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Anthropogenic Activities and Influence on Behavior of the Tana River Mangabey (*Cercocebus galeritus*) in Two Forest Fragments in Lower Tana River, Kenya

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Abstract: The survival of the Tana River mangabey (*Cercocebus galeritus*) is threatened primarily by habitat fragmentation and loss due to pressure from human activities. However, the effects of such anthropogenic disturbance on the species' behavioral ecology are poorly understood. This study aimed to identify the anthropogenic activities and their impacts on mangabey behavior in Mchelelo and Mkomani forest patches in the Tana River Primate National Reserve. We hypothesized that Mkomani would experience higher levels of anthropogenic activities compared to Mchelelo due to its proximity to human settlements. Because detrimental human activities – such as tree cutting, palm wine tapping, and palm leaf harvesting – alter the forest habitat's cover, density, and distribution of important mangabey plant foods, we predicted that the species' behavior will show differences between the two sites due to varying levels of these human activities. We used quadrat and focal animal sampling methods to collect data on anthropogenic activities and to score mangabey behavior, respectively. Overall, tree cutting was the dominant human disturbance, followed by palm leaf harvesting and fire. Tree cutting and palm leaf harvesting were both higher in Mkomani compared to Mchelelo, respectively. Palm wine tapping was recorded exclusively in Mchelelo, while fire burning occurred only in Mkomani. The most exploited and important plant foods for the mangabeys were *Phoenix reclinata, Polysphaeria multiflora, Lecaniodiscus fraxinifolius,* and *Thespesia danis*. The group in Mkomani forest spent more time feeding and engaging in social interactions compared to that in Mchelelo. Our findings suggest that high exploitation of mangabey plant foods correspond with increased time spent feeding and in social interaction. Our findings are critical for informing the management and conservation of the *Cercocebus galeritus* and their habitat – especially in efforts to mitigate the detrimental anthropogenic activities in the lower Tana River forest patches.

Key words: anthropogenic activities, Tana River mangabeys, forest fragments, Tana River

INTRODUCTION

The human population explosion and high levels of poverty in Africa have been suggested as the major contributing factors for an approximately 1.6 million hectares of annual forest loss (Foley *et al.* 2005; FAO & JRC 2012). Previous studies indicate that there is a positive correlation between high human densities and forest disturbances, particularly in areas of high levels of endemism and species richness in Sub-Saharan Africa (Peres 2001; Irwin *et al.* 2010; Alroy 2017). While the meaning

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of forest/habitat disturbances can be applied in different contexts, here we define it as processes, particularly anthropogenic, that remove or alter the habitat cover or vegetation – resulting in habitat loss, fragmentation, and degradation (Fahrig 1997; Alroy 2017).

Increased degradation, fragmentation, and loss of the forest habitats has been attributed to the sharp decline of forest-dwelling primate populations (Chapman & Lambert 2000; Cowlishaw & Dunbar 2000; Farwig *et al.* 2006; Borgerson 2015). A number of studies cite that forest fragmentation creates small and isolated habitats, which are characterized by high loss of biological resources (Uhl *et al.* 1982; Anderson *et al.* 2007) and low species diversity (Oates 1996; MacArthur & Wilson 2001; Arroyo-Rodríguez & Dias 2010), reducing the potential of such habitats to sustain viable populations of primates. Anthropogenic disturbances, regardless of level and frequency, have high probability of causing biodiversity collapse in diverse wildlife habitats. Such effects limit individual dispersal and promote inbreeding, trigger nutritional stress, impair reproductive success, and negatively impact ecosystem structure and functioning (Svensson *et al.* 2012).

Primate habitat disturbances not only pose a threat to the already declining primate populations (Chapman & Lambert 2000) but also alter their behavior affecting the species' general ecology, reproductive fitness, and long-term survival (Kulp & Heymann 2015). For example, habitat fragmentation causes dispersion of food resources leading to increased travelling distance between food patches and more time spent looking for food (Kulp & Heymann 2015; Donati *et al.* 2016; Mekonnen *et al.* 2018). Similarly, the nutritional quality and quantity of primate food resources also decline with the increased level of anthropogenic disturbances, as shown in Tana River mangabey studies (*Cercocebus galeritus*) (Kivai 2018). This implies that, where certain macro- or micronutrients are limited, foraging and ranging behavior may be altered in an effort to meet such nutritional deficiencies. This may include searching for food in areas of high predation risk. Moreover, invasive species often colonize cleared and abandoned agricultural fields (Irwin *et al.* 2010). Such areas might have an advantage or disadvantage to the primate species based on whether the species prefers secondary or primary vegetation to meet their ecological requirements. This is well illustrated by studies on southern bamboo lemurs (*Hapalemur meridionalis*) in Madagascar, where the species was found to spend more time feeding and resting in a secondary habitat dominated by the invasive *Melaleuca quinquenervia* plant (Eppley *et al.* 2015).

