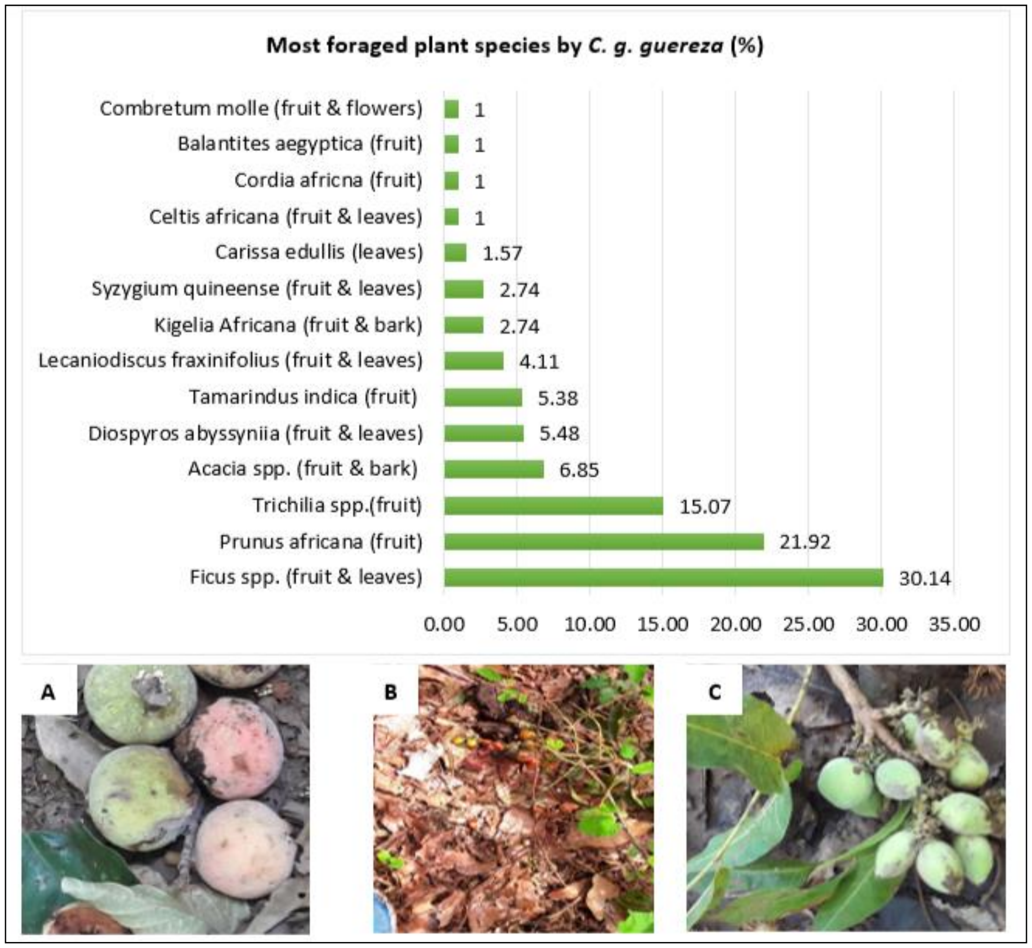

Figure 4. A ranked list of 14 plant species preferred by *C. g. guereza* for foraging. The three plates, below the bar chart, show the plant parts most commonly eaten by guerezas: *Ficus vasta* (Fig. 4A); *Prunus africana* (Fig. 4B), *Trichiliaemetica* (Fig. 4C) (photographed by Solomon on 27 March 2018).

4. DISCUSSION

Compared with similar studies from tropical forests in Africa, our density estimates are among the intermediate values (100 to 168 animals km^{-2}) (Oates, 1974; Fashing and Cords, 2000). Such intermediate estimates are characteristic of moist tropical forests that have been exposed to various levels of human disturbance (Table 3), with the problems also prevalent in our study area. In most cases, high density estimates of *C. guereza* show characteristics of small patches of forest, along lakes and rivers (Table 3), while low density estimates reflect a broad area of undisturbed moist forest (Kingdon *et al*., 2013).

Table 3. Comparison of *C. guereza* density estimates from this study with those of similar studies conducted in tropical forests of Africa, which are differentially affected by human disturbance.