Primate tolerance, responses, and resilience to habitat disturbances vary considerably across species (Oates, 1996). For instance, howling monkeys (*Alouatta palliata*) are known for their tolerance to habitat disturbance relative to other primates, and the species has been observed to survive in small forest fragments (< 5 ha) (Arroyo-Rodríguez & Dias 2010). This, however, reaches a threshold with high levels of anthropogenic disturbances, where small forest fragments are unable to meet the nutritional goals of the monkeys. With low to moderate disturbances, howling monkeys respond and cope with such changes by increased movement between isolated fragments or food patches and increased time spent feeding to compensate for reduction in food availability due to habitat loss (Arroyo-Rodríguez & Dias 2010). A shift in feeding behavior as a coping strategy to respond to habitat disturbance has also been observed in saki monkeys (*Chiropotes satanas chiropotes*). In that case, habitat degradation and loss of key plant food species resulted in the species expanding its dietary content to include plant foods that were ignored before the habitat deteriorated, thus enabling the saki monkeys to survive in fragmented habitats (Boyle *et al.* 2012). Similarly, chimpanzees (*Pan troglodytes*) have been observed to respond differently to habitat changes. Chimpanzees in Uganda's Bulindi forest reserve preferred riverine forests with less disturbance to areas disturbed by agricultural expansion and logging of fruit trees. They used the riverine forests as a mechanism to cope with reduced food resources due to habitat degradation (McLennan & Plumptre 2012). However, the chimpanzees in Bossou Guinea altered their pattern of habitat use in response to anthropogenic activities and pressures; they preferred forest habitat for moving and resting, but socialized more often in highly disturbed areas (i.e., cultivated fields, coffee plantations, and fallowed areas) (Bryson-Morrison *et al.* 2017). This chimpanzee population also preferred to forage more than 200 m away from habitats characterized by high human activities such as cultivated fields. This clearly demonstrates that understanding primate responses to habitat disturbances is fundamental for the human conservation interventions to promote their persistence in disturbed environments, especially in highly threatened species such as the Tana River mangabey.

The lower Tana flood plain forest patches are the only remaining habitat for the two endemic and critically endangered primates in the lower Tana River: the Tana River red colobus (*Piliocolobus rufomitratus*) and Tana River mangabey (Kivai *et al.* 2019). These forest fragments continue to suffer severe anthropogenic activities yet the Tana River mangabeys still thrive in such fragments (Karere *et al.* 2004; Moinde-Fockler *et al.* 2007; Kivai 2018) and little is known about their behavioral response to such disturbances. Previous studies on the Tana River mangabey have instead focused on forest products used by the community (Kinnaird 1992; Medley 1993), human and natural impacts on the forests (Moinde-Fockler *et al.* 2007; Mbora *et al.* 2009), ecological and behavioral aspects of the mangabeys (Homewood 1976; Medley 1992; Wieczkowski 2004), gastrointestinal parasites of the monkeys (Mbora & Munene 2006), human-nonhuman primate conflicts (Kivai 2010), and predation on the mangabeys (Wieczkowski *et al*. 2012; Kivai 2013). Thus, to understand the effects of the anthropogenic disturbances on the Tana River mangabey behavior as a necessary missing link in their conservation effort, we focused on two groups of mangabeys, one utilizing the Mchelelo forest patch (less disturbed) and the other living in the Mkomani forests (highly disturbed). We recorded the mangabeys' behavior and scored the levels of various anthropogenic disturbances in the two forest fragments to test our two hypotheses; first, that Mkomani forest will experience higher levels of human activities than Mchelelo due to its closeness to human settlements. Thus, we predicted that Mkomani forest would suffer from more forms of detrimental human activities and at higher levels compared to Mchelelo forest. Secondly, we hypothesized that mangabeys in Mkomani forest would alter their activity patterns in response to the effects of human disturbances on their habitat such as decline in food resources due to the detrimental human activities. We predicted that, compared to Mchelelo group, Mkomani group will increase the time spent feeding, moving, and engaging in social interaction to compensate for the reduction and dispersion of food resources and to mitigate physiological stress resulting from high human disturbances.

METHODS AND MATERIALS

Study Area

We conducted our study in the Tana River Primate National Reserve (TRPNR), within Tana River County in the coastal region of Kenya. The reserve was established in 1976 to protect the riverine forest and the endangered primates, particularly the Tana River mangabey and Tana River red colobus. It covers approximately 171 hectares (Butynski & Mwangi 1994) and lies at latitude -1°21'59.99" S and longitude 40°00'60.00" E (Figure 1). The reserve is dominated by a mosaic of regenerating and primary forest communities, which are influenced by the flooding and water table of the river (Medley 1995). In the Mkomani area, community farms are located along the edge of the forest, thus humans have more access to the forest than at Mchelelo, which has only a research station. The two forest patches are on the west side of the river.

The area falls within the arid and semi-arid parts of Kenya, where the annual rainfall ranges between 400 mm to 600 mm (Andrews *et al.* 1975). The daily temperatures range between a maximum of 30 – 38°C and a minimum of 17 – 25°C (Medley 1992). January and February are hot and dry months, while March to April and November to December are wet and cold months (Butynski & Mwangi 1994; Karere *et al.* 2004).

Study Species

The Tana River mangabey is a medium-sized frugivorous monkey endemic to forest patches along the Tana River, Kenya. The species is sympatric to the Tana River red colobus. Both species are listed as critically endangered (Butyinski *et al.* 2020a,b) and placed under Appendix I by the Convention on International Trade in Endangered Species of Wild Fauna and Flora and Class A by the African Convention on the Conservation of Nature and Natural Resources. The Tana River mangabey population is estimated to be around 1,200 individuals and is mainly threatened by habitat degradation, fragmentation, and loss due to human activities (Butynski & Mwangi 1994). They are dependent on the riverine forest patches (Butynski *et al.* 2020b). Their distributional range extends about 60 km along the river, from Nkanjonja to Hewani forests (Butynski & Mwangi 1994). The species is considered to be a generalist feeder and, due to its flexibility in diet, it adapts well to habitat changes (Wieczkowski 2004).

Study Groups

We collected data from two groups of Tana River mangabeys, one occupying Mchelelo forest and the other Mkomani forest (Figure 1). These groups were selected for behavioral studies because they were well-habituated and individuals were positively identified. Mchelelo group consisted of 68 individuals, which included seven adult males, 20 adult females, 28 juveniles, and 13 infants. The group