Higher density estimates (in small patches of forest along lakes, rivers and in isolated forests)			
Country	Study site	Estimates (km^{-2})	Author (year)
Uganda	Murchison Falls	800	Leskes and Acheson (1971)
	Kyambura Gorge	347	Kruger et al. (1998)
Kenya	Limuru	483	Dunbar (1987)
	Naivsha	396	Rose (1978)
Ethiopia	Bole Valley	315	Dunbar (1987)
Intermediate density estimates (in moist forests under low to moderate levels of disturbance)			
Kenya	Kakamega forest	100-168	(Oates 1974; Fashing and cords 2000)
Ethiopia	Upper Bole Valley	140	Dunbar (1974)
	Arba Minch groundwater forest (NSNP)	102	This study
	Lake Shalla, Ethiopia	138	Dunbar (1987)
Low density estimates (in large areas of undisturbed moist forest)			
Kenya	Kakamega forest	20.8	von Hippel (1996)
Uganda	Kibale Forest	4.5	Struhsaker (1997)
DR Congo	Ituri Forest	3	Bocian (1997)

On this basis, we provide two lines of evidence that could explain why the density estimates of *C. g. guereza* for our study site are in the middle range, while its abundance was not yet robust. The first reason is related to reduced range size following anthropogenic disturbance (Dunbar, 1987; Kingdon *et al*., 2008). Since the 1970s, the NSNP has been subjected to a continuous human disturbance history (logging, illegal settlement, illegal poaching, illegal fishing, livestock grazing, agriculture) (Bolton, 1970; Duckworth *et al*, 1992; NSNP Report, 2008; Demeke and Afework, 2011; Yosef *et al*., 2012; Belay *et al*, 2014; Aramde*et al*, 2011, 2014; 2016; Solomon and Dereje, 2015; Genaye *et al*, 2017; Shetie *et al*, 2017). A considerable amount of wood was cleared from the park daily (Alemu, 2017) and an average of 147 people entered the park per day (Aramde *et al*., 2012). As a result of such threats, C. g. guereza were forced to concentrate in some localized areas of the park and are therefore found at an intermediate density. Furthermore, our results are consistent with reports by Dunbar (1987), Fashing (2002) and Kingdon *et al*. (2013) that *C. g. guereza* is resilient to habitat degradation, often reaching medium to high densities.

The second reason why *C. g. guereza* occurs at intermediate (to high) densities in our study may be related to habitat quality. Dunbar (1974) suggested that habitat quality had a major influence on primate population density. Accordingly, it would be related to the amount of forest that allows animals to more accurately assess food supply, as well as the number of preferred trees available as a food source. In this regard, we accordingly surveyed vegetation (foraging) that these forests, with a large *C. g. guereza* density, were conspicuously structured by *Ficus vasta* (Moraceae), *Ficus syncromus* (Moraceae) and, *Syzygiumquineense* (Myrtaceae), *Prunus afrricana* (Rosaceae), *Tricheliaemetica*, (Meliaceae), and *Lecaniodiscusfraxinifolius* (Sapindaceae). These tree species were ranked in order of feeding preference by *C. g. guereza*(Figure 4). We, therefore, hypothesise that guerezas settle at higher densities near these preferred plant species, which indirectly influences their spatial distribution and abundance(Figure 1; Table 1).

In addition, the African Crowned Eagle (*Stephanoaetuscoronatus*) and the Chimpanzees (*Pan troglodytes*) in the Kiable forests (Uganda) and the leopards (*Panthera pardus*) in the Ituri forest (DR Congo) are predators of *C. g. guereza* (Kingdon*et al*., 2013). Of these three predators of *C. g. guereza*, only *Panthera pardus* occurs in NSNP and may have contributed to the mean density values in our results. However, we lacked a previous report on whether it controlled the population of guerezas.

To assess the population trend of *C. g. guereza*, we searched for previous studies conducted for the same study species and study region. We found only one patrol-based study by Aramde *et al*. (2011) on five large mammals, including *C. g. guereza*, which was more informative about the local distribution and habitat preference of the study species than about their abundance. We therefore cannot make a reliable comparison about the population trends of guerezas because the sampling methods used by Aramde and his colleagues differ from those we used. For this reason, we were unable to determine whether the population of *C. g. guereza* in NSNP was decreasing or increasing. Nevertheless, several reports indicated that NSNP has been severely degraded by continuous human disturbance, and therefore it is likely that the population of *C. g. guereza* is declining and locally threatened.

5. CONCLUSION

We estimated the abundance of *C. g. guereza* within the natural forest of NSNP to be 2,153 animals, distributed over an area of 21 km^2. Whereas, their estimated population density (102 animals km^{-2}) was placed in the medium density range. Given that the low density estimates indicate the presence of a large area of undisturbed wet forest, we conclude that our intermediate density estimates reflect that guerezas have suffered from a reduced habitat size as a result of logging. We also suggest that the presence of an adequate amount of food sources may be another reason that guerezas reach such concentrated densities. However, we could not make any definite statements about the current population trend because we lack reliable information about the past abundance of *C. g. guereza* in the study area.

6. RECOMMENDATIONS

We suggest that repeating the survey reported here with a longer period for data collection (e.g., for one year) would result in a more comprehensive abundance estimate. We also recommend studies that would address activity-time budget and population demographics of these monkeys. Our results provide a reference line for future studies in this area, particularly to evaluate population trends of *C. g. guereza*.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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