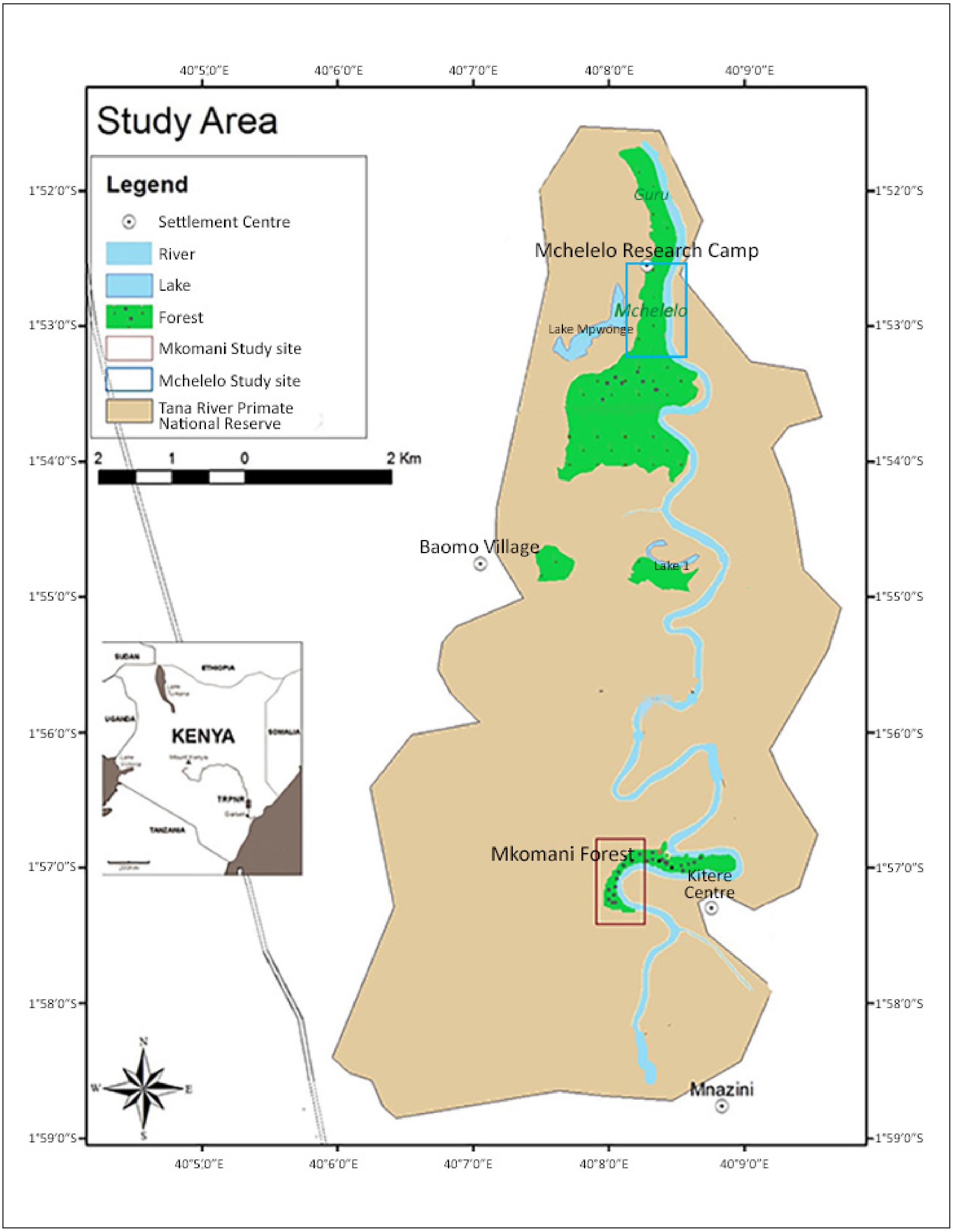

Figure 1. Map of the study area showing the two sampling sites (Mchelelo and Mkomani forests) within the Tana River Primate National Reserve and other features.

size in Mkomani was 53 individuals: six adult males, 14 adult females, 26 juveniles, and seven infants.

Data Collection

Assessment of anthropogenic disturbances

We systematically assessed habitat disturbances using 20 m by 20 m quadrats placed at an interval of 50 m from each other, along a line transect (Sutherland 2006). The line transects ran from east to west bearing and started from the riverbank and ended at the riverine forest edge, which varied from around 50 to 200 m. In each quadrat, we recorded all the individual plant species that were impacted by anthropogenic activities as well as any other signs of human activities. We calculated the level of anthropogenic disturbance by summing the occurrences of physical evidence of the following human activities: cutting of trees for poles or building materials, palm leaf harvesting (i.e., each palm that had evidence of cut fronds), palm wine harvesting (wine tapping), tree felling for boat construction, clearing forest for cultivation, fire incidences, natural honey harvesting, and the collecting of plants and their parts for medicinal purposes. We collected anthropogenic disturbance data once in each forest in June or July, after the wet season and shortly before the start of the dry season.

Data from each quadrat were summed, divided by the number of quadrats sampled, and used to compare human activities in the two sites and to determine which plant species were most affected by human activities. We used *ad libitum* recording to log any unique anthropogenic activities outside the plot boundaries to supplement the systematic collection of the disturbance data and to ensure nearly all possible human activities were captured. The data was used to test the hypothesis that the Mkomani forest had a high percentage of anthropogenic activities compared to the Mchelelo forest.

Behavioral monitoring

We used focal animal sampling to collect behavioral activity data as described by Altmann (1974). Behavioral data were collected by continuously recording data for 10 minutes for each focal individual with a resting interval of 5 minutes in between focal individuals. The general behavioral categories (feed, rest, social interaction, move, and out of sight) of the two study groups of Tana River mangabeys was recorded from February to July 2015. The operational definitions of the behavioral categories were as follows: “feed” – where the focal individual was observed searching, picking, processing, chewing, or orally ingesting food (Figure 2). If the individual was processing, chewing or ingesting food while on the move, it was recorded as "feeding." “Rest” was recorded when the focal individual was inactive or immobile for more than five seconds. “Social interaction” indicated that the focal animal was involved in either aggressive or friendly encounters with another conspecific individual, which included grooming, chasing, fighting, and copulation. “Move” was recorded when the focal animal engaged in traveling for more than five seconds either on the ground or within or between trees or food patches, but not feeding or engaged in any social interaction with another individual. “Out of sight” was recorded when an animal was not visible due to dense vegetation, and we recorded the duration it was not seen – until it became visible or the recording time elapsed. We discarded focal records during which the focal individual was out of sight for more than half of the recording time. We recorded data between 0700 hrs and 1800 hrs for six consecutive days every week during the study period. The focal animals were randomly selected, and individuals sampled were scheduled in a manner that balanced data collection across age and sex classes and avoided over- or under-sampling of certain individuals. The same observer and recorder conducted group observations in both study sites and data collection was alternated between the two sites whereby each group was followed for a week before switching to the other to minimize observer and seasonal bias. We analyzed data from only 1189 and 1440 focal samples collected on the Mchelelo and Mkomani groups, respectively. The smaller sample size than expected was due to loss of data for various reasons; i.e., incomplete focals recorded for less than three-quarters of the recording time were discarded, it took longer than the 5 minutes resting interval to locate the next scheduled focal individual due to poor visibility and group spread in the riverine forest, or the group left the sleeping site before we arrived. On other occasions, we were disrupted by elephants or bad weather.

Data analysis

We used both human activity and behavioral data to answer our hypothesis that, because Mkomani had high anthropogenic activities, it would have different Tana River mangabey behavioral responses compared to the Mchelelo forest group. We used the Statistical Package for Social Sciences for Windows (SPSS; Version 20.0) (IBM Corp 2016) for all data analyses. Descriptive analyses of both behavior and anthropogenic data were performed.

Figure 2. Juvenile mangabey feeding on young leaves in the Maramba Forest within the Kitere area of lower Tana River. Photograph by S. Kivai and C. Maingi.

We used the Shapiro-Wilk (W) test for normality, and log-transformed any non-normal data to achieve normal distribution for parametric tests as described by Zar (2010). We summed the time spent in each behavior category and divided it with the number of observation months to get the mean time allocation among the behavior categories. We used paired student t-test to identify any significant differences between the mean time allocations among the independent behavior activities in both study sites. Later, we compared the summed data per category in each group using an analysis of variance (ANOVA). From the disturbance data collected, we developed a list of the most affected plant species. We compared the generated species list to previous studies (Homewood 1978; Medley 1992; Wahungu 1998; Wieczkowski 2004; Kimuyu *et al.* 2012; Kivai 2018) on Tana River mangabey consumption of plants to identify the key plant foods. We developed a list of plant foods that were consumed by the Tana River mangabeys and were found to be affected by anthropogenic activities and summed the frequency scores of the human activities per disturbance categories (Moinde-Fockler *et al.* 2007). To compare the frequency scores between the two sites, we divided the total number of incidences with the total number of sampled plots in each site to obtain the mean disturbance incidences per plot and used paired student t-test for statistical analysis.

RESULTS

A total of 43 plots were sampled with 21 plots from Mchelelo and 22 plots from Mkomani. The disturbance values in both sites varied widely (Table 1). Cutting of trees was the most prominent observable human activity at 79.0%, followed by palm leaf harvesting (16.8%) and fire burning (3.1%) in Mkomani forest patch. In the Mchelelo study site, palm leaf harvesting was the main source of disturbance (51.9%) followed by cutting trees and palm wine tapping representing 33.0% and 15.1% of observable human activity, respectively (Table 1). Leaf harvesting in both sites by the community either targeted one or all of the three palm species in the Tana River forest: *Phoenix reclinata, Hyphaene compressa,* and *Borassus aethiopum*. The comparison of the human activities in both sites (Table 1, however, were not significantly different ($t = 1.08$, $df = 1$, $p = 0.298$).

Forty-three plant species (35 in Mkomani and 8 in Mchelelo) were exploited by humans for different purposes (Table 2). *Phoenix reclinata* was the most exploited plant species (61.7%) in the Mchelelo

Table 1. The magnitude and percentages of anthropogenic activities in Mkomani and Mchelelo study sites.

	Mkomani forest			**Mchelelo Forest**		
Human activity	Frequency scores	%	Activity per plot (N=22)	Frequency scores	%	Activity per plot (N=21)
Cutting of trees	556	79.0	26	35	33.0	1.7
Palm leaf harvesting	118	16.8	6	55	51.9	2.6
Fire burning	22	3.1	1	0	0.0	0.0
Boat construction	3	0.4	0	0	0.0	0.0
Medicine extraction	3	0.4	0	0	0.0	0.0
Cultivation	1	0.1	0	0	0.0	0.0
Honey harvesting	1	0.1	0	0	0.0	0.0
Palm Wine tapping	0	0.0	0	16	15.1	0.8
Total	704	100.0		106	100.0	

forest, followed by *Polysphaeria multiflora* (11.3%) and *Lecaniodiscus fraxinifolius* (8.7%) (Table 2). On the other hand, in Mkomani forest *Lecaniodiscus fraxinifolius* was the most exploited plant species (17.0%), followed by *Phoenix reclinata* (16.9%) and *Thespesia danis* at 10.6% (Table 2). The comparison of human disturbance scores of the exploited plant species differed between the sites ($t = 3.81$, $df = 1$, $p < 0.001$).

The two groups of mangabeys utilizing the two forest patches variably allocated time to different behaviors. The two groups generally spent most of their time on feeding relative to other activities. The Mchelelo group, however, spent less time feeding (50.0%) and in social interaction (5.9%) compared to the Mkomani group, which spent 53.5% and 13.1% of their time in the same activities, respectively. Moving and resting was reduced in Mkomani group (15.2% and 11.7%) compared to that in Mchelelo (27.0% and 12.7%). Overall, the Mkomani group spent more time feeding and engaging in social interaction than the Mchelelo group (Figure 3). The percent time allocated to various behavioral categories differed significantly within the Mchelelo (ANOVA; $F = 593.90$, $df = 4$, $p < 0.01$) as well as in Mkomani group (ANOVA; $F = 610.90$, $df = 4$, $p < 0.001$).

Behavioral comparison between the groups showed a significant difference in feeding ($t = 7.55$, $df = 1$, $p < 0.001$), moving ($t = 14.01$, $df = 1$, $p < 0.001$), and social interaction ($t = 13.49$, $df = 1$, $p < 0.001$). However, there was no significant difference in resting period between the two groups ($t = 0.14$, $df = 1$, $p = 0.681$).

DISCUSSION

The exponential global human population explosion continues to exert pressure on the remaining forest resources (Faulkner 2004; Giam 2017; Newmark & McNeally 2018). The local human population in the Tana River County, Kenya has increased from 240,075 to 315,943 over the last decade (Kenya National Bureau Statistics 2019), suggesting a marked demand for forest products to meet the basic needs of the rapidly growing population. This is supported by our findings whereby cutting of trees mainly for subsistence and commercial reasons was high in Mkomani forest, which is closer to human settlement. Moreover, the list of the highly exploited plant species or products in our study is similar to findings from previous research (Medley 1993; Wieczkowski 2004). *Phoenix reclinata*, which is among the preferred plant foods for the Tana River mangabeys, is highly exploited for mat and basket making, a key local industry that supports the local economy (Kinnaird 1992; Medley 1993). The competition for forest resources of huge economic and subsistence value such as *Phoenix reclinata* results in a scarcity of such plant resources, potentially forcing local people to encroach into more intact forest fragments key for mangabey survival within the reserve.

Anthropogenic disturbances in Mchelelo and Mkomani forest patches varied greatly as we predicted. Tree cutting, palm leaf harvesting, and fire burning were the most rampant human activities in Mkomani forest (Table 1). This may be explained by the forest's close proximity to the

Table 2. Human disturbances and percentages (%) per plant species for the Tana River mangabey plant foods in sampled plots in Mchelelo and Mkomani forests.

Plant Species	Frequency of Human disturbance on plant species				
	Lifeform	**Mkomani forest**	**%**	**Mchelelo forest**	**%**
*Lecaniodiscus fraxinifolius***	Tree	125	17.0	10	8.7
*Phoenix reclinata**	Tree	124	16.9	71	61.7
*Thespesia danis***	Tree	78	10.6	0	0.0
*Alangium salviifolium**	Tree	64	8.7	6	5.2
*Grewia densa***	Shrub	64	8.7	0	0.0
*Terminalia brevipes***	Tree	55	7.5	4	3.5
*Polysphaeria multiflora**	Tree	43	5.9	13	11.3
*Cordia sinensis***	Tree	41	5.6	0	0.0
*Lamprothamnus zanguebaricus***	Tree	23	3.1	0	0.0
*Flueggea virosa***	Shrub	21	2.9	0	0.0
*Lawsonia inermis***	Tree	19	2.6	0	0.0
*Cordia goetzei***	Tree	15	2.0	0	0.0
*Rinorea elliptica***	Tree	11	1.5	0	0.0
*Mimusops fruticosa**	Tree	8	1.1	0	0.0
*Diospyros mespiliformis**	Tree	7	1.0	0	0.0
*Tamarindus indica***	Tree	6	0.8	0	0.0
*Allophylus rubifolius***	Shrub	3	0.4	0	0.0
*Kigelia africana***	Tree	2	0.3	0	0
*Drypetes natalensis***	Tree	2	0.3	2	1.7
*Sorindeia madagascariensis**	Tree	2	0.3	0	0
Chytranthus obliquinervis	Tree	2	0.3	0	0
*Cassia abbreviata***	Tree	2	0.3	0	0
Mangifera indica	Tree	2	0.3	0	0
*Synsepalum msolo**	Tree	2	0.3	0	0
*Gardenia volkensii***	Shrub	2	0.3	0	0
*Garcinia livingstonei***	Tree	2	0.3	0	0
*Cynometra lukei***	Tree	2	0.3	2	1.7
*Spirostachys venenifera***	Tree	1	0.2	0	0
*Pavetta sphaerobotrys***	Tree	1	0.2	0	0
*Antidesma venosum***	Tree	1	0.2	0	0
*Keetia zanzibarica***	Climber	1	0.2	0	0
*Salacia erecta***	Climber	1	0.2	0	0
*Hunteria zeylanica***	Tree	1	0.2	7	6.1
*Citrus limon***	Shrub	1	0.2	0	0
*Ficus sycomorus**	Tree	1	0.2	0	0

**Listed as some of the top food species for Tana River mangabey (Wieczkowski 2004).*
*** Listed as other plant food species fed on by Tana River mangabeys (Homewood 1978; Wahungu 1998; Kivai 2018).*

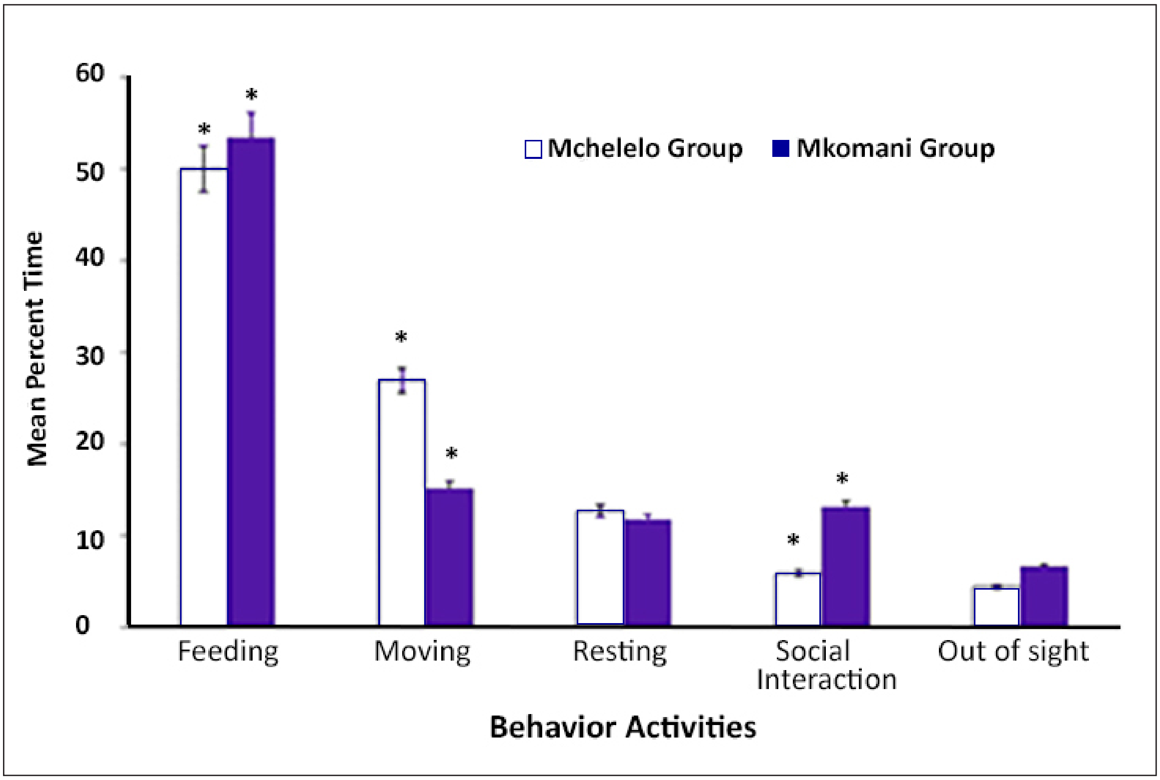

Figure 3. The mean percent time spent per behavioral activity in Mchelelo and Mkomani groups. The error bars represent the standard error of the mean. * Indicates significantly different at $p<0.005$.

human settlement and farming areas. The same reason can be attributed to boat constructing, cultivating in the forested area, fire burning, honey harvesting, and extracting of medicine, which were forest threats recorded only in Mkomani but not in Mchelelo. Moreover, the local community around Mkomani uses slash-and-burn method to prepare their farms for planting before the rainy season (Moinde-Fockler *et al.* 2007), which also explains the high fire incidents in Mkomani. Alternatively, Mchelelo forest experiences high extraction of palm leaf harvesting, tree cutting, and palm wine tapping as the key anthropogenic disturbances. While the Kenya Wildlife Service closely monitors Mchelelo forest, such human activities suggest the increased demand for such products following unsustainable exploitation and scarcity in forest patches adjacent to the communities with unrestricted access. This is also supported by our findings that Mkomani experiences more cutting down of trees compared to Mchelelo forest. Palm wine tapping (16%) was a major concern in the Mchelelo forest and the process resulted in the death of the entire plant especially due to over-harvesting of leaves or cutting off its growing top edible part – or palm heart – to obtain wine.

Our findings supported the hypothesis that the Mkomani forest had a high percentage of anthropogenic activities compared to the Mchelelo forest, especially tree cutting and the number of activities (Table 1). Exploitation of forest resources by the local communities occurred in both sites suggesting that the local communities heavily rely on the forest to meet key subsistence or economic needs. For instance, *Lecaniodiscus fraxinifolius* and *Thespesia danis* are important plant resources to the community (Table 2), as they are used as poles for construction. Unfortunately, some of the forest resource harvesting methods are unsustainable and impact negatively on the forest regeneration and persistence. This is supported by findings of Kinnaird (1992) that some of the local forest practices such as cutting palm trunks for building, palm heart extraction for beer production, and excessive leaf removal affected the meristem of the plant, preventing growth of the targeted tree individuals. Medley (1993) also observed that palm leaves from *Phoenix reclinata, Hyphaene compressa,* and *Borassus aethiopum* are used in mat-making and thatching of houses, and excessive harvesting for these purposes limits the palm generation. This, then, may affect plant species regeneration (Medley, 1995). These species contribute a high percentage to the diet of the Tana River mangabey (Homewood 1978; Wahungu 1998; Wieczkowski 2004; Kimuyu *et al.* 2012; Kivai 2018). Further, exploitation of medicinal plants such as *Ficus sycomorous, Ficus natalensis, Harrisonia abyssinica,* and *Acacia robustas*, which treat various ailments (Medley 1993; Kaingu *et al.* 2013, 2014) may have long-term negative effects on forest regeneration even though currently it is not a key threat to the forest.

Our second hypothesis that the Mkomani mangabey group will increase feeding time, movement and social interaction as coping strategies to human disturbances was partly supported. As we predicted, mangabeys in Mkomani forest spent more time feeding and engaging in social interactions. But, contrary to our prediction, movement was reduced in Mkomani compared to the Mchelelo group. Unsustainable exploitation of forest resources has been found to reduce the quality and quantity of primate food resources, enhance patchiness of food, and limit primate movement through habitat degradation, fragmentation, and loss (Moinde-Fockler *et al.* 2007; Arroyo-Rodríguez, 2010; Kivai 2010; Majumdar & Datta 2015). These changes are likely to alter the activity time budget for forest dwelling primates triggering some behavioral adjustments in response to the anthropogenic disturbances in their habitat (Boyle *et al.* 2012; Strier 2015). Thus, behavioral differences are expected in primate populations utilizing forests experiencing different levels of disturbance. These observations were supported by our behavioral findings from the Mchelelo and Mkomani groups of mangabeys. Feeding and moving claimed more of the time allocation for the two groups than resting and social interaction (Figure 2). However, significant behavioral differences were notable between the two groups, which might be explained partly by the level of anthropogenic activities in each site. The Mkomani group spent significant time feeding and in social interaction while the Mchelelo group moved more than the Mkomani group (Figure 2). Mkomani forest patch suffered from severe human activities potentially resulting in decline and sparse distribution of food patches. Thus, the group in this forest may have responded by increasing the feeding time to meet the daily-required food intake partly explaining the observed difference in feeding. The reduced movement of the Mkomani group could be explained by the increased fragmentation of the forested areas separated by farmlands, suggesting that the animals are limited in ranging widely or it could be a strategy to reduce energy expenditure in movement given the possibility of limited food resources (Milton 1998; Thatcher *et al.* 2019). Howling monkeys have been found to adopt similar strategies in coping to food dynamics following habitat disturbances (Arroyo-Rodríguez 2010).

Habitat fragmentation has been found to correlate with an increased rate of aggression among individuals, elevated physiological stress, and increased parasitic infestation in primates (Honess & Marin 2006; Martínez-Mota *et al.* 2007; Dunn *et al.* 2009; Arroyo-Rodríguez 2010). Thus, our study group living in the more disturbed forest fragment compared to Mchelelo is expected to experience a high level of aggression and nutritional stress – and perhaps a higher incidence of parasite infection (Mbora & Munene 2006; Mbora *et al.* 2009). Consequently, the group is likely to suffer more physiological stress than Mchelelo group. Thus, the high level of social interaction in Mkomani group may be explained by high aggressive interactions as well as engaging in more grooming activity as a counter strategy to dissipate stress and reduce parasite manifestation (Madden & Clutton-Brock 2009; Wilson *et al.* 2020).

Our study shows that the Tana River mangabeys living in more disturbed habitat increase their time spent in feeding and engage more in social interaction, which could be interpreted as coping strategies to adapt to habitat disturbances. These findings, however, should be treated with caution since the study focused only on two forest fragments with two mangabey groups and was undertaken for a short period. Thus, we recommend further studies encompassing a longer sampling period, more forest fragments, and more study groups. Altogether, the results are informative and emphasize the need to integrate anthropogenic disturbances and behavioral consideration of endangered primates in their conservation and management approaches. Future efforts to protect the Tana River mangabey should pay attention to mitigating further habitat fragmentation and educating the local communities on sustainable forest resource utilization to ensure long-term persistence of the species.

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